MINI REVIEW

Sokoto Journal of Veterinary Sciences
(P-ISSN 1595-093X/ E-ISSN 2315-6201)
Uwagie-Ero & Awasum /*Sokoto Journal of Veterinary Sciences* (2017) 15(3): 1 – 9.
http://dx.doi.org/10.4314/sokjvs.v15i3.1

The challenges and limitations of magnetic resonance imaging technique in veterinary curriculum and clinical practice in Nigeria

EA Uwagie-Ero[1]* & CA Awasum[2]

[1.] *Department of Veterinary Surgery, Faculty of Veterinary Medicine, University of Benin, Nigeria*
[2.] *Department of Veterinary Surgery, Faculty of Veterinary Medicine, Ahmadu Bello University, Zaria, Nigeria*

*Correspondence: Tel.: +2348033977590; E-mail: edwin.uwagie-ero@uniben.edu

Abstract

As veterinary practice advances globally, the outcome of most treatments depends largely upon appropriate definitive diagnosis. Over the years projection radiography was the main imaging technique being utilised for radio-diagnosis of clinical conditions that would give the 2D images of a 3D structure and had narrow exposure latitude. However, with the advent of modern diagnostic techniques, such problems have been largely resolved. There are a number of imaging techniques like ultrasonography, computed tomography, nuclear medicine scintigraphy and magnetic resonance imaging that are currently available for clinical veterinary diagnosis. Each with its strengths and weaknesses. More than one technique therefore, may be used to compliment or supplement the findings of other techniques to arrive at a final diagnosis. The modern imaging diagnosis though well established in developed countries across the globe, it is yet to be embraced or remains in its infancy stage in veterinary curriculum and practice in Nigeria; due to heavy initial investment and maintenance costs, lack of professionals, requirements of specialized skilled technical staff to manage the machines and the need for adjustable machines to accommodate the different species of animal. This study presents a brief review and update of the development, challenges and status of a diagnostic imaging technique – Magnetic Resonance Imaging in veterinary medical curriculum and practice in Nigeria.

Keywords: Clinical practice, Challenges, Limitation, Magnetic resonance imaging, Nigeria

Received: 17-02- 2017 Accepted: 05-05-2017

Introduction

Medical imaging was far from the minds of Dr. Felix Bloch and Dr. Edward Purcell in 1946, when each independently discovered how to measure magnetic resonance (Bloch *et al*., 1946; Purcell *et al*., 1946), the breakthrough that led several decades later to Magnetic Resonance (MR) imaging. The goal of all imaging modalities is to aid in visualization of normal anatomical and patho-physiological conditions. Clinical Veterinary MR imaging started approximately 30 years ago, primarily as a result of veterinarians negotiating access, usually out of hours, to scanners in sympathetic local human hospitals. Early applications of most veterinary MR studies were of the canine head and brain (Goldstein *et al*., 1985; Kraft *et al*., 1989; Moore *et al*., 1991; Karkkainen *et al*., 1991; Dennis, 1993; Grahn *et al*., 1993). Today applications have broadly expanded to include spinal and orthopaedic conditions (Karkkainen *et al*., 1993; De Risio *et al*., 2009). In recent years, there has been a rapid increase in the availability of magnetic resonance imaging. It is now public knowledge that diagnosis of brain diseases in dogs and cats is most accurate when MR modality is applied. Thus, MR imaging has become the choice modality in the diagnosis of most orthopaedic conditions and a one stop shop for diagnosis of most chronic equine lameness. MR imaging reveals the brain with greater clarity than ever before, and ante mortem diagnosis of neurologic conditions, such as intracranial neoplasia (Kraft *et al*., 1997; Garosi *et al*., 2001; Cerda-Gonzalez *et al*., 2009), has become increasingly common. In spine studies, MR imaging reveals conditions that hitherto could not be accurately diagnosed ante mortem and this has facilitated the study of their pathophysiology for example syringohydromyelia and fibrocartilaginous embolism (Couturier *et al*., 2008; Cerda-Gonzalez *et al*., 2009). In many veterinary practices, MR imaging has largely replaced myelography because it is non-invasive and provides superior anatomic detail for surgical guidance; however, despite these advances and benefits, it has been difficult to introduce MR imaging into the typical veterinary student curriculum and practice in Nigeria. This is demonstrated by a lack of knowledge of the cumbersome softwares and system application programmes, poor computer competency on the part of the diagnostic imaging technicians and a need to administer prolong anaesthesia for effective restraints of veterinary patients. The current status of veterinary clinical practice and diagnostic modalities are not moving towards the exigency of the need to incorporate and embrace MR imaging. Over and beyond cost of power, machines and manpower development for the sustainability and improved usage of MR imaging techniques is extremely thin. The aim of this article is to review MR imaging, discuss the indications and applications in veterinary medicine and highlight the need to incorporate it into veterinary medical practice and veterinary curriculum in Nigeria.

