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REVIEW ARTICLE

Translational Applications of MRI in Cancer: Human and Veterinary Perspectives

Abdullah G. M. AlMansour

Radiology and Medical Imaging Department, College of Applied Medical Sciences, Prince Sattam Bin Abdulaziz University, Alkharj 11942, Saudi Arabia
*Corresponding author: ag.alqahtani@psau.edu.sa

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ABSTRACT

In human and veterinary oncology, magnetic resonance imaging (MRI) is a radiation-free modality with unparalleled soft tissue contrast and functional information critical to the detection, staging, and treatment follow-up of cancer in a vast array of organs, such as the brain, breast, prostate, liver, and musculoskeletal system. By assessing cellularity, vascularity, metabolism, and functional impact, newer MRI modalities such as diffusion-weighted imaging (DWI), perfusion-weighted imaging (PWI), magnetic resonance spectroscopy (MRS), functional MRI (fMRI), diffusion tensor imaging (DTI), whole body-MRI (WB-MRI), and magnetic resonance angiography (MRA), as well as hypothetical experimental methods such as hyperpolarized MRI (hMRI), gain insights into tumor biology. The translation benefit of MR progress is evident by the relatively close analogy between human and animal cancers, notably dog models. This article describes different MRI techniques that are used in cancer diagnosis and treatment. It also highlights how advancements in human medicine can be applied to enhance veterinary cancer diagnosis and therapies. Furthermore, it also compares human and veterinary oncology and focuses on using shared innovations, diagnostic methods, and personalized treatments to connect both fields.

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INTRODUCTION

Cancer, an uncontrolled, proliferative, progressive, and permanent growth of normal cells, is an increasing risk in both animals and humans (Sriharikrishnaa *et al.,* 2023). Genomic instability, through the alteration of DNA that affects critical gene function and initiates neoplastic change, is the major cause of cancer, an intricate disease process involving both human and animal forms (Gull and Masood, 2020). The multifaceted process, which is influenced by environmental and genetic factors, drives the formation of solid tumors from normal tissue through hyperplastic and dysplastic stages (Yuan *et al.,* 2024). Molecularly, cancer is defined by changes in gene expression patterns, such as the overexpression of P-glycoprotein leading to drug resistance and changes in main regulatory genes, such as tumor suppressor genes, such as P53, and oncogenes such as C-MYC (Sarfraz and Ullah, 2024). In addition, cancer development is strongly facilitated by deficiencies in DNA damage response pathways, which are further compounded by extrinsic insults like radiation, chemical exposures, and viral infections (Huang and Zhou, 2021). The applicability of animal models to cancer research has been confirmed by the common molecular and pathological basis of cancer in various species (Li *et al.,* 2021). These models are great platforms for comparative oncology and for unraveling the complex molecular mechanisms that underlie tumor initiation, growth, and metastasis (Shi *et al.,* 2024). Although these models, especially the dog, are very genetically and phenotypically comparable to human cancer. This makes them valuable and useful for studying cancer and assists in developing new drugs. However, important differences in tumor biology and immune function between species must be addressed adequately before applying these results to human patients (Cahill *et al.,* 2024). These advances in molecular biology, nanotechnology, and advanced imaging technology have all together provided a tremendous impetus to the progress of cancer diagnostics in human medicine as well as in animal medicine, with the ultimate objective of enhancing the efficiency and precision of detection (Ambrose *et al.,* 2025). Conventional methods, including the gold standard of histopathology and biopsy (though invasive), newer imaging modalities such as magnetic resonance imaging (MRI) and positron emission tomography (PET) for precise tumor characterization, and initial blood work for tumor markers (usually not specific), still have important roles in diagnosis in all species (Kang *et al.,* 2022; Acharya *et al.,* 2024). But when state-of-the-art techniques are added, the discipline is evolving rapidly. In recent years, some possible strategies for tumor behavior monitoring and detection of residual disease in human (breast, lung, colon) and selected animal cancers (lymphoma, osteosarcoma, hemangiosarcoma) include non-invasive liquid biopsies assessing circulating tumor DNA. A liquid biopsy detects cancer-like material (DNA or RNA) in body fluids, mainly from blood but sometimes also from urine, saliva, and cerebrospinal fluid. It also helps in early detection of tumors, monitoring treatment response, and detecting recurrence or resistance, while long coding RNAs and circular RNAs that are stable in blood and regulate gene expression for the detection of tumors at the molecular level in both humans and animals. Long non-coding RNAs and circular RNAs are among such very specific molecular markers, which are currently being discovered and investigated more actively for the detection of veterinary as well as human oncology conditions (e.g., lymphoma, canine mammary cancers) (Zhang *et al.,* 2023).

Nanobiosensors have been researched for minimally invasive early diagnosis of malignancies in humans (breast, lung) and animals (lymphoma, sarcoma) based on their sensitivity and ability to detect in real-time (Zhang *et al.,* 2023). Sentinel lymph node mapping is also investigated for similar applications in animal diseases such as lymphoma and sarcoma (Beer *et al.,* 2023). Sentinel lymph node mapping is crucial in human oncology for cancer staging and therapy planning in malignancies such as breast cancer and melanoma. Differences in access to and cost of advanced diagnostic technology still exist, however, and are often more readily available in human medicine, even in the face of these shared advances (Pulumati *et al.,* 2023). In addition, the existence of species-specific biomarkers necessitates further investigation. The synergistic combination of these advanced technologies, the cross-species translational potential of comparative oncology (especially due to the similarities between human and canine cancers), and the increasing application of personalized medicine are transforming cancer diagnosis. These approaches guided by individual genomic profiles in both human and veterinary oncology are the cornerstones of future innovations in oncology. Furthermore, the revolutionary possibilities of artificial intelligence and machine learning are being harnessed to enhance imaging and molecular analysis accuracy in both domains, including studying histomorphological criteria in cancer in the dog (Appleby and Basran, 2024). To patients with cancer in all species, this convergence holds the promise of a new day of earlier detection, improved staging, and ultimately improved outcomes (Chorny *et al.,* 2022).

