

Using Computed Tomography to aid in the diagnosis of neurological diseases in the horse

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Advanced imaging modalities, particularly computed tomography (CT), are becoming increasingly integrated in equine hospitals. CT offers advantages over conventional radiography, primarily by overcoming the limitations of anatomical superimposition, most notably in complex regions such as the head and neck. Neurological disease in horses often present a diagnostic conundrum as to the location and aetiology of the signs exhibited in the horse. CT enables high-resolution, cross-sectional evaluation of structures, thereby enhancing the clinician's ability to detect and localise lesions within the central nervous system. This, in turn, facilitates more accurate diagnosis, targeted management and informed prognostication in equine neurological cases.

Computed tomography is an advanced imaging modality that utilises X-ray technology, wherein an X-ray tube rotates within a gantry and is positioned opposite multiple detectors to acquire cross-sectional images. The X-ray tube emits a narrow collimated beam of ionizing radiation in which the attenuated radiation is detected. The level of attenuation varies based on tissue density and atomic composition. The detectors convert X-ray photons into analog electrical signals. Analog-to-Digital convertors (ADCs) then digitize these signals to raw data corresponding to intensity profiles across the scan plane. The image is then reconstructed using a reconstruction engine to mathematically reconstruct the raw data into a cross-sectional image representing relative tissue densities (measured in Hounsfield Units) that appear as different shades of grey, similar to conventional radiographs. Table 1 outlines different tissue densities and their respective HU. These reconstructed images are visualised in transverse (axial) slices and can be reformatted into dorsal, sagittal or 3D renderings using multiplanar reconstruction (MPR) or volume rendering techniques.

Table 1: Different tissues and their respective approximate Hounsfield Unit (HU) based on attenuation of X-ray photons.

Tissue	Hounsfield Unit (HU)
Air/gas	-1000
Water	0
Fat	-100
Bone	100 – 1000
Metal (ie/ surgical implants)	1500 – >3000
Blood	60 – 100
Muscle	50 – 80

To visualise specific tissue types (bone vs soft tissue) windowing is utilised through the differentiation of the wide dynamic range of HU. The bone window (~300-500 HU level and ~1500-2500 HU width) is used to optimise high-attenuation structures such as cortical and trabecular bone, mineralized lesions and orthopaedic implants. This allows enhanced contrast between dense osseous structures and surrounding tissues. The soft tissue window (~30 – 60 HU level and ~300 – 400 HU width) is designed to visualise lower-density structures such as organs, vasculature and musculature. This allows improved grey-scale differentiation. In this window, it is common that bone appears hyperdense and over-exposed.

Broadly, there are two types of ways radiation is emitted from the X-ray tube, fan or cone-beam. Traditionally fan beam is utilised and involves the X-ray photons as a narrow fan spanning a single cross-sectional slice with the imaging object perpendicular to the long axis. The multiple detectors are configured linearly in several rows. For acquisition the gantry rotates around the object to acquire data slice-by-slice. Often this is combined with helical scanning wherein the table/couch moves, creating a spiral of data. The advantages of fan beam are in that the image quality is high with excellent contrast resolution, along with rapid acquisition times. Further, there is reduced scatter compared to cone beam. Cone-beam involves a cone-shaped emission of X-ray photons that covers a larger 3D field of view in a single rotation, without any table/couch helical movement. It is commonly utilised in human dentistry and maxillofacial imaging.

Advantages include high spatial resolution of bony structures, more compact system, shorter scan time and lower radiation dose per scan. Disadvantages however include motion artifacts and poor soft tissue contrast. Typically fan-beam, helical CT is currently more commonplace in equine practice.¹

Historically only small bore CTs were available for use in veterinary medicine as they were derived from human-medicine. This limited their use in horses, in which only smaller body parts were able to be imaged under general anaesthesia (GA). More recently larger bore CT (with gantry size up to 90cm) has been developed. This has permitted imaging larger body parts and image acquisition can also be done standing. Depending on the type of CT, body part to be imaged, and patient conditions, either standing or general anaesthesia is elected. Image acquisition under GA does involve higher costs and potential more risk owing to GA itself, particularly a consideration in severely ataxic horses. However, not all procedures can be done standing, including myelograms and imaging of the caudal vertebrae/pelvis and not all patients are amenable to standing for image acquisition.