Basic Principles of MRI

Current clinical applications for MRI rely on visualization of the hydrogen atoms' nucleus. This physical property was previously known as nuclear magnetic resonance, that is, the hydrogen atom nuclei resonance. The word nuclear does not refer to radioactivity, but to the nucleus of the atom. This modality is what today has become known as MR imaging. The basic physical principle is that a moving electrical charge produces a magnetic field. The size of the magnetic field is dependent on the speed of movement (magnetic movement) and the size of charge. While the hydrogen nucleus has a small electric charge it spins very fast. These physical attributes, in consonance with the abundance of the hydrogen nucleus within the body tissues, produce a detectable magnetic field. Magnetic field strengths are measured in units of gauss (G) and tesla (T). One tesla is equal to 10,000 gauss (Kraft *et al*., 2007; Labruyère & Schwarz, 2013). The earth's magnetic field is approximately 0.5G. The strength of MR is similar to the electromagnets used to pick up large heavy scrap metal. Materials can be ferromagnetic, paramagnetic, supra-paramagnetic, or diamagnetic. Ferromagnetic materials generally contain iron, nickel, or cobalt. These materials can become magnetized when subjected to an external magnetic field. In MR images, these materials cause large artefacts characterized by the properties of signal and distortion of the image. These artefacts can be seen in MR images even when the ferromagnetic substances are too small to be seen on conventional radiography (Labruyère & Schwarz, 2013). MR imaging has undergone continuous technological improvement and a large number of scientific papers describing features of diseases in animals have been published, contributing greatly to the advancements in clinical veterinary medicine. One big advantage to MR imaging is that it is a non-invasive medical procedure. Nothing is inserted in a patient's body, no dyes are swallowed, and no contrast agents are injected, except under special circumstances. Moreover, patients are not exposed to ionizing radiation, as is the case with X-ray and computed tomography (CT) imaging. "Unlike other imaging modalities, which essentially have one tool, MRI is a big toolbox," (Gavin & Bagley, 2009; Labruyene & Schwarz, 2013). Choosing what kind of MRI to use may depend on whether a specific disease involves changes in blood flow, metabolism, structural anomalies, or particular interactions with therapeutic drugs. "The only difficulty with MRI is deciding which tool to use (Gavin & Bagley, 2009).

Low-field-strength MRI

These systems use a permanent magnet with a field strength of approximately 0.25 Tesla. The magnetic field is created between two horizontal discs allowing a relatively open access for the patient. This can be advantageous for the scanning of equine patients or large body parts of other animals. Low field systems have relatively low purchase price and maintenance; as they have no specific requirements for electric supply and cooling and also require inexpensive magnetic shielding. They also have a small footprint and the low magnetic field which is a bonus from a safety perspective. The image quality of current low-field strength systems is good for most body parts, but it is not excellent; because of the relatively small usable magnetic field, long body parts, such as the spine, need to be imaged in many small segments for which the animal needs to be repositioned. This increases the total examination time (Kraft *et al*., 2007; Labruyère & Schwarz, 2013).

High-field-strength MRI

These systems use superconducting magnets with a typical field strength of 1-1.5 Tesla. Their external appearance is similar to CT scanners (Plate I). A large cylindrical gantry composed of electromagnets super cooled with liquid helium creates the magnetic field. Superconducting magnets can achieve very high field strengths of up to 9 Tesla. The long enclosed tubular space for the patient creates challenges for monitoring and can be a limitation for large animal MR imaging. For instance, with most high-field-strength MR imaging units, it is not possible to fit in the equine neck or stifle. High-field-strength MR imaging units are very expensive to purchase and maintain, require ample space, expensive magnetic shielding and three phase power supply. However, the image quality is excellent for most body parts, longer body parts can be imaged without repositioning, and a wide range of functional imaging is possible. High-field-strength MR imaging scanners are more suited for advanced techniques, such as MR angiography (Labruyère & Schwarz, 2013; Kraft *et al*., 2007). Special sequences have also been developed to identify particular pathology, such as the diffusion-weighted imaging (DWI) used in the Characterisation of ischemic strokes (Warach *et al*., 1992; Warach *et al*., 1995; Fisher *et al*., 1995; Warach *et al*., 1996; Marks *et al*., 1996; Lutsep *et al*., 1997; McConnel *et al*., 2005; Nemanic *et al*., 2006). Unlike CT, no ionising radiation hazards are associated with MR imaging. So far, no health risks from strong magnetic fields have been identified and the procedure is regarded as safe for patients and operators. However, due to the strong magnetic field, any metallic device in the vicinity of the scanner can turn into a dangerous projectile. Vigilant monitoring of all personnel and patients for metal objects and implants is therefore mandatory with high-field-strength MR imaging units. This also means that anaesthetic and monitoring equipment must be non-ferrous and MR-compatible if they are to be positioned near the scanner. In most anatomical regions, MR imaging is a suitable cross sectional imaging techniques, should the choice arise however, MR imaging is superior for investigations of the central nervous system pathology (Pomper *et al*., 1999). Note that higher image quality is obtained with high-field-strength MR imaging scanners. The images from MRI are cross sections of the brain or