With its unparalleled soft tissue contrast, functional information, and radiation-free and non-invasive approach to cancer detection and treatment, magnetic resonance imaging (MRI) has become a pillar of modern oncology in humans and animals (Sharma *et al.,* 2022). Its application is extended to whole-body staging in multiple myeloma, prostate cancer, and melanoma, among others, and is supplemented by diffusion-weighted and dynamic contrast-enhanced imaging for metastasis detection and tumor vascularity evaluation (Petralia *et al.,* 2019). MRI's diagnostic capabilities are also boosted by its unique ability to provide functional and molecular information through techniques like hybrid PET/MRI systems, which integrate metabolic and high-resolution anatomical information, and MR spectroscopy, which indicates metabolic changes (Abhisheka *et al.,* 2024). Its lack of radiation is a significant advantage for long-term follow-up and screening, especially in vulnerable populations. MRI augments the deficiencies of CT in animal oncology via the capacity to provide enhanced detail of soft tissue necessary for diagnosing a diverse range of tumors across a spectrum of species, and DCE-MRI aids in establishing whether the tumor is cancerous (AlHarbi *et al.,* 2024).

While PET/MRI provides synergistic anatomical and metabolic information, it is less universally accessible and expensive. Comparative investigations prove MRI to be as effective as or better than PET/CT in some instances, especially for soft tissue imaging (Shah *et al.,* 2022). MRI technology continues to evolve with regard to speed, resolution, and clinical applicability (Alsaedi *et al.,* 2024). Examples are high-field imaging, AI processing, and 3-dimensional sequences. The expanding clinical applications of MRI for screening, treatment monitoring, and individualized medicine reflect its breakthrough promise in oncology for human and veterinary medicine, despite ongoing challenges such as cost, availability, and the need for expertise (Alanazi and Alhebs, 2024). So, this review article explores the translational applications of MRI in cancer diagnosis, treatment, planning, monitoring, and drawing similarities and dissimilarities in both humans and animals. It highlights how cross-species insights can enhance imaging strategies and improve clinical outcomes.

Principles and working of MRI: MRI employs nuclear magnetic resonance (NMR) to expose the subtle features present in living tissues (Nayak *et al.,* 2022). MRI is an improved technique that produces high-resolution images with the help of radiofrequency waves and a strong magnetic field (Darnell *et al.,* 2022). The hydrogen atoms' protons, which are spread almost everywhere in human and animal bodies' water and fat molecules, are at the center of MRI signals (Abed *et al.,* 2024). These protons line up parallel or antiparallel to a strong magnetic field, forming a net magnetization in the direction of the field. This simple principle allows MRI to create amazingly precise anatomical images (Takahashi, 2019).

A carefully tuned radiofrequency pulse (RF) is then applied to immediately cut off the aligned net magnetization as part of the MRI procedure (Kwok, 2022). The protons, excited by the RF pulse, start returning to their natural state as the RF pulse is switched off, generating measurable signals which are picked up by the receiver coils of the MRI machine (Smith, 2012). The signals are then carefully processed to generate highly realistic images of the internal anatomy. The union of magnetic field and radiofrequency pulses and the processes creating picture contrast are the two cornerstones of MRI. The alignment of proton spin depends on the intensity of the external magnetic field, usually 1.5 or 3.0 Tesla in a hospital (Smith, 2012; Williams *et al.,* 2023). The alignment is subsequently momentarily disturbed by RF pulses, and measurable energy fluctuations ensue. The foundation for creating images and describing tissues is the specific way various tissues release the absorbed energy at rest (Mai *et al.,*

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2022). To create picture contrast, MRI effectively employs differences in tissue relaxation characteristics. Different tissues, such as fat, muscle, and tumors, have rather different T1 relaxation rates (how quickly protons return to synchrony with the magnetic field) and T2 relaxation rates (how quickly they become out of synchrony). MRI can highlight such inherent differences by directly modifying image parameters with precision in order to be able to differentiate between healthy and diseased tissue with precision for diagnosis (Russek *et al.,* 2020). Various key components of MRI are given in Fig. 1.

Types of MRI for diagnosis and monitoring: MRI is a non-invasive imaging technique used both in medical and veterinary settings to produce detailed images of internal organs of the body (Callewaert *et al.,* 2021; Barbagianni and Gouletsou, 2023). Various types of MRI have been invented and used to increase the image quality, which provides specific information (Luca *et al.,* 2022). Each type of MRI provides unique advantages in visualizing various body structures, detecting abnormalities, and monitoring disease progression (Hussain *et al.,* 2022). Primarily, MRI is divided into two types, i.e., conventional MRI and advanced MRI, which are further subdivided into various types as shown in Fig. 2.

Conventional MRI in Cancer Diagnosis: Conventional MRI is one of the most precious assets in the early diagnosis and detection of various malignancies (Singh *et al.,* 2024). In its ability to capture high-resolution images of soft tissue in cancer detection of organs such as the brain, liver, prostate, and breast, no other asset can match its use. Most significant is the observation that conventional MRI is safer and non-invasive than standard testing against ionizing radiation-based imaging techniques (Vaddi *et al.,* 2025). While observing fine variations in tissue structure and composition, standard MRI can detect even subtle abnormalities, which enable physicians to identify tumors with high precision, measure their size, and observe how they interact with surrounding tissues.

The key advantage of conventional MRI is the exquisite soft-tissue contrast created by some T1-weighted and T2-weighted pulse sequences (Bhattacharjee and Thakran, 2022). T2-weighted images are more sensitive to edema and fluid, thus are particularly ideal for the detection of malignant neoplasms that may result in inflammation or necrosis (Harada *et al.,* 2021), while T1-weighted images are ideal for delineating anatomical structures (Kolokythas *et al.,* 2024). Additionally, fat suppression techniques can significantly enhance tumor visibility, especially in locations where there is extensive fatty tissue. Through accentuation of regions of greater vascular permeability, a shared characteristic of cancerous tumors, the use of contrast agents, e.g., gadolinium, can markedly enhance lesion detection (Duy Hung *et al.,* 2023). In a study by Su and Kao (2017), a comparison of the efficacy of MRI and ultrasonography with liver-specific contrast was made for cancer screening among a group of 407 patients with cirrhosis, who have a high risk of developing liver cancer. MRI was found to detect 86% of liver cancers within three years, much higher than the 27.9% that ultrasound detected. Of particular interest, two-thirds of these patients were cured with early treatment, and MRI identified most malignancies at an extremely early stage (single nodules <2 cm). It also demonstrated a reduced false positive rate (3% vs. 5.6% for ultrasound), suggesting its value in guiding immediate, potentially curative treatments as well as its

