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Review Article

Advancement in diagnostic imaging techniques in veterinary medicine

Mehroz Latif[1], Muhammad Saad Arshad[1], Muhammad Usman[2], Muhammad Mobashar[3], Zahid Wali[4], Haseeb Ashraf[1], Tanveer Ahmad[5], Muhammad Adnan Sabir Mughal[6*]

[1]Faculty of Veterinary Sciences, Bahauddin Zakariya University, Multan, Pakistan
[2]Department of Pathology, Faculty of Veterinary Science, University of Agriculture, Faisalabad, Pakistan
3Department of Animal Nutrition, University of Agriculture, Peshawar, Pakistan
[4]Ohio University, Athens Ohio, USA
[5]Department of Clinical Sciences, Faculty of Veterinary Sciences, Bahauddin Zakariya University, Multan, Pakistan
[6]Department of Pathobiology and Biomedical Sciences, MNS University of Agriculture, Faisalabad

*Correspondence: adnansabir330@gmail.com

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ABSTRACT

The early and precise diagnosis of the diseases is facilitated by diagnostic imaging in veterinary medicine. This promotes the effective care of the patient. This review article investigates the historical evolution of veterinary diagnostic imaging. This evolution spans from the emergence of X-rays in the 19th century to modern techniques like magnetic resonance imaging (MRI), computed tomography (CT), and ultrasonography. Where traditional radiography continues to form a keystone, the dawn of digital radiography is a revolution in better image quality, accessibility, and post-processing. Nowadays, ultrasonography is an underlined tool in the examination of abdominal organs, reproductive health, and soft tissue injuries in a wide variety of animal species. At the same time, CT and MRI have gained advanced diagnostic competencies. They provide the well-exposed views of internal anatomy, thus permitting the diagnosis of complex diseases. New techniques such as nuclear scintigraphy, positron emission tomography, optical coherence tomography, and micro-computed tomography continue to widen diagnostic horizons. AI in veterinary radiography can improve diagnostic accuracy, efficiency, and consistency by image analysis through machine learning models that identify abnormalities and standardize interpretations. It serves as educational tools for the upgradation of the skills of professionals involved and integrate with other technologies. Despite these successes, cost constraints, limited expertise, and specialized equipment requirements are continual challenges. By implementing these innovative technologies, clinical diagnosis can be significantly improved, and, finally, health and welfare for different species of animals enhanced

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Introduction

The effective treatment of any disease is largely dependent on early and precise diagnosis (Gugjoo et al. 2014). Diagnostic imaging is a valuable resource that provides a non-invasive means of accessing altered animal physiology. Its significant contribution to the advancement of accurate diagnosis highlights its critical role in clinical decision-making, which in turn promotes a new approach towards effective and individualized patient care (Prasad et al. 2021). Veterinary diagnostic imaging is used for a wide range of animals, including pets, cattle, and even birds, as well as large wild animals like elephants and small lab animals like mice (Brar et al. 2021).

Diagnostic imaging underwent a series of technological progression from emerging X-Rays in 19th century to current era of sophisticated diagnostic modalities. In past, veterinarians relied only on physical clinical examination along with therapeutic and diagnostic radiography for diagnosis and treatment (Yitbarek and Dagnaw 2022). The imaging technology took birth with discovery of cells in 1665 by Robert Hook which was followed by the discovery of X-Rays by Roentgen in 1895, thus giving birth to Radiography. Subsequently, this imaging technology moved with continuous progress in material sciences and instrumentation resulted into advance imaging techniques such as CT-Scan, MRI, ultrasonography etc. Ultrasonography was developed in 1940s, followed by Thermal Imaging in 1950s, Magnetic Resonance Imaging in 1971 and Computed tomography (CT scan) in 1990s. (Marino and Loughin 2010; Brar et al. 2021).

Unfortunately, the use of these modern diagnostic modalities is still in its infancy in veterinary medicine due to the lack of expertise, heavy investments and need of different adjustable machines to accurately accommodate the different range of animal sizes (Gugjoo et al. 2014). This review's main purpose is to carefully examine current developments in veterinary diagnostic imaging. A thorough analysis of many important techniques, including nuclear medicine, computed tomography, radiography, ultrasound, and magnetic resonance imaging, is carried out in order to better understand the revolutionary impact that these technologies have had on the accuracy of diagnosis in the veterinary medical field.

