Imaging the equine neck

The equine cervical spine is commonly implicated as the cause of ataxia, proprioceptive reflex deficits and potentially lameness. The cervical spine can be affected by a variety of conditions, including cervical vertebral malformation, articular process joint degenerative joint disease, congenital malformations, fractures and less frequently neoplasia. Surface palpation can only provide minimal diagnostic information, and imaging is therefore typically required. Radiography provides the mainstay of front-line imaging, with the use of laterolateral and oblique projections now commonplace. Advanced imaging options, furthered by the availability of large-bore computed tomography (CT) units, are revolutionising the ability to assess the neck; however, further work is required to fully validate CT myelography as a stand-alone technique to diagnose spinal cord compression. This may have potential to become a gold standard imaging test of the future.
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Jonathon Dixon BVetMed MVetMed DipECVDI MRCVS, RCVS & European Specialist in Veterinary Diagnostic Imaging, Rainbow Equine Hospital, Rainbow Lane, Old Malton, North Yorkshire YO17 6SG

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The equine cervical spine is an anatomically complex bony canal, which acts to protect and support the spinal cord and the emanating spinal nerves. Horses have seven cervical vertebrae, and eight pairs of cervical spinal nerves. The bony structures are largely identifiable by specific shapes and individual features when assessed using the variety of available diagnostic imaging modalities.

The first cervical vertebra (C1; atlas) is a flattened oval-shaped bone with large lateral wings that are palpable from the skin surface. The second cervical vertebra (C2; axis) is characterised by the odontoid process (dens), on the cranial margin, this is associated with a separate centre of ossification that closes around 7 months of age; this should not be confused with a fracture. The C2 vertebra has an extensive dorsal crest that is not found on other vertebrae. The third, fourth and fifth cervical vertebrae in many horses are similar to one another in structure and size, with prominent thin transverse processes extending to the left and right of the vertebral body, orientated ventrally. In young animals, open physes may be visible; the cranial growth plate of the vertebral body closes around 2 years of age, while the caudal physis closes much later, at 5 years of age. The sixth vertebra is typically shorter, and is associated with larger transverse processes than C3–C5, with an additional ventral component; considerable variation may be seen, however (Veera et al, 2016). The seventh vertebra is short, and often does not have a radiographically-visible transverse process, though there may be transposition of a transverse process of C6 onto C7, which can confuse interpretation. In some horses, a variably-sized spinous process of C7 can be present, mimicking that of T1.

Intervertebral discs are present between the bodies of the vertebrae caudal to C2. More dorsally, the bones articulate via cranial and caudal articular processes, forming the articular process joints ('facet joints'), which are synovial articulations. Spinal nerves exit between each pair of vertebrae through the intervertebral foraminae on the left and right of the spine. The entire cervical spine is supported by soft tissue structures, including the nuchal ligament and semispinalis capitis tendons dorsal to the vertebral column and attaching to the caudal margins of the occipital protuberance of the skull.

Common diseases of the cervical spine

Cervical vertebral malformation/cervical vertebral stenotic myelopathy

This condition is characterised by narrowing of the vertebral canal, resulting in extradural compression of the spinal cord (Nout and Reed, 2003). This typically results in ataxia or neurological abnormalities, i.e. proprioceptive reflex deficits (Janes et al, 2015). There are several of causes of spinal cord compression; these can be broadly classified as either static compression (including stenosis independent of movement, such as being caused by the vertebral canal being too narrow), or dynamic compression (narrowing of the vertebral canal at the junction between one vertebral body and the next upon movement of the vertebrae relative to one another). This dynamic condition is most frequently seen in young male Thoroughbred and Warmblood-type horses in the mid cervical spine (commonly C3–C5), though it can affect any site (Levine et al, 2010). Degenerative changes affecting the intervertebral discs have been identified in small numbers of horses, either seen as a chronic degenerative process, or as a result of discospondylitis. These can result in collapse of the intervertebral disc space between two respective vertebrae; intervertebral disc space collapse is clearly evident radiographically.