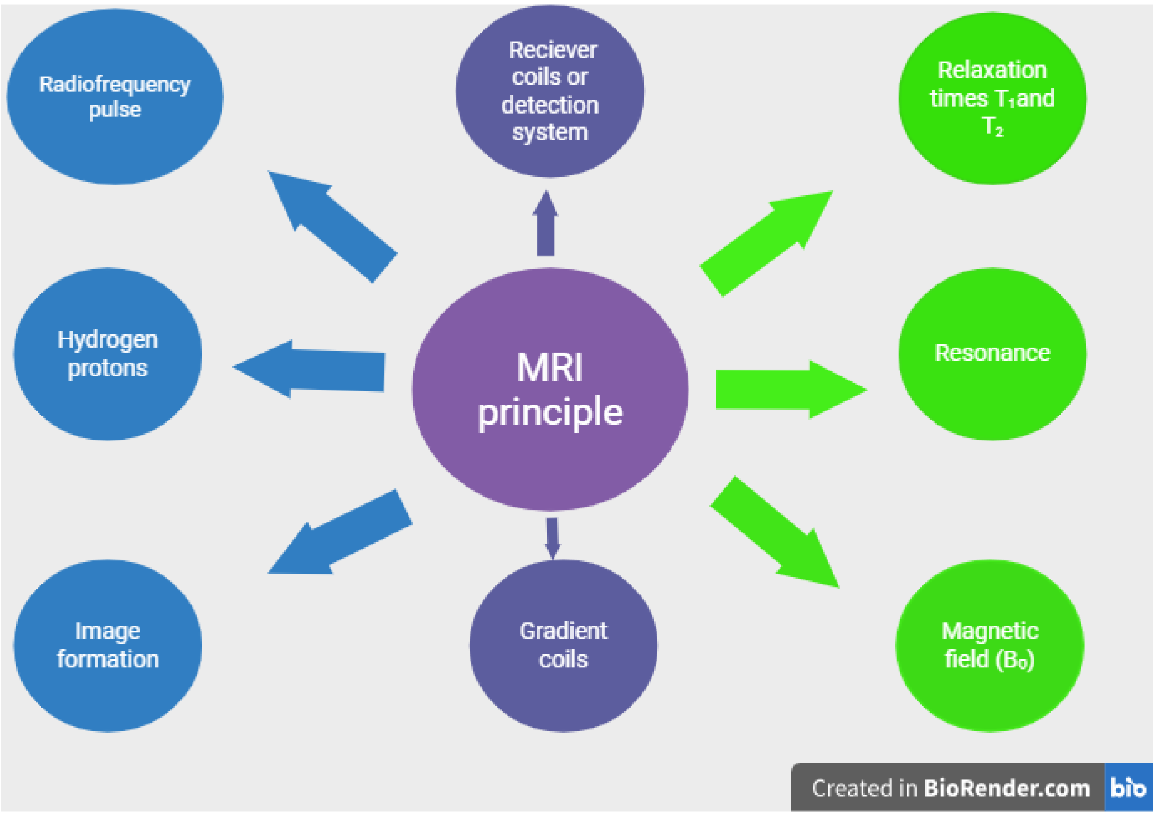

Fig. 1: Key components of the magnetic resonance imaging technique, including detection system, gradient coils, image formation, hydrogen protons, radiofrequency pulse, relaxation time, resonance, and magnetic field.

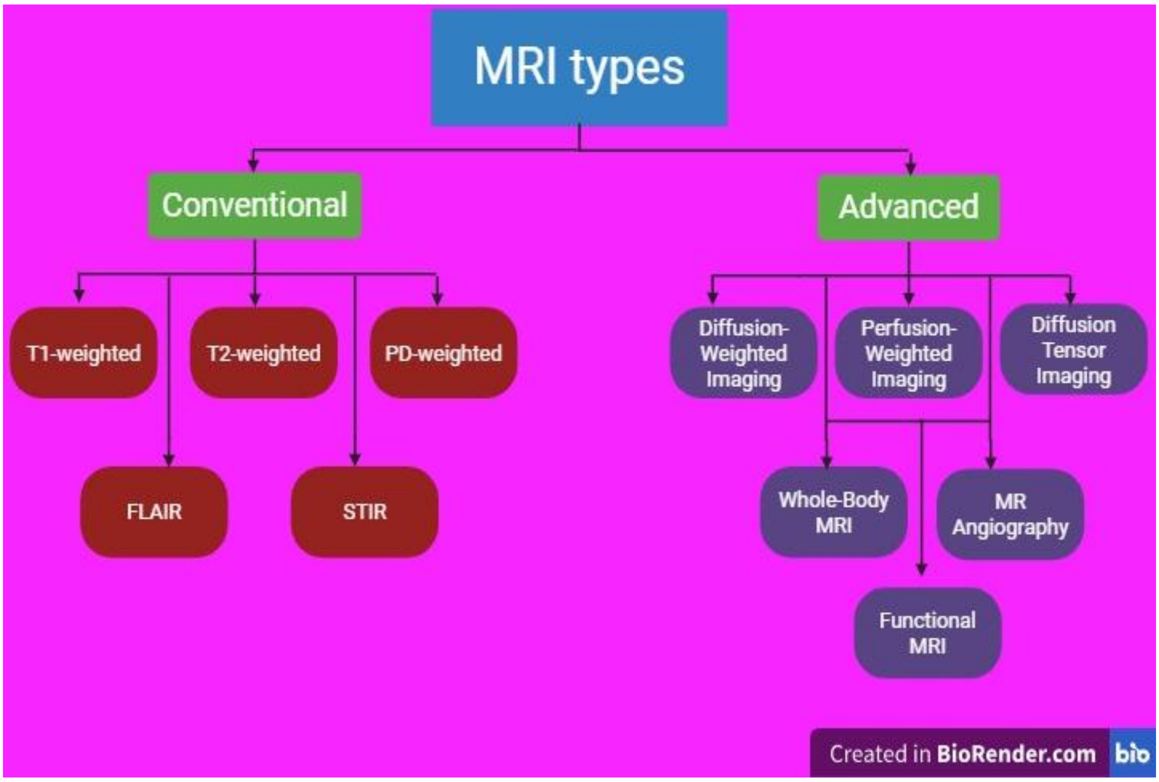

Fig. 2: Various types of conventional and advanced or modern MRIs used in cancer diagnosis.

increased sensitivity and specificity in the detection of early cancer. Similarly, a study was conducted by May *et al.* (2024) that elaborated on the effectiveness of conventional MRI in differentiating between canine intracranial meningiomas and histiocytic sarcomas. The research study revealed the effectiveness of conventional MRI in differentiating between canine intracranial meningioma and histiocytic sarcomas. Meningiomas appeared hyperintense on T2-weighted and FLAIR sequences, whereas histiocytic sarcomas often showed iso- to hypointense signals. This study shows the importance of conventional MRI in veterinary oncology.