Radiography in veterinary medicine

Radiography refers to the use of X-rays for the accurate non-invasive access to the skeleton. This allows us accurate diagnosis of the bone lesions and to check the efficacy of treatment & healing processes (Meomartino et al. 2021). Radiography works on the principle of absorption of X-rays by body. It utilizes very small amount of ionizing or non-ionizing radiations. Softer tissue absorbs fewer X-rays than the bone resulting into grey shades whereas bone appears radiopaque due to greater absorption of X-rays. These energy absorption properties make radiographs ideal for orthopedic diagnosis. However, Overexposure to X-rays has some dangers, including the possibility of skin burns, hair loss, and cancer but the advantages usually outweigh the disadvantages (Marino and Loughin 2010; Umar et al. 2019).

In traditional method of radiography, the patient is placed on the X-ray table followed by the thickness measurement of body part being radiographed. X-ray film, placed in cassette is placed under X-ray table. The patient is exposed to the X-rays which creates the latent image on the film. The exposed X-ray film is taken to the dark room, where film is developed and transformed into the radiograph. This radiograph is then interpreted by placing in the view boxes (Drost 2011).

With the advancements of science, the transition from traditional to digital radiography was considered as a marvel in diagnostic imaging. Traditional film is being replaced by digital systems, which use electronic detectors to transform X-ray data into digital pictures. Many benefits result from this transformation, such as improved image quality, instant accessibility, and customization possibilities after post-processing. The adoption of digital radiography is a significant step forward in reducing the constraints associated with conventional techniques (Vano et al. 2007; Ou et al. 2021).

Ultrasonography

Ultrasound has become an essential diagnostic tool in modern veterinary medicine, with a growing number of applications that are highly beneficial to veterinary services. With the advent of ultrasonography, scientists and veterinarians can now access and monitor a wide range of physiological and pathological events in companion, agricultural, and wild animals (Samir et al. 2022). Sound waves include ultrasound waves, which have frequencies higher than the human hearing range of 20–20,000 Hertz. When electrically activated, diagnostic ultrasonic probes, which contain piezoelectric crystals (usually constructed of zinc zarconate), produce sound waves. After passing through the body, some of these waves are reflected back as an echo, which might appear in many ways, when they come into contact with a reflecting surface. With amazing precision and accuracy, this non-invasive method creates precise photographs of internal body organs (Andualem et al. 2017). In diagnostic ultrasonography, two primary image display modes prevail: brightness mode and motion mode. The prevalent Doppler modes include pulsed wave Doppler, continuous wave Doppler, color Doppler, and power Doppler (Cole and Hespel 2020).

With recent technical breakthroughs improving picture quality, ultrasound is routinely used for monitoring uterine anatomy, diagnosing pregnancy, and researching embryonic mortality. In addition to providing information regarding the location, size, and shape of structures, ultrasonography also sheds light on the soft-tissue architecture of the organ under examination (Medan and Abd El-Aty 2010). The best method for differentiating solid structures from cavities (fluid-filled structures) is ultrasonography, which also offers internal information not seen on radiography (Thrawat et al. 2012).

This technique varies in its applications as; In small animals, it facilitates detailed assessments of abdominal organs and aids in reproductive evaluations. For large animals, particularly in bovine and ovine practices, ultrasonography proves instrumental in reproductive management and musculoskeletal evaluations. In equine medicine, it offers unparalleled diagnostics into soft tissue injuries, reproductive health, and cardiovascular assessments (Meomartino et al. 2021).

Computed tomography

Computed tomography (CT) is technique in which X-ray tube is made to revolve around the patient, recording electronic data as it goes. A synchronized high-kV X-ray beam goes through the patient's tissues while portion of the original beam is absorbed (Ohlerth and Scharf 2007). Cross-sectional pictures with a slice depth ranging from 1 to 10 mm are produced (Patel and Jesus 2023). The pictures are shown in pixels according to the Hounsfield scale, and contrast agents such as iodine are used to emphasize certain features. Different CT scans may be combined to create 3D pictures. The left side of the image represents the patient's orientation, and the right side represents the patient's right side (Kalender 2006).