Plate I: The external appearance of high-field-strength MRI scanner Photo courtesy: Anon (2016)

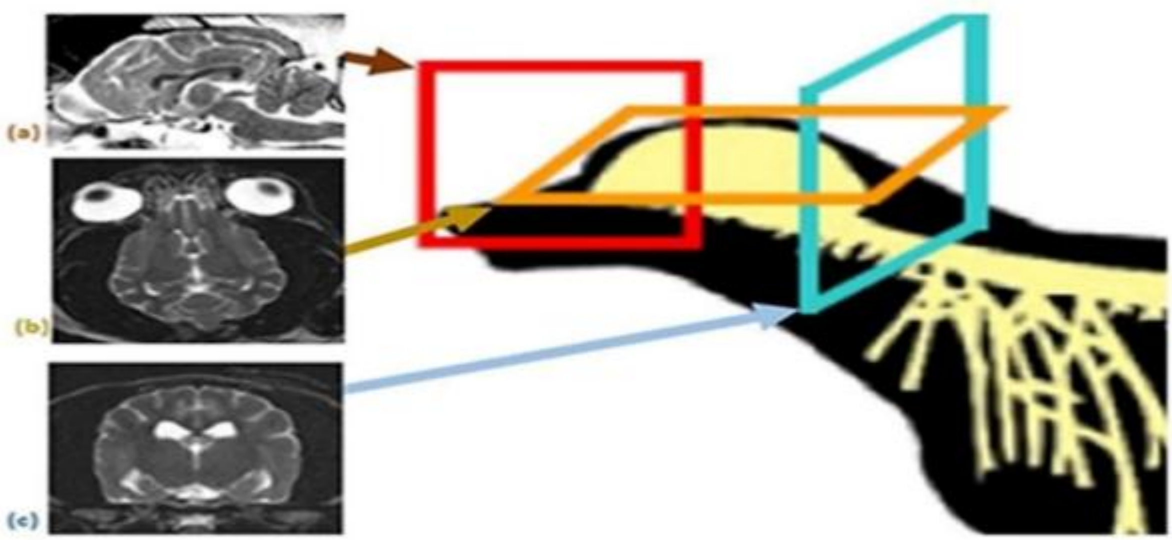

Plate II: Multiplanar imaging (a) sagittal (b) dorsal (c) transverse sectioning in MR imaging (Photo courtesy: Yapei, 2015)

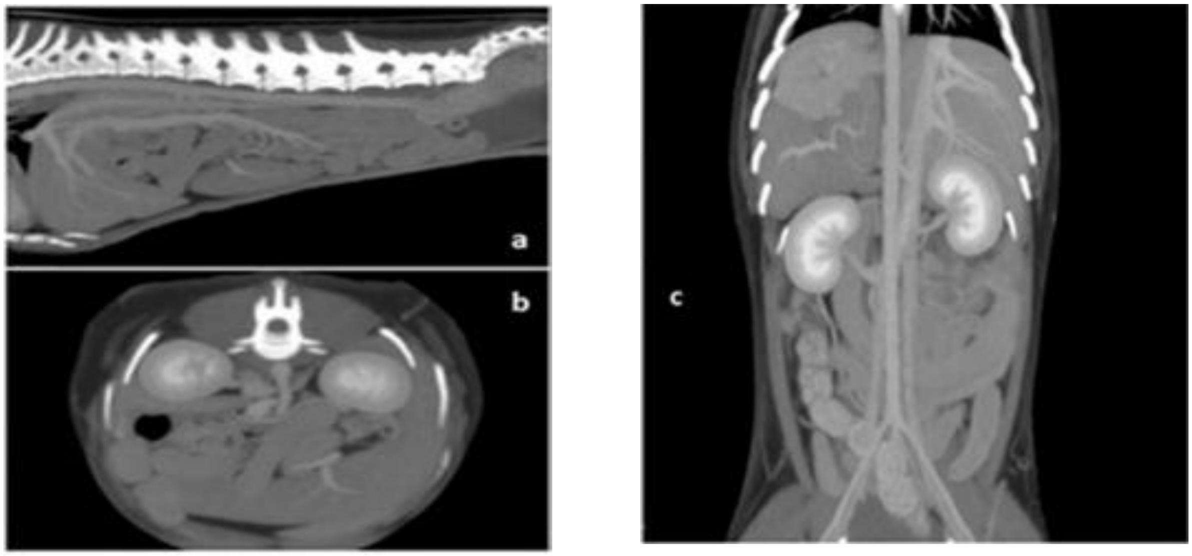

Plate III: Multiplanar reconstruction (MPR) is the computer technique that allows the images to be reformatted in any plane (a) sagittal (b) transverse (c) dorsal (Labruyère & Schwarz, 2013)