Conventional MRI is a routine procedure in the clinic for the detection of recurrence, response to therapy monitoring, and staging of cancer. For instance, it provides critical information on related edema, hemorrhage, and involvement of adjacent structures in addition to showing the mass in brain tumors. In like fashion, it is being used increasingly with mammography and ultrasound in the diagnosis of breast cancer to assess dense breast tissue and find multifocal or multicentric disease. Overall, it remains a mainstay of oncologic imaging, providing a complete and detailed perspective necessary for effective cancer management and treatment planning (Alberich-Bayarri *et al.,* 2020). For men with suspected prostate cancer, Hamm *et al*. (2025) tested an MRI-first strategy. Following elevated PSA levels, patients first received multipara metric MRIs rather than invasive biopsies. Biopsies were performed on men with abnormal MRI results only; the others were screened with standard urological tests. 96% of those patients who had negative MRI scans did not develop aggressive prostate cancer within a three-year timeline, proving that it can safely reduce the dangers that come with unnecessary biopsies without preventing the early detection of tumors that are clinically significant.

No doubt, conventional MRI is very useful in diagnosis, but it does not provide enough details about the anatomy, physiological processes, tissue composition, and blood flow (Hussain *et al.,* 2022). On the other hand, advanced techniques are very useful in diagnosing disease or tumors at an early stage as compared to the conventional technique (Bruno *et al.,* 2019). Furthermore, they are more precise and accurate and play an important role in modern medical imaging in oncology, neurology, and cardiovascular diagnosis.

Advanced MRI Techniques in Oncology: A range of sophisticated, advanced MRI methods has emerged that transcend the limitations of conventional MRI and offer profound insight into the intricate world of tumor biology, behavior, and treatment response (Hussain *et al*., 2024). These new methods significantly enhance the accuracy of cancer diagnosis and treatment by transcending mere anatomical visualization and venturing into the frontiers of physiology, metabolism, and microstructure (García-Figueiras *et al*., 2020). Some of the important modern MRI techniques are discussed below. Diffusion-Weighted Imaging: Diffusion-Weighted Imaging (DWI) is different from conventional MRI because conventional MRI relies on anatomical imaging by using sequences to visualize changes in structure while DWI traces the random movement of water molecules to reveal the microscopic world within tissues. Unimpeded water molecules flow freely in healthy tissue but are delayed in biological surroundings with high cell concentration, such as tumors (Behroozi *et al*., 2024). In DWI images, this limited diffusion appears as an increased signal, and therefore, cancerous regions become better visible to identify. The degree of the diffusion of water molecules is illustrated by the apparent diffusion coefficient (ADC) map, which is a quantifiable parameter from DWI. ADC is a measurable output from DWI that signifies how freely water molecules move within tissue, and in the case of a malignant tumor, the cells are packed, which restricts the movement of water molecules. As a result, these areas show lower ADC values. MRI helps to distinguish these cancerous tissues from normal or benign areas (Ratneswaren and Matys, 2020). Clinically, DWI finds particular utility for the early diagnosis of liver, prostate, and brain cancers. Furthermore, conventional MRI is effective in identifying tumors, size, locations, and associated edema, while DWI is sensitive to cellular density and membrane integrity allowing it to differentiate the tumor part from the non-cancerous part.

DWI can also detect metastases of lymph nodes, distinguish between benign and malignant disease, and gauge the effectiveness of treatment by measuring changes in the cellularity of tumors (Lother *et al.,* 2023). Of particular significance, DWI is a sensitive and secure non-invasive oncologic diagnostic modality, most beneficial for those patients with compromised renal function, because it does not rely upon contrast chemicals (Messina *et al.,* 2020). The possible use of DWI in the assessment of high-intensity focused ultrasound (HIFU) therapy was explored by Li *et al.* (2019) in a patient cohort of 48 with primary liver cancer. Tumors were pre-treatment on DWI and had higher signal intensity and lower ADC values, as expected with water-restricted diffusion within thick malignant tissue. In the case of renal impairment patients, this quantitative ADC change provided initial evidence of treatment response without employing contrast chemicals. The technique illustrated the utility of DWI in non-invasive treatment monitoring by targeted destruction of residual tumor locations for follow-up therapy.

Perfusion-Weighted Imaging (PWI): Through measurement of parameters such as blood flow, blood volume, and vascular permeability, perfusion-weighted imaging (PWI) provides information regarding tissue microvascular topography (Thijs *et al.,* 2004). Angiogenesis, potentially identified through PWI, is the growth of a pathologic blood supply that often serves to nourish the rapid expansion of tumors (Valenzuela *et al.,* 2024). PWI provides numerical data about perfusion parameters in tumors using methods like dynamic susceptibility contrast (DSC) MRI and dynamic contrast-enhanced (DCE) MRI (Romano *et al.,* 2012).

PWI is most useful in grading tumors since it allows one to distinguish between very aggressive, high-grade, and less aggressive, low-grade cancers (Pons-Escoda *et al.,* 2024). In addition, as therapeutic efficacy is generally reflected in the decrease in tumor vascularity, assessing treatment success is desirable. PWI can be of use in determining patient management in the setting of brain cancer by distinguishing recurrent tumor growth from post-radiation changes such as radiation necrosis (Dinh Hieu *et al.,* 2024). A new contrast-enhancing lesion appeared on a routine MRI in a study by Wang *et al.* (2016) after six months following chemotherapy and radiation therapy in a 58-year-old glioblastoma (WHO grade IV) patient.

Dynamic susceptibility contrast (DSC)-MRI is a type of perfusion-weighted imaging (PWI) that showed decreased percentage of signal-intensity recovery (PSR=65%) and increased relative cerebral blood volume (rCBV=3.2) in the lesion, suggestive of hypervascularity and disrupted microvasculature typical of tumor recurrence (Surendra *et al.,* 2020). PSR tells how much the MRI signal bounces back after contrast passes through the brain, while rCBV tells how much blood is present in a specific part of the brain. Glioblastoma cells were found to be viable on biopsy, which agreed with PWI findings (Pons-Escoda *et al.,* 2022). Another increasing lesion in the same patient, on the other hand, showed high PSR (92%) and low rCBV (1.1) that agreed with radiation necrosis and prevented unnecessary surgery. This demonstrates the significance of PWI in the resolution of diagnostic uncertainty and directing targeted therapy.