The use of iodinated contrast media is often used in imaging studies to enhance X-ray attenuation and improve contrast resolution of images. This is particularly useful in evaluation of soft tissue structures. Intravenous use allows spatial and temporal enhancement. Local administration (ie/ subarachnoid space with myelogram) allows enhanced contrast between soft tissues of similar attenuation. Typically, a nonionic agent, such as Iohexal (Omnipaque™) is utilised at a dose of 600-880 mg/kg IV. If used intra-arterially a lower dose can be administered (approximately 50% of the dose).²

Artifacts in CT images can degrade image quality or mimic pathology. They include beam hardening, motion and streaking artifacts. Beam hardening artifact occurs as X-ray photons pass through very dense tissues and lower-energy photons are preferentially absorbed, resulting in a 'harder' beam. This appears as a central portion of a uniform object appearing less attenuated or between dense structures, the appearance of streaks or dark bands. The latter is typically visualised at the hindbrain between petrous temporal bones. Motion artifact is more common in standing image acquisition studies or through normal respiration (ie/ thorax). The image will appear blurred or ghosted. Streak artifact occurs with highly attenuating objects such as metal implants in which bright streaks or dark bands will radiate from the metal object due to photon

starvation, beam hardening or scatter. Algorithms within the computer system can often help reduce artifacts including motion and beam hardening.

Advanced imaging, such as CT, is very useful in many conditions in horses, particularly neurological disease. What is paramount however, prior to embarking on imaging is neurolocalisation. This will guide where the imaging study will be focussed and whether it can be done as a standing or GA procedure. Neurolocalisation is achieved through a detailed neurological examination to ascertain lesion location to brain, cranial nerves, C1-C6, C7-T2, T3-L3, L4-caudally and neuromuscular junction. Sogaro-Robinson et al. in 2009, investigated factors predicting an abnormal head CT result in neurological horses in which abnormal mentation (OR 29.7) and cranial nerve (CN) deficits (11.3) had increased odds of abnormal imaging identification.³ Seizure-like activity was not predictive (OR 0.05). The latter is likely because CT is less useful for identification of structural brain abnormalities, in which MRI is best for identification of subtle changes within the white and grey matter. Further, the causes of seizures may not always be macroscopic in appearance.

If cranial nerve abnormalities, particularly vestibular disease or facial nerve dysfunction are identified, CT of the head is often recommended. Temporohyoid osteopathy (THO) is a common condition in which can cause CN VII and peripheral vestibular system dysfunction.

Abnormalities identified on CT include osseous proliferation of the stylohyoid bone and temporohyoid articulation, thickening of the ceratohyoid bone, fracture of the petrous temporal bone and stylohyoid bone, fluid accumulation within the remodelling of the tympanic bulla and narrowing and mucosal thickening of the external ear canal.² Though neurological disease is often unilateral, bilateral changes are often common. CT can identify the location and degree of abnormalities and guide treatments options, particularly whether surgical intervention is embarked upon.

Headshaking in horses often poses the equine practitioner with a marked diagnostic conundrum. This is owing to the quite exhaustive list causing the syndrome in horses. Once less invasive diagnostics have been completed and no answer obtained, CT is often the next diagnostic step. Perrier et al. investigated CT findings in 103 head-shaking horses identifying primary disease abnormalities in 22 cases ranging from otitis externa, dental disease, primary sinusitis, temporomandibular joint arthritis, nuchal bursitis, infraorbital mass and fracture of the

basisphenoid bone. Idiopathic trigeminal-mediated headshaking was diagnosed by exclusion in 62 horses.⁴ A recent study investigated morphological variations in the infraorbital canal finding that if there was no adjacent disease identified on CT that there was no association with headshaking.⁵ Changes of the infraorbital canal included increase mineralisation, decreased mineralisation, deformed shape, displaced position and disruption of the canal. If adjacent disease was identified on CT (including sinus abnormalities, masses, dental disease or trauma), along with increased mineralisation of the infraorbital canal, there was a significant association with headshaking. This study highlighted that though infraorbital canal changes can be observed, they may not necessarily be causing headshaking signs.

Advanced imaging is paramount in the diagnosis of the cause of intracranial disease in the horse. Though typically MRI is superior, CT can still be useful and is often selected based on availability. Intravenous contrast use is often recommended to help delineate subtle soft tissue changes. Abnormalities that can be observed on CT include cholesterol granulomas, hydrocephalus, cerebellar abiotrophy, haemorrhage and masses (including neoplasia and abscess). Cholesterol granulomas are often found incidentally and are more common in the older horse (15-20%).² They are located in the lateral and 4th ventricles and imaging features include variable density but often hyperdense regions, occasionally with dystrophic mineralisation. If they cause direct compression of the brain tissue or obstruct flow of cerebrospinal fluid leading to hydrocephalus, neurological symptoms may result. Lloyd-Edwards et al. investigated findings associated with cholesterol granulomas in horses, in which there was no increase in neurological disease in horses diagnosed with or without their presence.⁶ Often bilateral lesions were identified and there was an increase in lateral ventricle height with their presence.

Cerebellar abiotrophy is a genetic condition seen in Arabians causing progressive degeneration of Purkinje cells.⁷ It is also seen in Gotland ponies and Oldenberg horse breeds. CT-features include a smaller than normal cerebellum, which with clinical signs of cerebellar disease, is diagnostic. Haemorrhage can be associated with intracranial trauma. Features observed on CT include hyper-dense areas. Contrast may be useful in identifying active bleeding. Abscesses within brain tissue often causes a mass effect on CT images. A hypodense centre with hyperdense may be observed, in which this is enhanced with contrast. If there is oedema associated with the abscess this may appear as a hypodense surrounding area.