Articular process joint degenerative joint disease (DJD)

These joints are synovial articulations and therefore can develop degenerative joint disease (osteoarthritis). While articular process joint DJD is an important consideration in the development of cervical vertebral malformation/cervical vertebral stenotic myelopathy, this finding is more common in older horses, and may be of variable significance in the absence of either neurological deficits, signs of cervical pain or reduced ranges of movement. However, DJD can be identified in young horses secondary to developmental orthopaedic disease, for example osteochondrosis, as has been reported in a single recent case report (Tucker et al, 2018). Fragments within the joints can be identified using a variety of imaging modalities, including radiography, computed tomography (CT) and ultrasonography; however, superimposition can make assessment challenging and close attention to detail is required. Marked enlargement of the articular processes associated with DJD can result in dorsolateral compression of the spinal cord or the spinal nerves exiting the intervertebral foraminae, and subsequent neurological signs may be identified (van Biervliet et al, 2006). Additionally, enlarged articular processes have been described to cause compression of the spinal nerves, which can result in a radiculopathy/peripheral neuropathy (Moore et al, 1992).

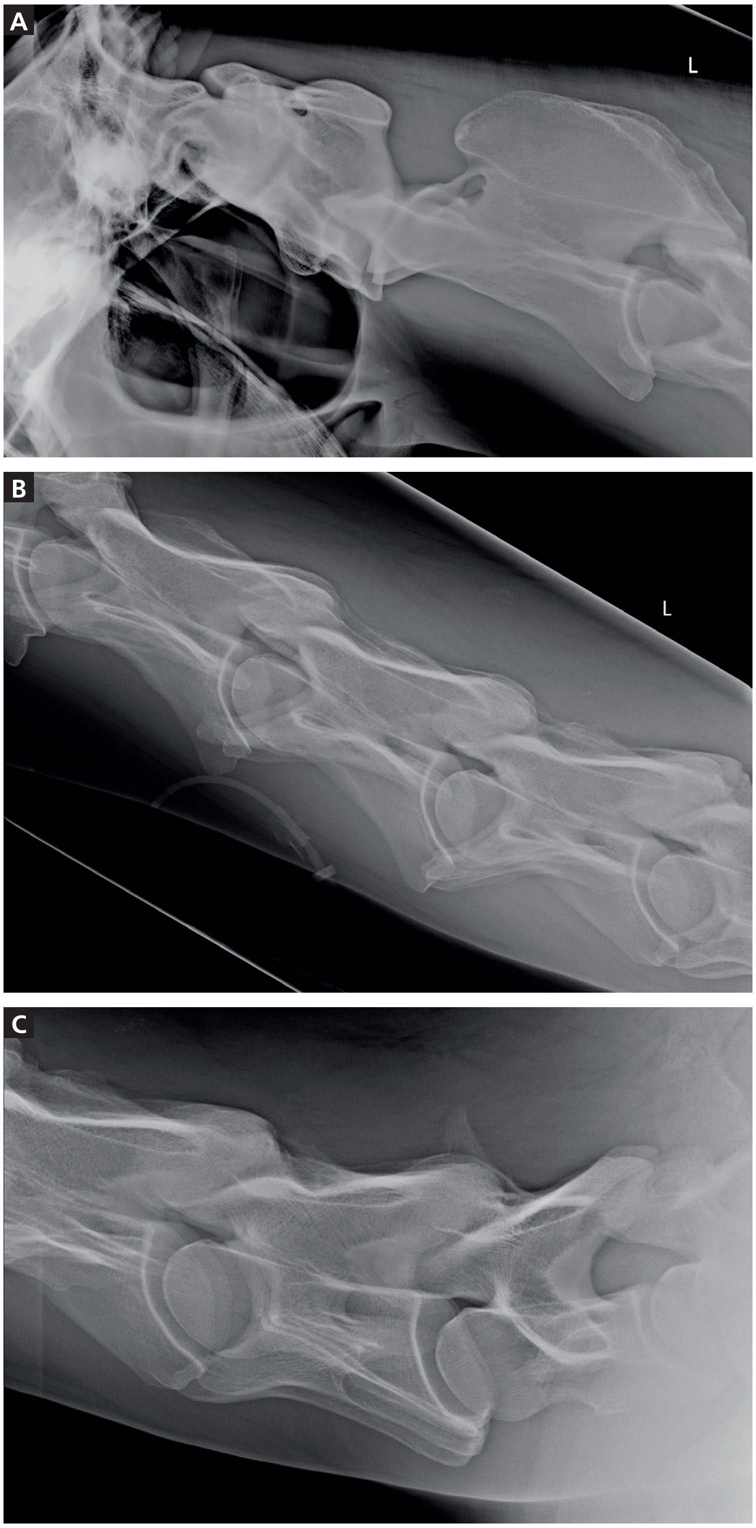

Figure 1. Laterolateral radiographs of the normal cervical spine. A; cranial, B; mid, C; caudal neck.

Congenital malformations

There are notable anomalies in the developmental anatomy of the spine in some breeds, with Arabian horses seemingly demonstrating a predilection for congenital deformities (Mayhew et al, 1978; Watson and Mayhew, 1986). The most common type of congenital lesion in the cervical spine of horses is occipitoatlantoaxial malformation (OAAM) of variable severity; malformations can also be seen further caudally (Butler et al, 2017).

Fractures/subluxations

Traumatic injuries of the cervical spine can be identified in horses, in particular when competing at cross country events, and also associated with the recovery period following general anaesthesia, among other times.

Due to movement between the vertebrae, there is the possibility for subluxation of one vertebral body relative to the adjacent one; these can result in static anomalies, or dynamic compression of the spinal cord if the neck moves into a hyperextended or hyperflexed position.

