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Diagnostic imaging modalities – an overview of basic principles and applications

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ABSTRACT: Over the last decade, the quality of diagnostic imaging equipment in veterinary practice has greatly improved. Advanced imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) have become widely available, leading to greater demands and expectations from veterinary clients. While often expensive, with the influx of pet insurance policies onto the market these imaging procedures have become more accessible to clients. While radiography and, to a lesser extent, ultrasonography remain the most commonly employed diagnostic imaging modalities in veterinary practice, the use of CT, MRI and fluoroscopy has also greatly increased.

Radiography

Since their discovery by Wilhelm Röntgen in 1895 (Sullivan, 2012), medical X-rays have revolutionised the field of diagnostic imaging in human medicine. Soon after, conventional film-based radiography was introduced to the veterinary world, becoming a commonly used imaging modality across our industry today.

Radiography is indicated where a view of internal structures of the body is required without making an incision in the patient. The list of clinical indications is too long for inclusion here, but some situations where radiography may be helpful are:

- appendicular skeleton – suspected fracture(s), dislocation, bone lesions; or arthritis
- axial skeleton – suspected skull fractures and dislocations, spinal fractures, spondylosis
- thorax – primary pulmonary parenchymal disease, cardiomegaly, pneumothorax, metastatic disease, diaphragmatic rupture or hernia, megoesophagus
- abdomen – gastric dilation (± volvulus), ingested foreign bodies, urolithiasis, urethral obstruction, constipation, bladder rupture, abdominal wall rupture
- teeth – tooth fractures, tooth root abscess
- contrast studies – barium swallow study, pneumocystogram, positive-contrast cystography, double-contrast cystography, intravenous urography

Disadvantages

The disadvantages of radiography include superimposition of tissue structures, exposure of patients (and potentially personnel) to ionising radiation and lower contrast resolution (in comparison to CT). Pleural effusion or abdominal ascites could reduce serosal detail, making image interpretation difficult: fluid attenuates the X-ray beam to the same degree as soft tissue and this can obscure abdominal organs from view. Movement artefact from patient non-compliance is a common problem, and chemical restraint should be considered in these cases.

Advantages

One important advantage of conventional film-based radiography is better spatial resolution (the ability to distinguish between two structures lying next to each other) than both CT and MRI.

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Figure 1. Ultrasound machine set up in a dedicated ultrasound examination room

Non-film radiography

Over the decades, radiographic film-processing techniques have changed drastically. In the earlier days of film-based radiography, an image captured on a piece of film was developed by wet chemical processing using methods similar to those in photographic development. From here we progressed to automatic processing machines, reducing processing times and resulting in a rapid demise of manual developing and fixing techniques.

The automatic processor remained the mainstay of image processing until the first digital system, known as computed radiography (CR), created by Fuji, came into use in the early 1980s (Mattoon, 2007). Since this time, filmless digital radiography has grown in popularity and is now in widespread use across the country.

Among the many advantages of non-film radiography is the ability to manipulate the final image digitally, after taking the X-ray. Under- and over-exposed radiographs no longer need repeating unless the exposure error is severe. Instead they are tweaked using the software provided, enabling the operator to alter factors such as latitude (number of shades of grey visible) and contrast. This reduces the risk of exposure to personnel, sedation/anaesthesia times for patients and cost to the client.

Computed radiography

CR processing systems operate a two-stage process to develop the image. First, electrons within a photostimulable phosphor plate housed within the cassette are transferred by excitation to a higher state of energy. When exposed to X-rays, these become trapped and produce a latent image on the plate (Drost, 2011).

Next, the cassette is fed into the processor, where the inner plate is extracted and scanned by a helium neon laser. As the laser works its way over the plate, the previously excited electrons return to a lower state of energy, producing light. This light is detected, amplified and converted to an image in approximately one minute (Hoines, 2013). Once formed, the radiographic image is sent to the computer screen for manipulation, interpretation and storage. The plate is then erased by a bright white light, re-housed inside the cassette and ejected ready for re-use.