Cervical vertebral compressive myelopathy (CVCM) is a common disease causing spinal ataxia neurolocalised to C1-C6 in the horse.⁷ It involves malformation and malarticulation of the cervical vertebrae and degeneration of the articular process joints and is broadly defined as Type 1 and 2. Type 1 is considered a developmental condition occurring in young, rapidly growing Thoroughbred and Warmblood breeds and is often dynamic. Type 2 is considered a degenerative condition associated with osteoarthritis of the articular process joints, usually occurring in older horses, affecting all breeds. Typically, lesions are more caudal and static in nature and may cause peripheral nerve compression. There is a continuum and broadly not every case can be defined as Type 1 or 2. CT is superior to radiographs in identification of vertebral and soft tissue changes seen with CVCM. Features observed on plain CT include stenosis of the vertebral canal, malformation (including osteochondrosis), osteoarthritis and enlargement of the articular process joints, malalignment (kyphosis), caudal epiphyseal enlargement and soft tissue changes associated with the articular process joints (ligamentum flavum hypertrophy and joint capsule swelling).² During CT interpretation it is crucial that if changes are observed that their contribution to spinal cord impingement is considered, ie/ are the lesions axial or abaxially located and could they be compressing the spinal cord. CT-myelogram is usually indicated to specifically identify any spinal cord compression and is recommended in most cases of suspect CVCM. If a myelogram is elected, the image acquisition is often performed under GA in most cases. Limitations of CT and CT-myelograms for CVCM evaluation include the limited ability to assess dynamic nature due to the size of the horse when flexed and extended and thus often radiographs still need to be performed after the CT has been performed. Further, to date, there is no validated 'cut-offs' for identification of spinal cord compression and largely they are extrapolated from radiograph-myelograms. With increasing use there are many publications describing the use of CT and CT-myelograms for investigating abnormalities of the cervical vertebrae.⁸⁻¹¹ Thus validated cut-offs will likely be published in the near future.

Occipito-atlantoaxial malformation (OAAM) is another vertebral abnormality causing spinal ataxia. It is considered a more severe abnormality with most cases showing signs at a very young age (foals). Often radiographs are sufficient in identification of abnormalities, but CT can provide improved detail to the exact abnormality. Abnormalities include fusion of two or more vertebrae (involving occipital bone and atlas and or axis) and hypoplasia of the atlas or dens of the axis.⁷

Trauma causing fractures of the skull and vertebrae are not uncommon incidents in horses and can lead to neurological disease of varying degree. Radiographs of these locations is particularly limited owing to the degree of superimposition. Thus, CT is often indicated to truly ascertain location and severity and can help with tailored treatment (including surgical planning).

Fractures are quite clear on CT and haemorrhage can be seen as hyperdense regions. If free gas is visualised this may be caused by open fractures or fractures involving the sinus or nasopharynx.

Within the cerebral tissue brain contusions can appear as hypodense with oedema, hyperdense with haemorrhage and a large haematoma may cause a mass effect.² Poll injury is seen more commonly in young horses owing to incidents causing them to flip over backwards. This can lead to fractures of the basilar bones as the sutures lines have not yet closed between the basisphenoid, basioccipital and temporal bones.⁷ Damage will usually occur within the cerebrum, optic nerves and other cranial nerves as they exit this area (particularly CN VII as it exits the hypoglossal foramen). Uncommonly, cerebellar disease is seen. Petrous temporal bone fracture is another traumatic condition. This can lead to peripheral vestibular and CN VII abnormalities. CT is particularly useful to diagnose this as radiographs can be difficult to interpret in this region.

Infection and osteomyelitis of the vertebrae is uncommon but occasionally seen in the foal. CT is very useful to evaluate for infection and degree of soft tissue and bony changes observed. The author has observed *Rhodococcus equi* causing osteomyelitis, soft tissue abscessation and varying degrees of infection leading to meningiomyelitis and traumatic vertebral fractures in older foals.

Primary neural neoplasms are rare in the horse, excluding pituitary adenomas.² Metastatic neoplasms include haemangiosarcoma and lymphoma and these may involve the spinal cord and less commonly the brain. They may also lead to lytic bone lesions of the vertebrae.

Ethmoid haematomas are common neoplasms originating from the highly vascular ethmoid turbinates. If they involve the sphenopalantine sinus or breach the cribriform plate they can cause neurological disease in the horse, including blindness. Thus, CT is usually recommended in all cases of ethmoid haematomas to assess degree of erosion and extension, and guide surgical planning and prognostication.

Overall, CT as an advanced imaging modality is extremely useful and importantly becoming more commonplace in equine internal medicine. This is owing to its usefulness in evaluation and

diagnosis of causes of neurological disease and increasing availability of large-animal specific units. It is fast becoming one of the essential tools in the equine practitioner's toolkit in evaluating the neurological horse.

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