Veterinary CT was initially used to examine cancer and diseases of the CNS in dogs and cats in the 1980s. Accessibility has expanded due to ongoing technical developments with CT frequently offering new insights beyond radiography and ultrasound in veterinary medicine (Yitbarek and Dagnaw 2022). CT is essential for accurate tumor identification, grading, and diagnosis of illnesses affecting the central nervous system. In addition to assisting wildlife research by spiral CT angiography, and enabling tailored therapies in veterinary medicine, it helps to diagnose a variety of problems pertaining to internal organs, cranial structures, and musculoskeletal issues (Prasad et al. 2021). CT is superior to radiography because it provides superimposition-free, clear internal anatomy, which is especially useful for assessing complex structures like the teeth and skull (Mackey et al. 2008).

Spiral CT angiography is the volume acquisition mode in CT, allows continuous scanning of anatomical ranges in 20-60 seconds. It is also a flexible diagnostic tool for pulmonary thromboembolism, animal problems, targeted to their treatments. It can also be combined with other imaging modalities to provide advanced veterinary diagnostics (Brar et al. 2021). CT is frequently used for intervertebral disc disease. It also provides detailed anatomical descriptions of bones in different animals, which helps with lameness studies, bone measurements, and accurate visualization of internal organs for disease detection (Yitbarek and Dagnaw 2022).

Certain advancements in the field of Computed tomography includes:

Low dose CT*:* Low-dose CT (≤30 mAs) is used for screening the renal colic, ureteral issues and has shown a 50% decrease in radiation, there are limitaions in overweight individuals and the representation of alternative diagnoses (Poletti et al 2007). The popularization of cutting-edge research and the provision of patient-centered services are essential to the progress of veterinary medicine. High-contrast tomographic pictures are provided by (MRI), an advanced diagnostic technique that is extensively employed in veterinary, which enhances the study of anatomy and disease in vivo (Yitbarek and Dagnaw 2022)

Cone beam CT*:* High-contrast pictures of osseous structures in the craniofacial region are provided by Cone Beam CT (CBCT), which is suited because of its smaller size and cheaper cost as compared to CT. CBCT is a supplementary imaging modality that provides good imaging in oral and maxillofacial applications at possibly reduced radiation doses and costs (Nemtoi et al. 2013). This technology offers several benefits for clinical dentistry practices (Scarfe and Farman 2008).

Magnetic resonance imaging in veterinary medicine

As a diagnostic imaging technique, (MRI) has essentially replaced (CT) during the last 10 years. MRI provides high-resolution, radiation-free cross-sectional pictures based on magnetic fields and radiofrequency signals, giving precise anatomical information for medical diagnosis. (Dennis 1998). Due to the scanner's strong magnetic field, MRI uses radiofrequency energy and magnetic fields to provide cross-sectional imaging. This means that equipment must be used, particularly in anesthetic patients and monitored devices (Dennis 2003).

Because of its unmatched capacity to image soft tissue structures, MRI has emerged as a diagnostic tool in veterinary medicine. It is especially useful for small animal brain and spinal illnesses, auditory, nasal, and ocular problems, soft tissue surgery, cancer, and orthopedics. (Gilbert et al. 2010). MRI is useful, especially for brain imaging as it provides accurate visualization of abnormalities in small animals, helps diagnose diseases like brain tumors and late-onset epilepsy, and helps "rule-out" diagnoses. Additionally, MRI enables contrast studies, which improve tissue and lesion visibility and help with surgical planning and treatment. (Dennis 1998).

Accurate assessment is necessary for the best possible clinical management. Recent developments in MR imaging, such as multiparametric techniques and targeted biopsy guidance, improve the accuracy of localization. This technique is further strengthened by staging, and therapy selection (Bonekamp et al. 2011). For instance, clinical improvements for horse lameness and osteopathology depend heavily on MRI because of its availability, safety, and capacity to offer precise and economical diagnoses without ionizing radiation. MRI is a great diagnostic technique for diagnosing soft tissue problems (Riley 2018).