Fractures of the transverse processes of the vertebral bodies can occur secondary to trauma; in the author's opinion these can be challenging to identify on laterolateral radiographs alone, however they are often readily identifiable on oblique radiographic projections. These types of fracture carry a more favourable prognosis than those involving the joints, and as a solitary finding are unlikely to cause spinal cord compression without more extensive involvement of the vertebral body.

Common modalities for imaging of the neck

Common modalities for imaging of the neck include:

- Radiography
- Computed tomography (CT)
- Myelography
- Ultrasonography
- Nuclear scintigraphy.

Radiography

The most common imaging modality employed to image the neck is radiography. Traditionally, laterolateral projections are acquired from either the left or right side of the neck. Three overlapping projections are generally required to image the whole length of the cervical spine (*Figure 1*). Use of anatomical markers at several levels may aid in recognition of the vertebral anatomy, though care is needed not to obscure the regions of interest. For images of the caudal cervical spine, relatively high-output x-ray generators are required for optimal-quality images to be produced; this is more an issue for large breed horses with thick overlying regions of soft tissues.

Example exposure values used at the author's institution for the equine cervical spine using a gantry-mounted x-ray generator are:

- Cranial cervical spine: 70 kVp, 12 mAs
- Mid cervical spine: 76 kVp, 14–22 mAs
- Caudal cervical spine: 85–90 kVp, 36–45 mAs.

Laterolateral radiographs result in significant superimposition of anatomy, specifically the articular process joints on the left and right. As such, using these projections alone it is often impossible to lateralise a lesion.

More recently, acquisition of oblique radiographic projections (Left lateral45–55ventral-dorsolateral oblique, and right lateral45–55ventral-dorsolateral oblique) have been described (Withers et al, 2009). These must be acquired from both the left and the right, facilitating a more detailed evaluation of the articular process joints (*Figures 2* and *3*). It is important that the correct angulations are used to obtain images that are diagnostic. In the author's opinion, these projections should now form part of the routine radiographic examination of the cervical spine.

Ventrodorsal radiographs are possible in foals and small ponies; however they are challenging in horses. They can however be performed in horses under general anaesthesia using a gantry-mounted high-output generator, though they may not offer a great diagnostic benefit over other acquired projections and are uncommonly obtained.