Magnetic Resonance Spectroscopy (MRS): Through measurement of some chemical constituents, MRS reveals the biochemical fingerprint of tissues (Guleken *et al.,* 2022). MRS gives specific information on tissue health through quantification of the amounts of such major metabolites as choline, an indicator of cell membrane turnover, creatine, a player in energy metabolism, and N-acetylaspartate (NAA), a marker of neural health (Öz, 2021). For instance, MRS assists in the discrimination of brain tumors from normal brain tissue or benign lesions since high choline and reduced NAA (peak spectrum) are commonly encountered in brain tumors. In another control study, MRS was carried out to assess brain metabolites in the thalamus of dogs with idiopathic epilepsy, with and without antiepileptic drugs. Significant reductions in NAA and glutamate-glutamine (Glx) ratios were observed in treated groups. In contrast to human findings, Glx was reduced rather than increased. These results suggest that MRS is a valuable tool for evaluating metabolic changes in epileptic dogs (Miguel-Garcés *et al.,* 2024).

MRS is heavily applied to investigate breast, prostate, and brain cancers. By directing the sample towards areas with the highest metabolic rates, it is capable of identifying malignancies characteristically (Sharma and Jagannathan, 2022). Besides that, through detecting changes that might appear even before overt changes in structure using conventional MRI, MRS proves very helpful to monitor response to therapy. Such therapeutic intervention would be significantly affected by this capability for early detection (Payne, 2018).

Functional MRI (fMRI) and Diffusion Tensor Imaging (DTI): By detecting small variations in oxygenation and blood flow, an effect termed blood oxygen level dependent (BOLD) contrast, fMRI creates a dynamic image of brain activity (Guensch *et al.,* 2021). BOLD is a key principle behind fMRI that detects changes in the oxygen level of blood in the brain and uses that to show which areas are more active. The fMRI is highly sensitive to measuring local differences in blood flow produced by the enhanced oxygen demand of individual regions of the brain as they become activated (Chen *et al.,* 2022). This technique produces functional maps, highlighting areas of the brain that are responsible for such basic functions as speech, movement, and sensation (Yarmish and Lipton, 2003).

In brain tumor patients, fMRI is an essential tool in pre-operative planning for the oncology field (Manan *et al.,* 2021). Neurosurgeons can direct the removal of tumors without compromising critical neurological function by registering significant functional areas. This systematic process reduces postoperative deficits, improves surgical results, and ultimately enhances the patient's quality of life (Pasquini *et al.,* 2023). Water diffusion directionality, or anisotropy, is studied with the extremely sophisticated derivative of DWI called diffusion tensor imaging (DTI). DTI tracks the directional motion of water molecules meticulously, which have a propensity to diffuse in a preferential direction along the well-ordered bundles of white matter tracts within the brain (Taoka *et al.,* 2024). This creates complex fiber tractography maps that provide a visual representation of the intricate neuronal network of the brain (Yoo, 2021). Fiber tractography is a special imaging technique used in MRI to visually map the pathways of white matter fibers called nerve tracts in the brain. DTI is a valuable aid in planning surgery with brain tumors in the oncology setting. Tumor enlargement will displace or invade overlying tracts of white matter, and DTI excels at these important alterations (Behler *et al.,* 2023). Physicians are able to plan sensibly the extent of resection and prevent damaging vital brain function by accurately measuring the spatial relationship of the tumor to significant tracts of white matter (Khalil *et al.,* 2022).

Whole-Body MRI (WB-MRI) and MR angiography: Whole-Body MRI (WB-MRI) provides a potent, non-invasive method for imaging the entire body in exquisite detail without ionizing radiation hazards (Petralia *et al.,* 2019). WB-MRI is extremely sensitive for the detection of metastases in soft tissues, bones, and lymph nodes by utilizing the sensitivity of DWI and conventional MRI sequences. In the case of the treatment of diseases such as multiple myeloma, lymphoma, and metastatic breast or prostate cancer, this technique proves to be very useful (Summers *et al.,* 2021).

Since WB-MRI is a comprehensive full-body assessment in one imaging session, it is increasingly used for cancer staging and surveillance (Zugni *et al.,* 2020). This facility allows for early detection of metastatic disease, acceptable assessment of response to treatment, and careful follow-up for recurrence. Because it does not subject patients to radiation, it's particularly attractive in pediatric oncology and in those patients who need repeated follow-up studies over a prolonged period of time (Guimarães *et al.,* 2024).

The specialized MRI technique known as MR angiography is used to image blood vessels non-invasively (Javed *et al.,* 2024). Contrast-enhanced MRA typically has better quality images, while it can be done either with or without the use of contrast agents. MRA enables detection of vessel narrowing, thrombosis, characterization of abnormal tumor-related vessels, and evaluation of interaction of malignancy with the vascular bed (Kuo *et al.,* 2019).

WB-MRI is an advanced diagnostic tool and it is also used in veterinary medicine to assess dogs and cats for a wide range of systemic diseases, particularly benign and malignant tumors. Unlike conventional MRI, it targets specific regions of the body and gives comprehensive visualization of soft tissues and organs. Mostly it is used in tumor staging, detecting metastasis, and evaluates musculoskeletal or neurological disorders (Petralia *et al.,* 2019). MRA is especially useful in the treatment of liver, kidney, and head-and-neck cancer in the oncology department (Kumar *et al.,* 2010). In demonstrating the tumors' spatial relation to nearby blood vessels, it can help considerably in planning surgery and serve as a safeguard against the unintended damage of vital artery structures by surgeons. MRA can also prove to be very useful in assessing vascular cancer and in the planning of interventional radiologic procedures like embolization. Some of the important MRI techniques are given in Table 1 along with their advantages and limitations.

Application of MRI: High contrast, anatomically detailed tomographic images are supplied by MRI, which is increasingly used in veterinary medicine (Velavan, 2024). The technology offers a lot of potential for the visualization of soft tissues. This recently developed but powerful imaging modality has a range of applications and enhances our ability to study both healthy anatomy and disease change in living animals. MRI is readily available in veterinary medicine today and has proven its crucial role in diagnosing a host of disorders, such as orthopedic, neurologic, oncologic, and other disease processes (Butt and Bach, 2025). It holds the key to unraveling the secrets of musculoskeletal disorders, such as the etiology of Wobbler syndrome in the dog and navicular disease, traumatic arthritis (joint inflammation), and osteo-chondrosis (bone and cartilage disease) in horses (Yitbarek and Dagnaw, 2022). Its utility as a diagnostic tool is further complemented by novel applications, including MRS and MRA.