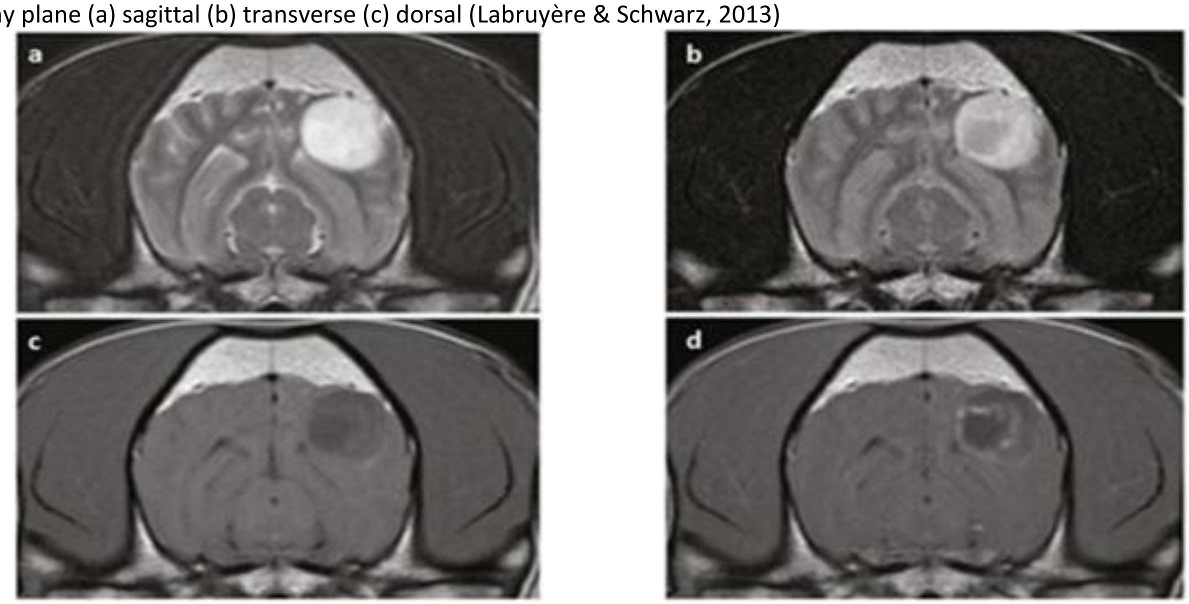

Plate IV: Transverse MRI images of the brain of a dog with a histologically confirmed brain tumour (oligodendroglioma)
The brightness of the tumour and the contrast to the neighbouring brain tissue varies between the T2-weighted image (a) FLAIR (b) T1-weighted image (c) and T1-weighted image post-contrast (d)
The use of multiple MRI sequences helps to localise the lesion in the frontal lobe and characterises its fluid-filled nature. Photo courtesy: Anon (2016)

body, thin slices of tissue, like slices of bread from a loaf. Computer programs can be used to assemble These image slices into three dimensional datasets (Plate II and Plate III). The computer power needed for this fast analysis, which was unavailable a few years ago, now fits on a desktop. Most of the time, however, veterinary radiologists analyze these images slice by slice (Plate IV).

MR imaging use in some specific organ system

Central nervous system: The use of cross sectional imaging in the investigation of brain diseases has revolutionised neurology and neuroradiology. Due to its high tissue contrast capability, MRI has become the diagnostic imaging technique of choice to evaluate the brain parenchyma (McConnel *et al*., 2005; Nemanic *et al*., 2006; Cerda-Gonzalez *et al*., 2009; De Risio *et al*., 2009).

Vascular lesions: Cerebrovascular accidents or 'strokes' are characterised by an area of ischemia with or without haemorrhage. Ischemic infarcts most commonly affect specific vascular territories. Haemorrhagic strokes can have a varied appearance, primarily based on the duration of the haemorrhage and alteration in blood haemoglobin (Garosi *et al*., 2001). Diffusion-weighted MR imaging sequences allowing the mapping of water molecules can aid in the diagnosis of infarcts. Gradient echo MRI sequences are commonly used for the diagnosis of haemorrhage (McConnel *et al*., 2005; Mai *et al*., 2010).

Inflammation: Inflammatory brain diseases can affect the brain parenchyma (encephalitis) or meninges (meningitis) and can be divided into infectious inflammatory and non-infectious inflammatory diseases (Li *et al*., 2002; Li *et al*., 2005). They produce highly suggestive changes on MRI, such as mass effect, contrast enhancement and perilesional oedema. Because of its high contrast resolution and the use of specific sequences, such as Fluid-attenuated Inversion Recovery (FLAIR), MR imaging is far superior for the evaluation of brain oedema and subtle periventricular lesions (McConnel *et al*., 2005; Cerda-Gonzalez *et al*., 2009).

Spinal diseases: The use of MR imaging for investigation of spinal cord disease in acutely paraplegic patients is superior to conventional radiography, myelography and CT. MR imaging is more sensitive when the disc lesion is not mineralised (De Risio *et al*., 2009; Labruyère & Schwarz, 2013). Presence of small intra-parenchymal lesions is much better recognised on MRI without the inherent risk of myelography (Couturier *et al*., 2008).