Emerging techniques:

Some of the emerging techniques are as follows:

(A)Nuclear scintigraphy

Scintillation or scintigraphy is the process of creating an image from light flashes that arise from the interaction of energy with an absorbing substance. This is a non-invasive procedure that uses a radiopharmaceutical to release gamma radiation. A gamma camera records the radiation released by these gamma rays as they contact with tissues, allowing for the generation of finely detailed pictures that depict the distribution of the radiopharmaceutical throughout the body. The four components of scintigraphy are the radiation detector, the patient, the radiopharmaceutical agent, and a means of storing and processing data (Hoskinson 2001; Montilla-Soler and Makanji 2017). Nuclear scintigraphy uses radiopharmaceuticals and radionuclides for specific applications in veterinary medicine, such as glomerular filtration rate studies, shunt detection, liver function, bone metabolism, thyroid function, and mucociliary function (Huyhn et al. 2023).

Positron emission tomography

Positron emission tomography is a very sensitive modern imaging technique with superb possibilities of discovering numerous diseases at their incipient stage of disorders. Positron emission tomography is one of the novel, noninvasive imaging techniques that have made a huge impact on veterinary medicine. It visualizes metabolic and functional processes at a molecular level (Marinov and Bojilova 2021). The collision with electrons releases the proton from the radiopharmaceutical gives off gamma-ray photons. The PET scanners detect these photons to produce three-dimensional intricate images of the distribution of radiopharmaceutical in the body (Kasban et al. 2015). In oncology, neurology, and cardiology, PET using positron radiopharmaceuticals remains a paramount diagnostic tool for cancer identification, staging, therapy planning, and control. It is also broadly applied in veterinary medicine for the detailed conduction of diagnostics within the field of oncologic and fungal diseases. It is also being used for research purposes in the respect of neurology and cardiology (Łojszczyk et al. 2020).

Optical coherence tomography

Optical Coherence Tomography is a non-invasive medical imaging technique that has exponentially grown in importance during the past two decades when the regular assessment and treatment of neuro-ophthalmic disorders are considered (Minakaren et al. 2023). It is an advanced light-based imaging technique for in vivo tissue research. It was developed at MIT in the early 1990s, derived from OCDR and white-light interferometry. Its light source, interferometer, and beam scanning optics have all undergone improvement (Regar et al. 2023). This was established to diagnose the retinal pathologies in human eyes and now has been adapted to small animal models and birds. This makes it crucial for determining the effectiveness of treatment for traumatized wild birds intended for release back into the wild, or for genetic retinal abnormalities, especially in valuable breeding animals (Rauscher et al. 2013). Further advancements in technology have made OCT a, noninvasive imaging, technique that can monitor posterior segment disease with high-resolution, retinal and optic nerve images. However, it is difficult to modify equipment meant for human patients for usage in veterinary sciences. It is feasible to acquire repeatable, high-quality OCT pictures in a range of animals, including rats, dogs, cats, pigs, and monkeys. This feasibility requires the unique set of changes in the instruments as per the specie to be examined (McLellan and Rasmussen 2012).

Micro computed tomography

Micro-CT stands as an advanced X-ray tomography technique, delivering unprecedented (sub)micron resolution in X-ray imaging. Initially incorporated in the biological sciences, its versatile and non-invasive attributes have propelled its utilization across various scientific disciplines, particularly in materials science research. The adaptability of Micro-CT permits comprehensive exploration of diverse specimens, from biological entities to inorganic materials. Its non-destructive nature enables researchers to conduct investigations in real-world settings, offering insights into both in situ and in operando conditions (Vásárhelyi et al. 2020). Nowadays, it has been adapted for dental applications, allowing for high-resolution imaging of microscopic bone structures. This has directed to the development of a cone-beam X-ray CT system. This system was limited with improved characteristics (Arai et al. 2005). Micro-CT is one of the high-resolution techniques of vascular exploration in small animals; however, the technique has drawbacks involving different defined procedures, quantification, and physical preparation (Zagorchev et al. 2010).

Infrared thermoradiograpgy

It is an ancillary diagnostic tool of great value in veterinary medicine for detecting anomalies and advising locations that would necessitate further imaging or treatment. Infrared thermography is a method of imaging that allows the discovery of differences in temperature from the surface of the body with an infrared camera, which maps the neurological, vascular, or inflammatory conditions. The thermography is at least ten times sensitive than that of human hand palpation for changes in temperature (Soroko and Howell 2018). It is used to track animal's physiological condition. E.g. it can help us determine whether an animal is pregnant, or it can help us measure feed efficiency. Infrared thermography helps in the evaluation of animal welfare. It helps us to track stress reactions in horses and detect soring in them (Rekant et al. 2016). This is affected by various factors such as the technical specifications of the cameras, the environment, the expertise of the operator, traits of the animal, and protocol of testing. Therefore, the impact of any stimulus will change the outcome of the thermogram. Lack of comparing the thermograms recorded under different environmental conditions is the major factor blocking the implementation of these standards in livestock animal thermography (Racewicz et al. 2018).