Once diagnostic quality images have been obtained, the following structures are assessed: the vertebral canal, vertebral bodies, articular process joints, intervertebral disc spaces and the surrounding soft tissues. Measurements can be made on laterolateral radiographs to evaluate the size of the vertebral canal; intra-vertebral and inter-vertebral sagittal ratios (van Biervliet et al, 2006). These measurements are associated with some inter- and intra-operator variation (Hughes et al, 2014); however, values <48.5% have been demonstrated to be highly likely associated with a site of spinal cord compression (Hahn et al, 2008). It must be stressed, however, that the spinal cord itself cannot be visualised on modalities using x-ray radiation: we are aiming to detect signs which may infer an affliction of the spinal cord; further investigations are needed to evaluate signs suggestive of compression. Careful attention should be paid subjectively to the alignment between the vertebrae; assessment of 'step formation' from one to the next on the ventral floor of the vertebral canal; and subluxations. Additionally, the intervertebral disc spaces should be examined (*Figure 4*).

The articular processes should be evaluated for size, shape, margination and opacity. Assessment of the margins should be

Figure 2. Positioning of the horse and the radiographic equipment in order to obtain a correctly angled oblique radiograph of the caudal cervical spine.

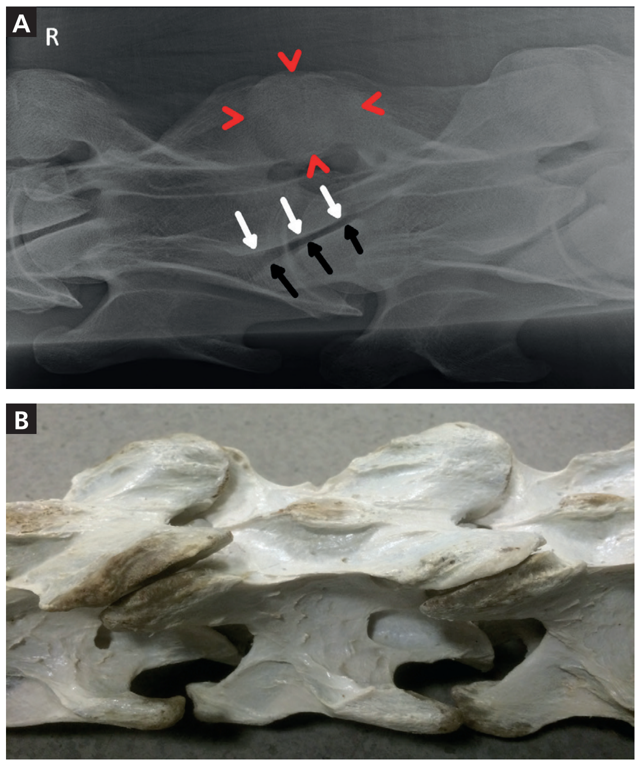

Figure 3. A) left ventral-right dorsal oblique radiograph of the normal mid-cervical spine. Black arrows indicate the joint surface of the respective right cranial articular process, white arrows the joint surface of the opposing right caudal articular process, red arrows indicate the left articular processes which are skylined, the left and right superimposed; B) anatomical photograph of cadaver material indicates the appearance of the articular process joints when a radiograph would be obtained at the correct angulation.

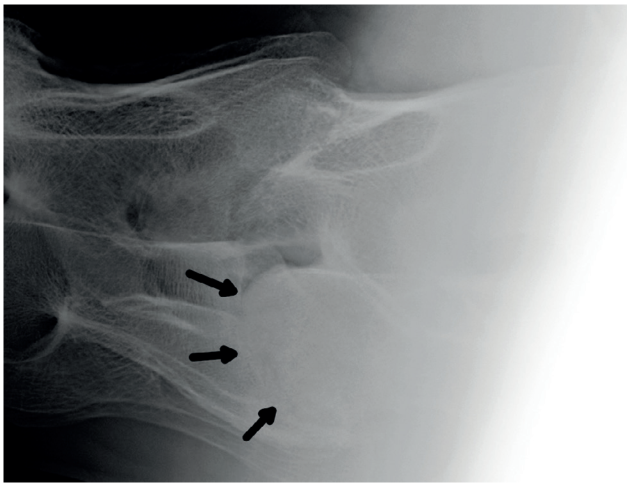

Figure 4. Laterolateral radiograph of the caudal cervical spine in a horse presented for ataxia and neck stiffness. Arrows indicate collapse of the intervertebral disc space between C6 and C7 with surrounding sclerosis of the vertebral body end plates.