MRI is particularly useful in separating edema from tumor and inflammatory disease from neoplastic masses (Nardi *et al.,* 2022). It is extremely helpful in osteomyelitis (inflammation of bones in dogs), cellulitis (swelling of skin in small and large ruminants), and abscess (pus) due to increased sensitivity and specificity (Weaver *et al.,* 2022). Because of its increased soft-tissue contrast and multiplanar, multislice imaging capabilities, MRI has proven to be useful in veterinary ophthalmology in diseases such as feline orbital melanoma, feline optic nerve meningioma, and canine orbital fibrosarcoma (May *et al.,* 2024). These imaging modalities provide excellent anatomical detail of the feline and canine eye, orbit, and optic nerves.

Whereas MRI has played a core role in central nervous system disease diagnosis, such as inflammation and neoplasia, for decades, therapeutic applications in veterinary practice have expanded significantly over the past couple of years (Prasad *et al.,* 2021). In cases such as nasal neoplasia, ocular and eye illness, and various musculoskeletal illnesses such as shoulder osteo-chondrosis, elbow dysplasia in dogs, and injuries of the cranial cruciate ligament, it is currently a necessary diagnostic tool (Scarpante *et al.,* 2016). In addition to precise measurements of the pituitary gland and key regions in the cranial fossa and ventricles, MRI has also been effective in detecting sensitive structures like the optic, trigeminal, and portions of the facial, vestibulocochlear, and trochlear nerves in rabbits (Nathani *et al.,* 2021).

Table 1: Advanced MRI Modalities in Cancer Diagnosis and Treatment

Technique	Principle of operation	Key applications in human oncology	Key applications in veterinary oncology	Advantages	Limitations	References
Diffusion-Weighted Imaging	Quantifies trapped diffusion at high cellularity and random water molecule motion	Early detection of liver, prostate, and brain cancers; distinguishing between benign and malignant lesions; and assessing the efficacy of treatment	Early detection of liver, prostate, and brain tumors; distinguishing between benign and malignant lesions; and assessing the efficacy of treatment	• Not invasive • Cellularity sensitive • Does not need contrast chemicals	• Has lower spatial resolution • Potentially vulnerable to motion artifacts	*(AlHarbi et al., 2024)*
Perfusion-Weighted Imaging (PWI)	*Measures blood flow, volume, and permeability, which are microvascular characteristics*	*Distinguishing repeat tumors from radiation necrosis in the brain, monitoring therapy response, and grading tumors (high vs. low grade)*	*Separating recurrent tumors from post-treatment brain changes, monitoring for response to treatment, and grading tumors*	• *Give information on the tumor's vascularity* • *Assists with prognosis*	• *Involves difficult post-processing, motion* • *Susceptibility artifacts, and contrast agents*	(Bhinder, 2023)
Magnetic Resonance Spectroscopy (MRS)	*Detects and measures specific metabolic metabolites (e.g., choline, creatine, NAA)*	*Distinguishing between tumor types (e.g., brain tumors), directing biopsies, and tracking response to treatment by measuring metabolic changes*	*Tumor characterization, directing biopsies to areas of metabolic activity, and tracking treatment response*	• *Gives metabolic data regarding tissues* • *Identify changes prior to anatomical changes*	• *Low spatial resolution, long scanning times, and difficult-to-interpret complex spectra*	*(Soufi et al.,* 2019)
Functional MRI (fMRI)	*Records brain activity through detection of blood oxygenation changes (BOLD contrast)*	*Preoperative planning of brain tumors (functional mapping); knowledge of brain function and tumor*	*Pre-surgical planning for brain tumors (mapping functional areas)*	• *Non-invasive; yields functional information regarding brain activity*	• *Sensitive to motion artifacts* • *Indirect measure of neuronal activity* • *Complicated experimental design and analysis*	*(Lakhani et al., 2023)*
Diffusion Tensor Imaging (DTI)	*Evaluates water diffusion directionality (anisotropy) to image white matter tracts*	*Pre-surgical planning of brain tumors (mapping white matter tracts); evaluation of white matter integrity in neurological disorders*	*Pre-surgical planning of brain tumors (white matter tracts mapping); evaluation of white matter integrity in neurological disease*	• *Offers information about white matter* • *Valuable for surgical planning*	• *Motion-sensitive artifacts* • *Crossing fibers* • *Challenging post-processing and interpretation*	(ElSheikh *et al.,* 2022)
Whole-Body MRI (WB-MRI)	*Extended whole-body imaging, usually in association with DWI*	*Staging and monitoring of multiple myeloma, lymphoma, metastatic breast/prostate cancer; identification of distant metastases*	*Staging and monitoring of lymphoma, sarcomas, other cancers; identifying distant metastases*	• *Non-invasive* • *Non- ionizing radiation* • *Global assessment in one session*	• *Longer time to acquire; reduced spatial resolution* • *In expensve*	*(Summers et al.,* 2021)
Dynamic Contrast-Enhanced MRI (DCE-MRI)	*Evaluates tissue vascularity and permeability by observing washout and contrast material uptake over time*	*Early detection and classification of breast, prostate, and brain cancers; tracking response to therapy by assessing changes in vascularity*	*Assessing tumor vascularity, differentiating benign from malignant lesions; monitoring treatment response*	• *Provides comprehensive information on tumor angiogenesis and perfusion* • *Help to differentiate tumor grades*	• *Requires contrast agents;* • *Prone to motion artifacts* • *Analysis can be difficult and require special software*	*(Sachani et al., 2024)*
Magnetic Resonance Angiography	*Non-invasive imaging of blood vessels, frequently with contrast agents to make images brighter*	*Evaluation of tumor involvement of vessels (e.g., head and neck, renal, liver); identifying vessel stenosis or thrombosis; assessment of vascular tumors*	*Evaluation of tumor involvement of vessels; identification of vascular malformations (e.g., portosystemic shunts); planning interventional procedures*	• *Non-invasive imaging of blood vessels*	• *Can be sensitive to flow artifacts* • *Contrast-enhanced MRA has risks related to contrast agents* • *May be of lower spatial resolution than standard MRI*	*(Vo et al.,* 2014)
Hyperpolarized MRI	*Strongly improves the MRI signal of infused metabolites (such as carbon-13 pyruvate) to image metabolic processes*	*Real-time visualization of tumor metabolism; discrimination between aggressive versus indolent tumors; early evaluation of treatment response on basis of metabolic changes*	*Real-time imaging of tumor metabolism (research applications mainly); possibility of early evaluation of response to treatment*	• *Offers direct evidence of metabolic activity in tumors* • *Possibility of early identification of response to treatment*	• *Still largely experimental and costly; requires hyperpolarization technology and specialized equipment; limited availability of hyperpolarized agents*	*(Peters et al., 2022)*
PET/MRI (Hybrid Imaging)	*Combines the anatomical data of MRI with the metabolic information of Positron Emission Tomography*	*Comprehensive staging and characterization of neoplastic illnesses; identification of metastatic cancer; quantitation of treatment result by measurement of*	*Extensive staging and characterization of metastatic disease (less availability); detection of metastatic disease; response to treatment*	• *Provides synergistic anatomical and metabolic information* • *Potentially more accurate for staging and restaging*	• *Limited access and high cost* • *Involves exposure to a low dose of ionizing radiation from PET component* • *Longer acquisition time*	*(Romero et al., 2023)*