Skull and splanchnocranium: MR imaging is equally useful in the investigation of the orbit, nasal cavities, sinuses and ears. MRI allow clear visualisation of the palpebral region, the anterior and posterior segments of the eye, the retrobulbar structures, and the zygomatic salivary glands (Cerda-Gonzalez *et al*., 2009). Abnormalities of the optic nerve, such as optic neuritis, are readily identified. Due to the large amount of fat in the orbital region, MRI fat-suppressed sequences, such as Short Tau Inversion Recovery (*STIR*) also called short T1 inversion recovery, are particularly useful to demonstrate the extent of an orbital neoplasm (Kraft *et al*., 2007; Couturier *et al*., 2008; Labruyère & Schwarz, 2013). Rostral meningeal enhancement is better demonstrated with MRI (De Risio *et al*., 2009). This can be helpful to detect the early signs of intracranial involvement of nasal neoplasia. (Plate IV).

Extremities: The use of MRI in small animal musculoskeletal diseases is still in its early days compared to its use in horses (Barrett *et al*., 2009). The size of small animal joints is a limiting factor when the acquisition of images is performed with low-field-strength MR imaging. The MR image

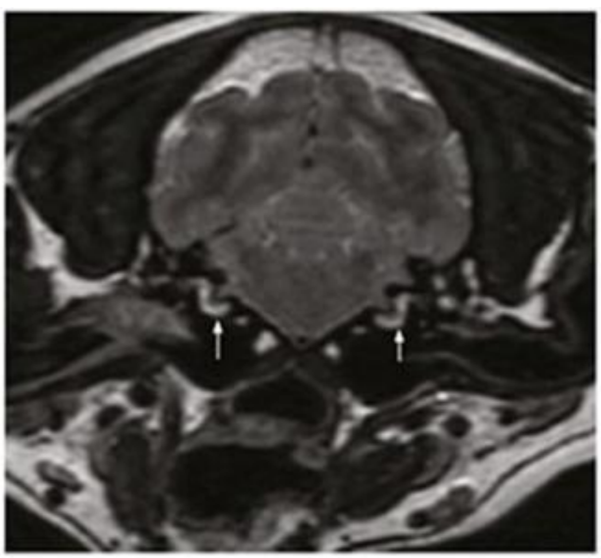

Plate V: Transverse plane MRI image T2-weighted sequence of a normal dog at the level of the tympanic bullae. The cochlea of the inner ears are visible as hyper intense signals (arrows), and have the shape of a duck. Photo courtesy: Anon (2016)

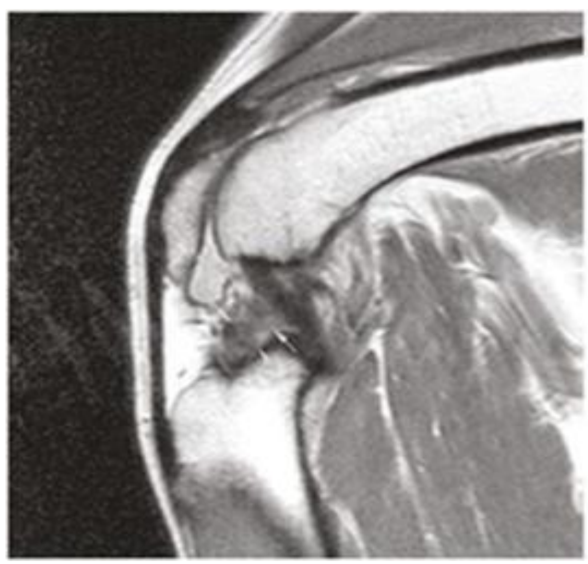

Plate VI: Sagittal plane proton weighted MR image of the stifle of a dog. The normally hypointense cranial cruciate ligament is no longer visible and is replaced by thick, hyperintense and heterogeneous material (arrows) consistent with incomplete cruciate ligament rupture. Photo courtesy: Anon (2016) anatomy and standard patient positioning are still in the process of being described. Finally, while MR imaging is the gold standard for investigation of early sport injuries in horses, athletic injuries are not commonly presented in dogs and cats. To date, the shoulder and the stifle joints are the most common extrimities examined with MR imaging (Kraft *et al*., 2007; Young *et al*., 2011; Labruyère & Schwarz, 2013). Reports on biceps and supraspinatus tendon pathology, neoplasia, cranial cruciate ligament discontinuity and meniscal injuries have been published (Kraft *et al*., 2007; Barrett *et al.,* 2009). MR imaging is also more sensitive for the detection of subtle bone marrow changes. It is greatly utilised in the investigation of neoplasia, in particular for surgical planning. MR imaging is very well suited for the diagnosis of brachial plexus diseases (Labruyère & Schwarz, 2013).

Whole body imaging: Recently, whole body MRI protocols have been described for cancer staging in animals with a sufficient image quality to detect mass lesions, pulmonary infiltration, lymphadenomegaly and lesions of the appendicular skeleton (Kraft *et al.,* 2007)(Plate VI).