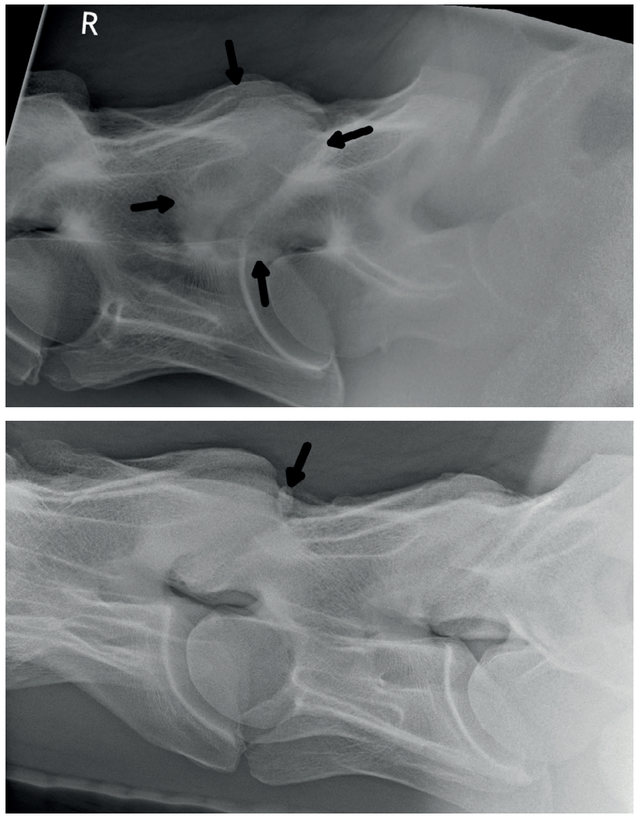

Figure 5. A) Laterolateral radiograph of the caudal cervical spine of a 6-year-old Warmblood mare; black arrows indicate enlarged articular processes between C6 and C7, considered greater than that normally expected. Note loss of visibility of the intervertebral foramina; B) laterolateral radiograph of the caudal cervical spine. Black arrow indicates a single oval-shaped bone fragment at the caudodorsal margin of the articular process joints of C5-C6 (osteochondrosis dissecans).

carefully performed in order to detect the presence of bony fragments associated with the joints. As is commonly seen in synovial joints with DJD, the resultant appearance is that of bony proliferation and enlargement (*Figure 5A*). It is a 'normal' finding in horses that the most caudal cervical joints are overall slightly larger than the more cranial ones (Down and Henson, 2009), however, loss of visibility of the intervertebral foramina, and roughened margins, are progressively abnormal as the severity of DJD increases. These findings should, however, be interpreted in light of the patient's age and presenting complaint. Bony fragments as a result of developmental joint disease (*Figure 5B*) and fractures of the articular processes are possible, and can be challenging to identify. Use of oblique radiographs can be of specific benefit here.

Infrequently, regional or focal bone lysis can be identified; this can be either alone, or in combination with presence of pathological fractures (*Figure 6*), which can be a result of a neoplastic process. The hallmark features of aggressive bone disease include cortical lysis, a poorly defined zone of transition, and active (irregular) periosteal reaction (Thrall, 2013), and should not be overlooked.

Computed tomography

The size of the equine neck in the live horse has until recently prevented the use of CT to examine the structure, except in smaller ponies and thin-necked horses, due to the trunk of the body obstructing the neck from fitting within the scanner bore. There are now large-bore human CT scanners in use in the veterinary market, with gantry sizes up to 85–90cm in diameter. In addition, there are purpose-designed large-bore veterinary CT scanners, that are technically able to acquire images of the whole spine in the standing horse, though this is in its infancy. With the availability of large diameter human bariatric CT scanners, the entire neck of an adult horse can now be readily imaged in patients that are under general anaesthesia.