Digital radiography

Digital radiography (DR) systems work differently from CR systems. Rather than using a traditional X-ray cassette, a fixed panel underneath the X-ray table is exposed instead. DR units are then further divided into *indirect-conversion* and *direct-conversion* systems (AGFA). In indirect-conversion, the panel (comprised of scintillated material) converts X-ray energy to light. It is subsequently transformed to a digital signal and then converted to a radiographic image (Hoines, 2013). Direct-conversion systems have a photoconductor layer capable of converting X-rays directly into a digital signal rather than into light first. In both systems, the resultant radiographic image appears on a computer screen within seconds (Page, 2014).

Initial purchasing costs of digital radiography systems are relatively high; however, this may be outweighed by the ongoing costs of buying film, wet-processing chemical purchase/disposal, increased patient anaesthesia/sedation time, frequent radiographic re-takes and volume of storage required when keeping film radiographs.

Health and safety

Strict health and safety protocols must be adhered to when working with ionising radiation. An external Radiation Protection Advisor (RPA) must be appointed to devise local rules, systems of work and written arrangements for working with X-rays in practice safely. Documents and protocols will be tailor-made for each practice and overseen on a daily basis by the Radiation Protection Supervisor(s) who work on the premises. The Ionising Radiations Regulations (IRR99); Guidance Notes for the Safe Use of Ionising Radiations in Veterinary Practice (2002) is the official document published by the British Veterinary Association outlining the legal requirements when working with X-rays in veterinary practice. Personal protective equipment, such as aprons, thyroid guards and gloves of a suitable thickness of lead-equivalent material (as directed in the local rules) must be available for use where necessary.

Ultrasound

Frequently found in first opinion veterinary practices, ultrasound is an imaging modality using high-frequency sound waves to create a real-time moving image. Machines for all budgets are available, from smaller portable units, suitable for domiciliary work, to larger types, often found in referral institutions (**Figure 1**). Note that no ionising radiation is used with ultrasound, therefore no special health and safety rules are associated with its use.

The hand-held probe placed upon the patient is called a transducer, and it is here that ultrasound waves are formed. Transducers come in a variety of shapes, sizes and frequency, each being suitable for scanning a particular area(s) or depth of tissue (Kircher, 2011).

Inside transducers are ceramic crystals producing pulsatile high-frequency sound waves when voltage is applied. Sound waves pass through the patient's tissues, are reflected back and effectively compress the crystals. As this occurs (many times per second) an electrical impulse is created by a process called piezoelectricity. Finally, impulses are amplified and a continuous image is formed and displayed on the monitor (Easton, 2002).

The on-screen image can be frozen to take measurements, save or print, then unfrozen to continue the examination. Video loops of real-time images can also be saved and, depending upon the individual network systems installed, images produced can also be saved to the patient's record for future reference.

Ultrasound is indicated in cases with acute abdominal signs, due to its ability

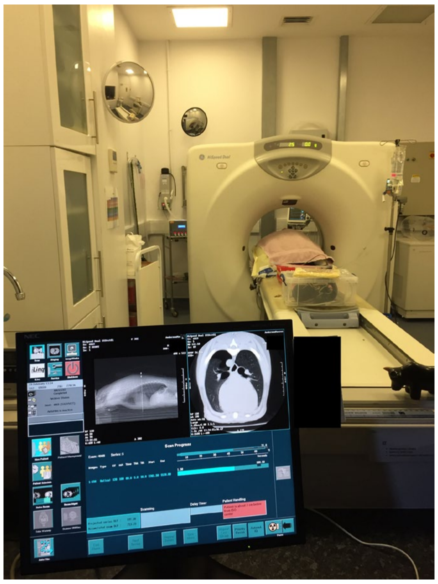

Figure 2. Computed tomography suite

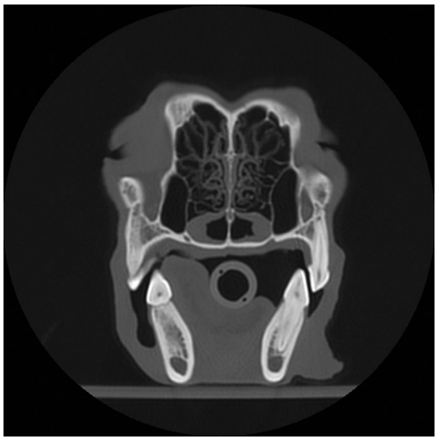

Figure 3. Computed tomography scan of a canine head, showing the clearly visible scrolled ethmoturbinate bones within the nasal cavity