Challenges of MR imaging in Veterinary practice in Nigeria

Despite the adequacies of MR imaging, embracing this modality in veterinary practice and curriculum in Nigeria seems difficult. Epileptic power supply in the country remains a major setback that cannot be overlooked if the modality were to be embraced. This is further heightened by the fact that the techniques involved are specific and need specialized training, specialized software, and professional computer capability by today's standards. Again, administering of prolonged anaesthesia for veterinary patients for effective handling during the imaging procedure must be considered. If it were to be done off-site the need for an accompanying veterinary anaesthesiologist becomes important. Therefore, cost implications become a major focus and this outweighs the need in practice especially as most private veterinary practices are small and patient size is limited. The government established clinics, institutions of veterinary learning (Veterinary teaching hospitals) have not adopted this all important diagnostic modality either due to cost on the one hand or a lack of adequately trained and competent personnel to drive the processes on the other. There are no information on the availability of an MRI scanner in any of the government owned veterinary establishments or any of the institutions currently engaged in the residency training programme across the country either for diagnostic, teaching or research purposes. The current residency programme of the Postgraduate College of Veterinary Surgeons of Nigeria highlights MR imaging techniques in its curriculum; however, due to non-availability of the MR imaging machines/scanners in the diagnostic imaging centres of the institutions currently engaging resident veterinarians in training; the result is that residents have to primarily negotiate access, usually out of hours, to scanners in sympathetic human teaching hospitals. The result is usually limited exposure and the outcome is poor knowledge and little or no skill acquisition. Training opportunities overseas are difficult to access not only because the veterinary graduates from Nigeria would have to go through a long and repeated process of board certification before they can get enrolled for the residency programme that would give them the required exposure to clinical applications of this imaging modalities in veterinary practice.

Recently, in the developed economies there has been a rapid increase in the availability of magnetic resonance imaging (MRI) modality. Previously, this modality was only available in universities or large referral institutions. Today, first opinion practices are acquiring low field MR scanners, and mobile imaging units make this advanced imaging modalities readily accessible to the veterinary profession.

While there are great opportunities of MRI market in the developing world, there are also huge challenges before us. They include uncertain outcome of healthcare system reforms, lack of properly trained personnel, and high cost. Shortage or absolute lack of properly trained staff is another severe challenge to the rapid growth of MRI in veterinary clinical applications and research. While veterinary radiologists are few and those who are interested in newer imaging methods are even fewer, some are acquiring the necessary skills informally and this does little to highlight such efforts. The dilemma for Nigeria's veterinarians who are interested in MRI is that many of them have limited knowledge of MR physics and limited experience in MRI clinical applications and research due to the exclusion of these in the training curriculum. Study for advanced degree program of MRI is almost non-existent in Nigeria's universities. Some MRI concepts and practices common in the developed countries are not as familiar to the Nigerian veterinarians and professionals. However the diagnostic imaging community needs to work hard to build up training programs and degree programs for MRI at universities and research institutions, so as to catch up with the rapid development of the imaging science.

While quality is an important factor for advanced medical equipment like MRI scanners, affordability is often-times even more important. The living standards are still low in the developing world including Nigeria. It is difficult for veterinary medical institutions or centres to charge patients for MRI examination at the same level as that in the developed countries if they were available. But at the same time, the market prices of MRI scanner remain the same no matter whether it is used in Nigeria, China, or in USA. As such, it is more difficult for an institutions to recoup its investment on MRI scanners. The need however, outweighs the cost – the need for the development and advancement of knowledge, for adequate and precise diagnosis and for meeting up with the trends in modern medical imaging techniques.

Need for Modern Medical Imaging Systems in Veterinary practice

Several studies were carried out to determine the sufficiency of screen film images and low quality photo–flouroscopic diagnostic modalities in diagnosis of clinical abnormalities. It was observed that as high as 30% lesions were missed by radiologists and that too mainly by inter–observer variations (Garland, 1949; Yerushalmy, 1955). To avoid such problems a need for highly precise and advanced imaging techniques was realised and thus modern diagnostic modalities that possess digitalized system came into existence. However, many other recent studies have reported that clinicians often miss different kinds of lesions even with modern diagnostic modalities like CT/MRI (Li *et al*., 2002; Li *et al*., 2005; Armato *et al*., 2002) and is comparable to the rates reported earlier necessitating further advancement in clinical diagnostic imaging techniques. The problem of mis–diagnosis however, can be managed to a greater extent by utilising different imaging techniques that are complementary to each other. Many state of the art diagnostic imaging techniques have been popular in the medical field for many years but veterinary practice has seen the development and introduction of new methods for diagnostic imaging only recently (Alkan, 1999; Braun, 2003; Kurt & Cihan, 2013).

The Future: PET Scan

Positron emission tomography (PET) is becoming increasingly available as an imaging modality in veterinary medicine (Hansen *et al.,* 2011). PET is a nuclear medicine imaging technique that detects gamma rays indirectly emitted by a positron-emitting tracer, the fluorodeoxyglucose (FDG) (KouKourakis *et al*., 2008). FDG is an analogue of glucose that is metabolised by high-glucose- using cells, such as neoplastic cells. By combining PET information and MR imaging, it becomes possible to correlate metabolic and anatomic information on the same image (Hansen *et al*., 2011). PET/MRI may eventually become the gold standard for cancer staging in our canine and feline patients (Kraft *et al*., 2007).