		structure and metabolism				
Chemical Exchange Saturation Transfer (CEST) MRI	*A novel contrast mechanism that indirectly senses the presence of certain molecules (e.g., amide protons) by their exchange with bulk water*	*Tumor pH imaging, concentration of amide protons corresponding to protein concentration; possibilities of tumor grade discrimination and treatment outcome assessment*	*Research applications for imaging tumor pH and cellularity; potential for differentiating tumor types*	• *Contrast is inherent (no need for exogenous contrast media in certain applications)* • *Sensitive to certain molecular surroundings*	• *Still in development and refinement* • *Sensitivity may be less than standard contrast-enhanced MRI* • *Interpretation of images may be difficult*	*(Koike et al., 2023)*

MRI has become the preferred diagnostic method for equine medicine for the investigation of the orbit, lymph nodes, blood vessels, muscles, and salivary glands (Kozłowska *et al.,* 2022). It has also been vital in the detection of abnormalities associated with acute, serious unilateral forelimb lameness that begins at the heel. The significant role that MRI has to play in the detection and treatment of various types of cancer in animals is increasingly becoming evident based on its extensive series of growing uses (Schmidt and Doerfler, 2020). Based on a clinical study by Hadžijunuzović-Alagić and Hadžimusić (2024), MRI is the most accurate means of detecting brain and spinal cord disorders of the dog, such as disc herniation, stenosis, tumors, and inflammation. For example, MRI scans of dogs that presented neurological symptoms or were experiencing unexplained lameness revealed abnormalities in the spinal cord or small ligament damage that were not detected by CT or X-rays. Therefore, outcomes for recovery were enhanced with more accurate diagnoses and targeted treatments. According to a study by Stewart (2017), MRI has revolutionized the diagnosis of equine musculoskeletal disease, including osteo-chondrosis, traumatic arthritis, and navicular disease. MRI was able to show lesions in soft tissues and bone edema in the hoof and fetlock of horses that were chronically lame and failed to respond to normal imaging. This allowed for a better prognosis and more precise treatment planning, especially in the case of acute unilateral forelimb lameness. Similarly, Ludewig and Vali (2024) demonstrated that over the past few decades, CT and MRI have been widely used for the diagnosis of middle and inner ear diseases in canines and felines. Unlike CT, MRI has a superior advantage in diagnosing diseases of soft tissues, nerves, and brain tumors. The study also demonstrated that MRI is very important in assessing the central spread of otitis media. In the tumor diagnosis of conditions such as canine orbital fibrosarcoma and feline orbital melanoma, MRI has been invaluable, according to Lin *et al*. (2019).

MRI provided high-resolution, multiplanar images in the majority of cases that separated tumor from inflammatory mass and delineated its size, including involvement of the optic nerve. That knowledge was needed to plan surgeries and determine whether further therapy was necessary. Both human and veterinary medicine utilize MRI in the treatment, follow-up, and staging of cancer according to Bruno *et al*. (2019). Both human and canine patients with soft tissue sarcoma have their vascularity, tumor size, and response to therapy assessed on MRI in comparison studies. For both species, the ability to distinguish edema, tumor tissue, and post-treatment changes with advanced MRI sequences improved diagnostic accuracy and directed clinical decision-making. MRI is used for almost all parts of the body as shown in Fig. 3.

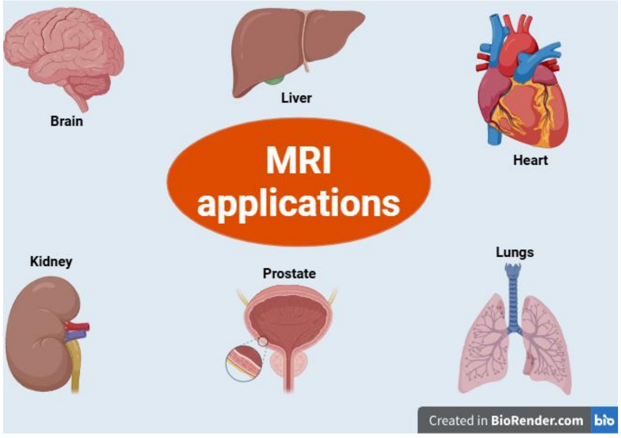

Fig. 3: Use of MRI for various organs for the diagnosis and treatment.

Uses of MRI against various tumors: The standard of early detection, complete treatment planning, and strict post-treatment follow-up in the scenario of brain tumors is magnetic resonance imaging, or MRI (Kamepalli *et al.,* 2023). Owing to its unparalleled soft tissue contrast, tumors may be accurately localized and sufficiently described. Extremely advanced MRI sequences further enhance diagnostic yield, while conventional MRI sequences yield critical information regarding tumor size, location, and impact on adjacent brain structures (Dalaqua *et al.,* 2022). More detailed information is acquired through specialized MRI methods. While MRS provides metabolic fingerprints helpful in tumor type characterization and discrimination of recurrent tumors from treatment effects, DWI helps detect highly cellular tumors like glioblastomas (Jung *et al.,* 2021). Through tumor vascularity measurement, perfusion MRI adds another dimension helpful in tumor grading and prognosis determination in the brain. When combined, these efficient MRI machines greatly enhance the overall treatment of brain cancer patients (Romano *et al.,* 2019).

MRI is also increasingly being utilized as a vital weapon in breast cancer combat, particularly for imaging women at elevated risk of developing the disease, including those carrying BRCA1/BRCA2 mutations, and for meticulous tracking of neoadjuvant chemotherapy efficacy (Arslan *et al.,* 2024). MRI is more sensitive to cancer than mammography and ultrasound and is thus a great agent for detecting very small, otherwise occult cancers (Bleicher and Morrow, 2007). Early detection is significantly enhanced through DCE-MRI, which provides an abundance of detailed information regarding vascularity and tumor shape. Diffusion imaging examines tumor cellularity and also DCE-MRI, providing crucial information on the predictability of treatment response (Mui *et al.,* 2021). Additionally, by explaining the volume of the disease very accurately, MRI facilitates much smoother pre-operative planning and also provides assurance that the whole tumor can be removed during the operation (Verma and Patkar, 2023).