to show internal architecture of abdominal viscera clearly. Intussusceptions, bowel perforation, urolithiasis, splenic torsion, abdominal masses, pyometra and septic abdomen are all examples of disease processes that would benefit from thorough ultrasound examinations. Using ultrasound-guided techniques, masses can be sampled and body cavity effusions drained, allowing for culture and cytology to aid in diagnosis.

Patients requiring ultrasound of an area that has recently been surgically treated may yield poor image quality due to the presence of gas artefacts. The same can also be said for patients with penetrating foreign bodies.

Because ultrasound images are viewed as real-time moving images rather than static snapshots, it makes ultrasound an excellent medium for observing bodily functions such as gut peristalsis. This allows direct assessment of the frequency and strength of peristaltic waves, which could not be achieved with the use of radiographs, CT or MRI.

Doppler methods are a feature on many ultrasound machines, allowing the operator to assess blood flow; for example, formation of thrombi, direction and velocity of blood flow and tissue perfusion. This can be of particular use during echocardiography.

Computed tomography (CT)

According to Ohlerth and Scharf (2007), since being introduced to veterinary medicine in the 1970s, CT (**Figure 2**) has become one of the most important imaging modalities used in the diagnosis of neurological, oncological and orthopaedic conditions in small animals (canines and felines). It is also very helpful in cases of acute trauma involving complex areas of anatomy such as the skull, spine and pelvis. Patients undergoing examination with this method will usually require general anaesthesia or deep sedation in order to ensure complete immobilisation.

Like conventional radiography, CT uses ionising radiation to form an image of a patient. However, where the former produces a two-dimensional (2D) image of the portion of the patient's body included in the collimation, CT gives us several transverse images as cross-sectional slices through the animal (Easton, 2002). Note that the same basic health and safety rules as used with conventional radiography will apply here (British Veterinary Association, 2002), with some details amended as appropriate for working with a CT machine.

Unlike conventional X-ray machines, instead of a single tube head mounted above the patient, the high-powered tube located inside a CT machine rotates around the patient's anatomy, slice by slice. As the X-ray beam is attenuated by the patient (weakened, depending upon the density of the tissue through which it travels), a panel of detectors on the opposing side receive the remaining radiation, producing an electrical signal. Labruyère and Schwarz (2013) describe how the signal generated is directly proportional to the density of the tissue it has penetrated.

From here, the computer creates a matrix picture corresponding directly to those projectional-beam density values. These values (CT numbers) are represented in units known as Hounsfield units (HU) after the founder of CT technology, Godfrey Hounsfield (Goldman, 2007). They are shown on the CT computer screen as varying shades of grey (Labruyère & Schwarz, 2013), and thus an image is produced.

Although CT images are initially displayed as transverse pictures, the data can be reconstructed into various three-dimensional (3D) planes, depending on the software available. This can be helpful when planning complex surgical approaches, as images can be stored on a server and retrieved on a viewing screen within the operating theatre, or simply printed out and taken in with the surgeon.

CT may be indicated in patients where previous conventional imaging methods such as ultrasound and radiography have failed to provide enough information or a conclusive diagnosis. This advanced imaging modality is particularly useful in the diagnosis and staging of most tumours (Easton, 2002), and is considered to be particularly sensitive for identifying skeletal changes (**Figure 3**) (Dennis, 2003). This makes CT invaluable for assessing many orthopaedic conditions where conventional radiography does not provide enough information. Due to the improved contrast resolution, soft tissue is also visualised relatively well when compared to a radiograph.

Contrast media are often used during CT studies to highlight suspicious lesions and assist with disease diagnosis, by increasing vascular and soft tissue contrast (Labruyère & Schwarz, 2013).