In the author's institution, CT examinations of the cervical spine are performed in lateral recumbency, with the horse positioned on a purpose-built, padded general anaesthesia table, with the head and neck to the level of the shoulders positioned on a carbon fibre table extension overlying the human patient table (*Figure 7*). This allows for examination to the level of the T1 vertebra in the majority of subjects. It is also possible to position horses in dorsal recumbency; this is dependent on equine table design. Lateral recumbency imaging enables access to the dorsal aspect of the cranial cervical spine should subarachnoid contrast media administration (myelography) be required.

Computed tomography images are obtained typically in a transverse plane, from 0.5–2.5 mm thick slices dependent on CT scanner used, which can be reconstructed into three-dimensional models and re-sliced in any orientation (multiplanar reconstruction; MPR). This removes anatomical superimposition, and therefore a thorough examination of the cervical vertebral column is facilitated, including differentiation of left and right articular processes individually.

The joint surfaces can be evaluated in great detail for bony fragments (OCD), articular surface defects, osseous cyst-like lesions (OCLL), and periarticular osteophytes (*Figures 8, 9* and *10*). Other bony lesions, in particular, can be evaluated in minute detail, and CT may provide additional information not obtained using conventional radiography.

Myelography can be performed as part of a radiographic or CT examination of the cervical spine (Grant et al, 2006). The hair over the dorsal aspect of the atlanto-occipital cistern is clipped, scrubbed and aseptically prepared. A sterile iodine bandage is placed over the region and a small hole created for placement of an 18g 3-inch spinal needle. This is advanced, with the head and neck in 90-degree flexion, into the subarachnoid space, where the stylet is removed and 50 ml of cerebrospinal fluid (CSF) is slowly withdrawn, followed by gradual injection of contrast media; the needle and bandage are then removed. The process to perform this injection can be performed from start to finish in 10 minutes, including patient preparation. A sample of the CSF obtained can be submitted for laboratory analysis, should this be considered of benefit in individual cases.

The horse's neck is subsequently elevated for 5 minutes on a purpose-made ramp, or foam padding, to encourage caudal flow of contrast media, followed by image acquisition. Typically, for a radiographic myelogram, laterolateral radiographs are acquired of the entire cervical spine in a neutral, hyperflexed and extended position. More recently, cross sectional imaging has been used to obtain images of the cervical spine (CT myelography). Currently, it is not possible to obtain the flexed views of the spine within the CT scanner; therefore the author would typically obtain CT images in neutral and extended positions, followed by radiographs in a hyperflexed position in the recovery box at the end of the procedure. Overall, the process of obtaining a plain CT scan, a CT myelogram, and a radiographic myelogram can be comfortably accomplished within a 1-hour period of general anaesthesia.

Images are assessed for evidence of narrowing of the contrast media column dorsal and dorsolateral to the spinal cord, which could suggest spinal cord or peripheral nerve root compression. Narrowing >50% of the dorsal contrast media column on a laterolateral radiograph has been identified as suggestive for spinal cord compression with moderate sensitivity and moderate–high specificity (van Biervliet et al, 2004). In efforts to reduce the risks of false positive results, some clinicians use greater reductions (i.e. >70%) in the contrast media column as individual cut-off values (*Figure 11*). On CT images, the same sagittal plane measurements have not been validated, with some early findings suggesting that there may be more significant overlap between normal and abnormal horses on a sagittal plane MPR image. Use of cross sectional spinal cord: vertebral canal area ratios in cadaver material on MRI (Janes et al, 2014) may be a promising indicator of an alternative technique for the evaluation of advanced imaging.