Prostate cancer staging and diagnosis have been transformed through multiparametric MRI (mpMRI) (Dwivedi and Jagannathan, 2002). mpMRI dramatically enhances detection, precise staging, and biopsies targeted at combining T2-weighted imaging, DWI, DCE-MRI, and often MRS in an imperceptible process. The advanced method has the capability of visualizing suspect lesions clearly and thereby potentially sparing patients from avoidable biopsies while obtaining correct sampling of aggressive cancers (Javed *et al.,* 2024).

All of the modalities of mpMRI contain distinct and precious information: MRS detects minute changes in metabolism, DWI evaluates cell density, DCE-MRI measures tumor vascularity, and T2-weighted imaging provides overall anatomical resolution (Wang *et al.,* 2022). The synergistic strength enormously expands the capacity for discrimination of indolent from clinically relevant tumors, paving the way for individualized treatment plans including potential radiation therapy, surgery, or active surveillance.

MRI is an essential diagnostic and characterization tool for liver cancers, most importantly hepatocellular carcinoma (HCC) (Nadarevic *et al.,* 2022). In the early diagnosis, correct staging, and assessment of the efficacy of treatment by tumor viability, its high contrast resolution ability between lesions and surrounding liver tissue is most important (Jiang *et al.,* 2024). By emphasizing liver-specific uptake variation, the conscious use of hepatobiliary-specific contrast agents like gadoxetate disodium enhances lesion characterization (Kwok *et al.,* 2023). DWI, which detects lesions based on cell density, adds an important layer to this. MRI is also critical for patient follow-up post-treatment to allow for process evaluation of therapy like trans arterial chemoembolization (TACE) or radiofrequency ablation (Zerunian *et al.,* 2022). MRI is the modality of choice for local staging of bone and soft tissue sarcomas. MRI provides extremely precise anatomical information about the tumor margins, involvement of major neurovascular structures, and extension into adjacent soft tissues or bone. It is highly valuable information for cautious planning of radiation and surgery (Victor *et al.,* 2025).

Tumor anatomy is clearly delineated by well-experienced T1- and T2-weighted sequences, which highlight important inner details such as necrosis, hemorrhage, and cystic change. Contrast-enhanced MRI scans also discriminate between tumor tissue of active growth and necrosis or fibrosis by highlighting tumor vascularity. These strongly dominant features significantly augment preoperative planning and allow physicians to develop very individualized treatment programs (Holzapfel *et al.,* 2015).

Low-level radiation exposure is paramount in the delicate subspecialty of children's cancer care. One key, non-radiation alternative to exhaustive staging and ongoing surveillance of certain cancers in children, including neuroblastoma, lymphoma, and sarcomas, is whole-body MRI (Nievelstein and Littooij, 2019). Whole-body MRI is exquisitely sensitive for finding soft tissue and bone metastasis, especially in combination with DWI. It is also a very useful tool in the accurate monitoring of the effectiveness of the medication and determining the severity of the disease without the risks involved in repeated CT or PET-CT scanning. It is a crucial tool in the successful treatment of pediatric malignancies owing to its strong diagnostic capability and inherent safety profile (McCowan *et al.,* 2022). On the other hand, it is also useful in diagnosis of tumors in dogs and cats. Auger *et al.* (2021) demonstrated that MRI is highly useful in diagnosis and helps to contrast superior soft tissues. It also possesses multiplanar imaging capabilities. The MRI study revealed and helped to differentiate tumor types. For example, round cell tumors like lymphoma typically show bone-centered lesions with an increase in homogenous contrast and preservation of vertebral shape. While mesenchymal tumors involve surrounding tissues with heterogeneous enhancement with distort vertebral architecture. These allow vegetarians to differentiate diagnosis and provide guidelines for clinical decision making.

Challenges and Future Prospects: There are significant hurdles to straightforward introduction of MRI into practice in the veterinary sector, although it possesses excellent diagnostic potential. Widespread use of MRI techniques is severely impaired by their extremely highly specialized nature, necessitating extensive training, advanced software, and massive processing capacity. A considerable added degree of complexity and cost is created by the demand that veterinary patients undergo extended general anesthesia in an effort to achieve immobility during lengthy imaging studies. The MRI industry of the emerging world is immense in its potential but is faced with several challenges such as the vagueness of healthcare reforms, severe personnel shortage with the required training, and huge initial and operating expenses. The shortage of suitably trained individuals is a serious bottleneck to the quick development of MRI in veterinary research and therapeutic applications. Virtually all veterinarians interested in MRI often have minimal knowledge of the fundamental concepts of MR physics and minimal hands-on exposure to its research and clinical applications. Thus, the critical need for this advanced imaging modality in practice is very often overridden by the substantial financial investment involved with complete training and effective marketing. Access to MRI for teaching, research, or diagnostic applications in government-operated veterinary clinics or institutes involved in residency training programs remains very limited in most poor nations. But the availability of MRI technology has accelerated with recent economic growth booms in certain nations. In the future, small animal MRI studies will again become exciting due to the evolution of target-specific contrast agents from nanoparticles and novel contrast processes like Chemical Exchange Saturation Transfer (CEST). The development of comprehensive MRI training courses and research graduate curricula at universities and research centers must become the highest priority of the veterinary diagnostic imaging profession to best utilize the accelerated technical developments in this imaging technique. Ultimately, the immense benefits of precise and prompt diagnoses made possible by MRI are far more than the expense involved, and in order to keep pace with the fast-evolving branch of veterinary medicine, every effort should be made to enhance skills, gain knowledge, and implement this revolutionizing technique.

Conclusions: MRI provides valuable soft tissue and functional data and it is an essential tool in the diagnosis, staging, and monitoring of therapy of cancer. There is increasing understanding of tumor biology due to advances in technology, and comparative oncology places specific emphasis on specifically the translational value of these advances, specifically with canine models. Its potential will be even greater through overcoming barriers such as cost and availability by training and technology. State-of-the-art MRI along with molecular diagnosis and personalized treatment has the potential to bridge veterinary and human cancer medicine by providing earlier diagnosis, more targeted treatments, and improved outcomes for all cancer patient.

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