In conclusion, while the world advances in the modalities of diagnostic imaging from MR imaging to PET-MR imaging veterinarians in Nigeria can only hope that in the near future these challenges would be surmounted and that they too can move progressively along with the trends in advancing diagnostic technology. More than thirty years down the lane veterinarians in Nigeria are yet to have a feel of the current trends in this changing advancing technology.

References

Alkan Z (1999). Veterinary Radiology. First edition, Mina Ajans, Ankara. Pp 121-146.

Armato SG, Giger ML, MacMahon H, Sone S & Doi K (2002). Lung cancer performance of automated lung nodule detection applied to cancer missed in a Ct screening program. *Radiology*, **225**(3): 685-692.

Anonymous. (2016). Animal Health Trust, Diagnostic Services Laboratory, Lanwades Park, Kentford, UK http://www.aht.org.uk/cms-display/diagnostic_services.html, retrieved 17-10-2016.

Barrett E, Arrett E, Barr F, Owen M & Bradley K (2009). A retrospective study of the MRI findings in 18 dogs with stifle injuries. *Journal of Small Animal Practice*, **50**(9): 448-455.

Bloch F, Hansen WW & Packard M (1946). Nuclear Induction. *Physics Review*, **69**(7-8): 127-137.

Braun U (2003). Ultrasonography in gastrointestinal diseases in cattle. *Veterinary Journal*, **166**(2): 112-124.

Cerda-Gonzalez S, Olby NJ, Broadstone R, Broadstone R & McCullough S (2009). Characteristics of cerebrospinal fluid flow in Cavalier King Charles spaniels analyzed using phase velocity cine magnetic resonance imaging. *Veterinary Radiology and Ultrasound*, **50**(5): 467–476.

Couturier J, Rault D & Cauzinille L (2008). Chiari-like malformation and syringomyelia in normal Cavalier King Charles spaniels: a multiple diagnostic imaging approach. *Journal of Small Animal Practice*, **49**(2): 438–443.

De Risio L, Adams V, Dennis R & McConnell FJ (2009). Association of clinical and magnetic resonance imaging findings with outcome in dogs with presumptive acute noncompressive nucleus pulposus extrusion: 42 cases (2000–2007). *Journal of the American Veterinary Medical Association*, **234**(4): 495–504.

Dennis R (1993). Magnetic resonance imaging and its application to veterinary medicine. *Veterinary International*, **5**(2): 3–10.

Fisher M, Prichard JW & Warach S (1995). New magnetic resonance techniques for acute ischemic stroke. *Journal of the American Medical Association*, 2**74**(3): 908-911.

Garland LH (1949). The scientific evaluation of diagnostic procedures. *Radiology*, **52**(3): 309-328.

Garosi LS, Dennis R, Penderis J, Lamb CR, Targett MP, Cappello R & Delauche AJ (2001). Result of magnetic resonance imaging in dogs with vestibular disorders: 85 cases (1996–1999). *Journal of the American Veterinary Medical Association*, **218**(3): 385–391.

Gavin PR & Bagley RS (2009) Practical Small Animal MRI. Wiley-Blackwell. Second edition, Hoboken, New Jersey. Pp 234-247.

Goldstein EJ, Burnett KR, Wolf GL, Wortman J, Joseph P & Sen S (1985). Contrast enhancement of spontaneous animal CNS tumors with gadolinium DTPA: A correlation of MRI with x-ray CT. *Physiological Chemistry and Physics Medical Nuclear Magnetic Resonance*, **17**(1): 113–122.

Grahn BH, Stewart WA, Towner RA & Noseworthy MD (1993). Magnetic resonance imaging of the canine and feline eye, orbit, and optic nerves and its clinical application. *Canadian Veterinary Journal*, **34**(4): 418–424.

Hansen AE, McEvoy F, Engelholm SA, Law I & Kristensen AT (2011). FDG PET/CT imaging in canine cancer patients. *Veterinary Radiology and Ultrasound*, **52**(2): 201-206.

Karkkainen M, Mero M, Nummi P & Punto L (1991). Low field magnetic resonance imaging of the canine central nervous system. *Veterinary Radiology and Ultrasound*, **32**(3): 71–74.

Karkkainen M, Punto LU & Tulamo RM (1993). Magnetic resonance imaging of canine degenerative lumbar spine diseases. *Veterinary Radiology and Ultrasound* **349**(4):399–404.

Koukourakis G, Maravelis G, Koukouraki S, Padelakos P & Kouloulias V (2008). Overview of positron emission tomography chemistry: clinical and technical considerations and combination with computed tomography. *Journal of Balkan Unioin of Oncologists*, **14**(4): 575-580.

Kraft S, Randall E, Wilhelm M & Lana S (2007). Development of a whole body magnetic resonance imaging protocol in normal dogs and canine cancer patients. *Veterinary Radiology and Ultrasound*, **48**(3): 212-220.