Use of AI in radiography

With the expansion and development of Artificial Intelligence tools, they get introduced to radiography. Artificial intelligence stands at a Tempting position to develop medical imaging and, thereby, enhance healthcare delivery as a whole in the near future (Wuni et al., 2021). Artificial intelligence influences veterinary radiography, which enhances diagnostic consistency, efficiency, and accuracy. AI systems, especially machine learning models that include convolutional neural networks (CNNs) for image classification in radiography. It can capture, evaluate accurately, and spot an anomaly which the human eye might miss, such as cancers, fractures, and irregularities in organs (Hennessey et al., 2022). Image interpretation can be standardized by this approach with a reduction in variability among radiologists and expedite the processing of images quickly enough for diagnosis and immediate initiation of treatment. AI-powered systems provide interactive modules for the improvement of radiographic interpretation skills and thus are a potentially very useful instructional tool for veterinary professionals and students alike (Panayides et al., 2020). On the other hand, incorporating AI with other technologies, such as telemedicine and multimodal imaging, gives an overall view of the patients' condition and enables remote consultations (Bhaskar et al. 2020).

But this has a number of drawbacks as well. For instances where the use of AI-powered technology and software produces incorrect outcomes, more transparent accountability and medicolegal frameworks are needed. In addition to schooling in this profession where artificial intelligence will play a vital role, healthcare practitioners, especially radiographers, need clearer career trajectories and role extension provisions (Malamateniou et al., 2021).

Impact of advancements in veterinary medicine

For practical and financial reasons, radiography and ultrasound predominate in veterinary clinical practice; nevertheless, in recent decades, CT, MRI, and, to a lesser extent, nuclear medicine has become more popular. (Greco et al. 2023). Large animal imaging methods which use scanners and protocols and have applications in both anatomical and functional imaging, make translational research between preclinical and clinical settings easier. (Alstrup and Winterdahl 2009). Although clinical diagnosis has improved due to the development of imaging techniques, there are still issues in veterinary practice, including high costs, a lack of expert interpretation, anesthesia is required, and the requirement for specialized equipment for different animal sizes (Gugjoo et al. 2014). Over the last ten years, radiography and ultrasonography have remained the primary modalities used in veterinary practices, but significant advancements in diagnostic imaging equipment, such as computed tomography (CT) and magnetic resonance imaging (MRI), have raised client expectations and made these procedures more accessible through the increasing availability of pet insurance policies. (Bealey 2016). Veterinary imaging has been advanced by companion animal keeping, higher spending on animal health, a focus on the diagnosis of wildlife diseases, and technological innovations in view of zoonotic diseases and growing human-animal interactions. There is hardly any denying that the fact that strengthening veterinary diagnostic imaging will remain crucial for the "one health" conceptual framework (Brar et al. 2021).

Conclusion

Veterinary diagnostic imaging has evolved from conventional radiography to sophisticated modalities like magnetic resonance imaging, computed tomography, and ultrasonography. Proceeding with this evolution, exploratory methods have also developed that include nuclear scintigraphy, positron emission tomography, optical coherence tomography, and micro-computed tomography. These technologies facilitate early and accurate detection of a range of diseases in different animals, including pets, cattle, birds, and wild animals. The advancements have greatly enhanced the clinical diagnosis and care for patients, but high costs, lack of relevant expertise, and specialized equipment required for varying sizes of different animals are some of the challenges. However, with the increased number of policies on pet insurance and heightened attention currently paid to the diagnosis of wildlife diseases and the "one health" concept, strengthening veterinary diagnostic imaging makes more sense. Policies incorporating state-of-the-art methods for diagnostic imaging will be very instrumental in promoting the health and welfare of most species of animals as veterinary medicine advances.

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All the authors contributed equally.

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