Fluoroscopy

Fluoroscopy is a lesser-known diagnostic imaging tool, using ionising radiation to obtain a real-time moving image of a patient. Real-time is generally considered to be 30 frames per second which, according to Boone, Bushberg, Leidholdt, and Seibert (2012), is sufficient to give the appearance of continuous motion.

Digital fluoroscopic systems also record a sequence of images, which can be viewed as a movie loop and saved to a picture archiving and communications system for later retrieval (Boone et al., 2012).

Easton (2002) describes the multiple stages of image formation with fluoroscopy: a basic

Figure 4. C-Arm fluoroscopy unit set up in theatre, showing the X-ray tube and image intensifier positioned above and below the operating table

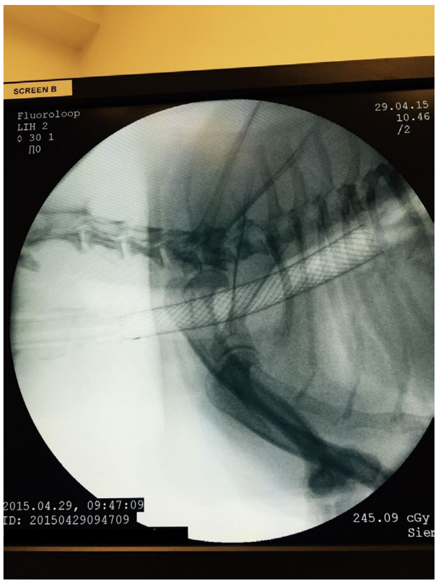

Figure 5. Fluoroscopic image showing successful insertion of a tracheal stent

X-ray tube is attached to an image intensifier (**Figure 4**), which allows the X-ray photons that pass through the patient to be turned into light when they emerge from the other side. The intensity of this light is then multiplied and transformed into photoelectrons, via the use of a photocathode. In the final stage, the photoelectrons strike the output phosphor and anode components of the machine, after which an image appears on a television screen.

Applications for using fluoroscopy are relatively few when compared to the other imaging modalities you might find in general practice. Common interventional and non-interventional procedures that benefit from its use include:

- barium-swallow studies looking at the mechanics of swallowing
- dynamic airway examinations and tracheal stent placement in patients with a collapsing trachea (**Figure 5**)
- portovenograms during portosystemic shunt attenuation surgery
- closure of patent ductus arteriosis with intravascular occlusion devices
- pacemaker implantations for cardiac rhythm abnormalities
- balloon valvuloplasty in the treatment of pulmonic or aortic stenosis
- orthopaedic procedures requiring image intensification and pin-point accuracy for placement of screws

Fluoroscopes are generally confined to referral hospitals and academic institutions due to cost and the specialised level of diagnostic imaging knowledge needed in order to interpret the images generated accurately.

Practices using fluoroscopy must adhere to the local rules as set out by their RPA and work within the guidance given in the IRR99 documents.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) is an increasingly popular diagnostic tool, now widely available across the veterinary industry (**Figure 6**). These machines often come housed within large trailers, driven up and down the country visiting veterinary practices for days at a time. There are also now a number of in-house MRI machines available for lease-hire or sale, and these are appearing in specialist referral hospitals and larger veterinary institutions. This means that patients can often be referred for same day or next day scans rather than having to wait a week or so for a mobile unit to be in the area before treatment is initiated.

Like ultrasound, MRI uses no ionising radiation so its use is not governed by the IRR99 regulations. Practices do, however, have to comply with stringent health and safety rules when working with MRI units, due to the high risk of injury they pose to personnel, patients and clients if used inappropriately. The Medicines and Healthcare Products Regulatory Agency publishes a document entitled *Guidelines for magnetic resonance equipment in clinical use* (2015) which provides detailed instructions on how to procure, install, operate and maintain MR machines safely. These guidelines are updated regularly (last updated March 2015) and should be adhered to at all times.