Kraft SL, Gavin PR, DeHaan C, Moore M, Wendling LR & Leathers CW (1997). Retrospective review of 50 canine intracranial tumors evaluated by magnetic resonance imaging. *Journal of Veterinary Internal Medicine*, **11**(4): 218–225.

Kraft SL, Gavin PR, Wendling LR & Reddy VK (1989). Canine brain anatomy on magnetic resonance images. *Veterinary Radiology and Ultrasound*, **30**(4): 147–158.

Kurt B & Cihan M (2013). Ultrasonographic valuation of the clinical and ultrasonographic findings in abdominal disorders in cattle. *Veterinarski Arhiv*, **83**(1): 11-21.

Labruyère J & Schwarz T (2013). CT and MRI in veterinary patients: an update on recent advances. *In Practice*, **35**(1): 546-563.

Li F, Arimura H, Suzuki K, Shiraishi J, Li Q, Abe H, Engelmann R, Sone S, MacMahon H & Doi K (2005). Computer–aided detection of peripheral lung cancers missed at CT: ROC analyses without and with localization. *Radiology*, **237**(2): 684–690.

Li F, Sone S, Abe H, MacMahon H, Armato S & Doi K (2002). Missed lung cancers in low–dose helical CT screening obtained from a general population. *Radiology*, **225**(3): 673–683.

Lutsep HL, Albers GW, DeCrespigny A, Kamat GN, Marks MP & Moseley ME (1997). Clinical utility of diffusion-weighted magnetic resonance imaging in the assessment of ischemic stroke. *Annals of Neurology*, **41**(5):574-580.

Mai W, Weisse C & Sleeper MM (2010). Cardiac magnetic resonance imaging in normal dogs and two dogs with heart base tumor. *Veterinary Radiology and Ultrasound*, **51**(4): 428-435.

Marks MP, De Crespigny A, Lentz D, Enzmann DR, Albers GW & Moseley ME (1996). Acute and chronic stroke: navigated spin-echo diffusion-weighted MR imaging. *Radiology*, **199**(2): 403-408.

McConnell JF, Garosi L & Platt SR (2005). Magnetic resonance imaging findings of presumed cerebellar cerebrovascular accident in twelve dogs. *Veterinary Radiology and Ultrasound*, **46**(1): 1–10.

Moore MP, Gavin PR, Kraft SL, DeHaan CE, Leathers CW & Dorn RV (1991). MR, CT and clinical features from four dogs with nasal tumors involving the rostral cerebrum. *Veterinary Radiology and Ultrasound*, **32**(1): 19–25.

Nemanic S, London, CA & Wisner ER (2006). Comparison of thoracic radiographs and single breath-hold helical CT for detection of pulmonary nodules in dogs with metastatic neoplasia. *Journal of Veterinary Internal Medicine*, **20**(5): 508–515.

Park RD, Nelson TR & Hoopes PJ (1987). Magnetic resonance imagining of the normal equine digit and metacarpophalangeal joint. *Veterinary Radiology and Ultrasound*, **28**(4): 105–116.

Pomper MG, Miller TJ, Stone JH, Tidmore WC & Hellmann DB (1999). CNS vasculitis in autoimmune disease: MR Imaging Findings and correlation with angiography. *American Journal of Neuroradiology*, **20**(1): 75-85.

Purcell EM, Torrey HC & Pound RV (1946). Resonance absorption by nuclear moments in a solid. *Physics Review*, **69**(1): 37-38.

Warach S, Chien D, Li W, Ronthal M & Edelman RR (1992). Fast magnetic resonance diffusion-weighted imaging of acute human stroke. *Neurology*, **42**(1): 17-23.

Warach S, Dashe JF & Edelman RR (1996). Clinical outcome in ischemic stroke predicted by early diffusion-weighted and perfusion magnetic resonance imaging: a preliminary analysis. *Journal of Cerebral Blood Flow Metabolism*, **16**(3): 53-59.

Warach S, Gaa J, Siewert B, Wielopolski P & Edelman RR (1995). Acute human stroke studied by whole brain echo planar diffusion-weighted magnetic resonance imaging. *Annals of Neurology*, **37**(5): 231-241.

Yapei C (2015) CT and MRI - Clinical applications in Veterinary Medicine. Clinical Notes. Institute of Veterinary Medical Sciences, School of Veterinary Medicine, National Taiwan University, Taipei, Taiwan. Pp 4.

Yerushalmy J (1955). The Statistical Assessment of Variability of Observer Perception of Roentgenographic Pulmonary Shadows. In: *The Radiologic Clinic of North America* (WJ Tuddenham, editor), Philadelphia WB Saunders. Pp 381-392.

Young BD, Levine JM, Porter BF, Allen AV, Rossemeisl JH, Platt TT, Kent SR, Fosgate GT & Schatberg SJ (2011). Magnetic resonance imaging features of intracranial astrocytomas and oligodendrogliomas in dogs. *Veterinary Radiology and Ultrasound*, **52**(2): 132-141.