Personnel should take particular care when entering MRI scanning rooms, as the machines are effectively very large magnets. Ferromagnetic objects such as oxygen cylinders, scissors, stethoscopes, hair grips, coins, keys and mobile tables will be drawn towards the magnet when they get too close, and this could result in serious injury or even death of personnel if hit or trapped by these objects. It is vital that all workers and visitors are aware of this risk and take steps to avoid them. MRI scanners can be differentiated by their magnetic strength into low-field and high-field scanners, the latter posing a higher potential health and safety risk due to the higher field strength.

The functionality of medical devices such as pacemakers may be disrupted by the strong electromagnetic fields of an MRI scanner. For this reason, staff must read and sign a health and safety questionnaire prior to working with MRI, to ensure they are deemed safe to do so. Further contraindications to working in MRI are ferromagnetic implants (for example, orthopaedic plates) and foreign bodies, which have the potential to heat up and/or migrate through tissues (Deyle, 2011).

Due to its superior soft-tissue contrast, MRI remains the primary method of imaging for diagnosing soft-tissue damage such as meniscal, ligament and tendon tears (as well as occult bone injuries), according to Crues and Bydder (2007) (as cited in Deyle, 2011). Labruyère and Schwarz (2013) suggest that MRI is superior for diagnosing pathology of the central nervous system (**Figure 7**), while CT remains the gold-standard imaging modality for scans of the thorax. CT also gives superior osseous detail compared with MRI, which makes it a better imaging tool to use for orthopaedic conditions. The positive contrast medium gadolinium (Gd) is often used to identify the location and character of CNS lesions (Chavhan, 2013).

Image acquisition from an MR scanner is very complex. As described by Chavhan (2013), the steps can be simplified as follows:

- the patient is placed within the magnet
- a radiofrequency (RF) pulse is sent out to the patient by a coil

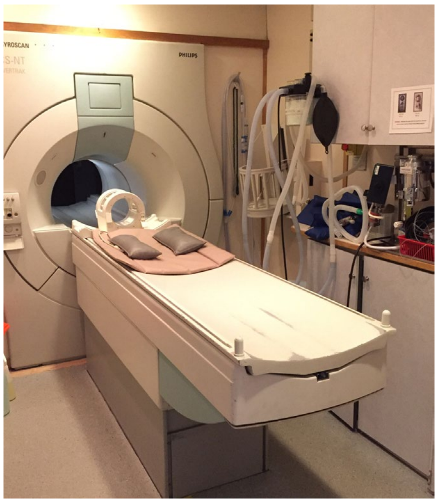

Figure 6. Magnetic resonance imaging unit; this particular machine is housed within a large truck permanently situated on-site

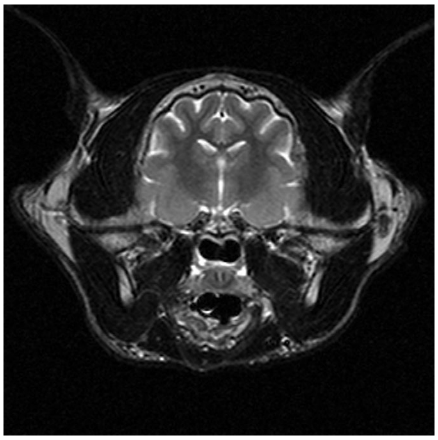

Figure 7. Magnetic resonance image of a feline brain

- the signal from the patient is received by a coil
- the signals received are transformed within the computer, producing an image

To expand on this: hydrogen atoms that occur naturally within the body are realigned as the RF pulse is applied. As the atoms revert to their usual alignment they emit signals of energy that vary according to the type of tissue whence they originate. From here, the diagnostic image is formed (RadiologyInfo.org, 2014).

MRI scans can be run in a variety of different sequences which has the effect of either suppressing or enhancing different types of tissue within the body in order to best enhance the area of interest. The detailed discussion of these sequences is beyond the scope of this article.

Conclusion

There are several options available to the veterinary clinician to perform diagnostic imaging studies. The choice will depend on a number of factors, including cost, availability, expertise of staff to carry out the examination and interpret the images afterwards and the disease process under investigation. Often there is no right or wrong imaging modality for a case, and using more than one method to build a complete picture of the condition may be of great benefit.

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