Ultrasonography

Ultrasonographic examination of the cervical spine is most commonly performed to assess, and guide treatment to perform medication of, the articular process joints. These joints are superficially located under muscle bellies, and with the skin clipped and prepared, high-quality images can be obtained. Use of a microconvex transducer is beneficial, and an in-plane injection to track a needle path from the skin to the level of the joints can result in greater confidence of injection success. It is possible for ultrasonography to provide useful information for cases of soft tissue masses (including neoplasia), nuchal ligament damage or nuchal bursitis, or

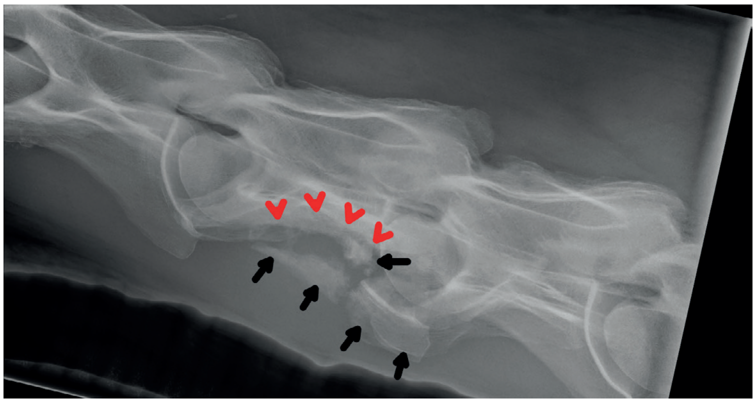

Figure 6. Laterolateral radiograph of the mid cervical spine of an aged Shire horse centered on C4. There is marked lysis (aggressive bone disease) of the vertebral body of C4, outlined by the red arrowheads. There are pathological fractures of the vertebral body (black arrows indicate fragments), and collapse of the C4–C5 intervertebral disc space. This was the result of a vertebral tumour that had also invaded the vertebral canal and compressed the spinal cord.

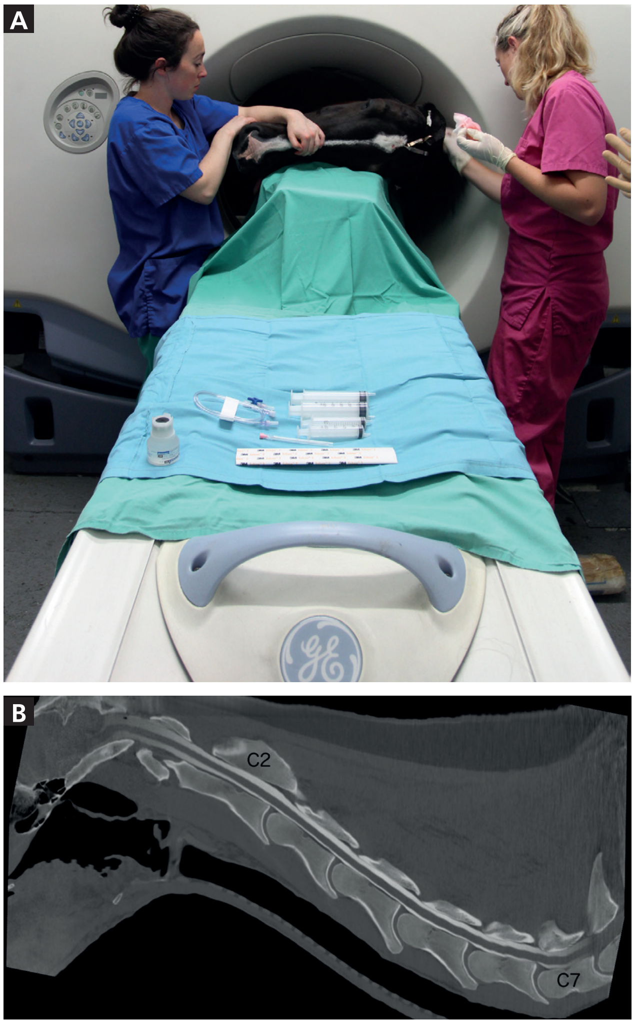

Figure 7. A) Photograph of a horse undergoing computed tomographic (CT) myelography indicating patient positioning and equipment required; B) curved multiplanar reconstruction (MPR) sagittal plane CT image of the entire cervical spine following intrathecal contrast administration, demonstrating the appearance of a CT myelogram in an adult horse.

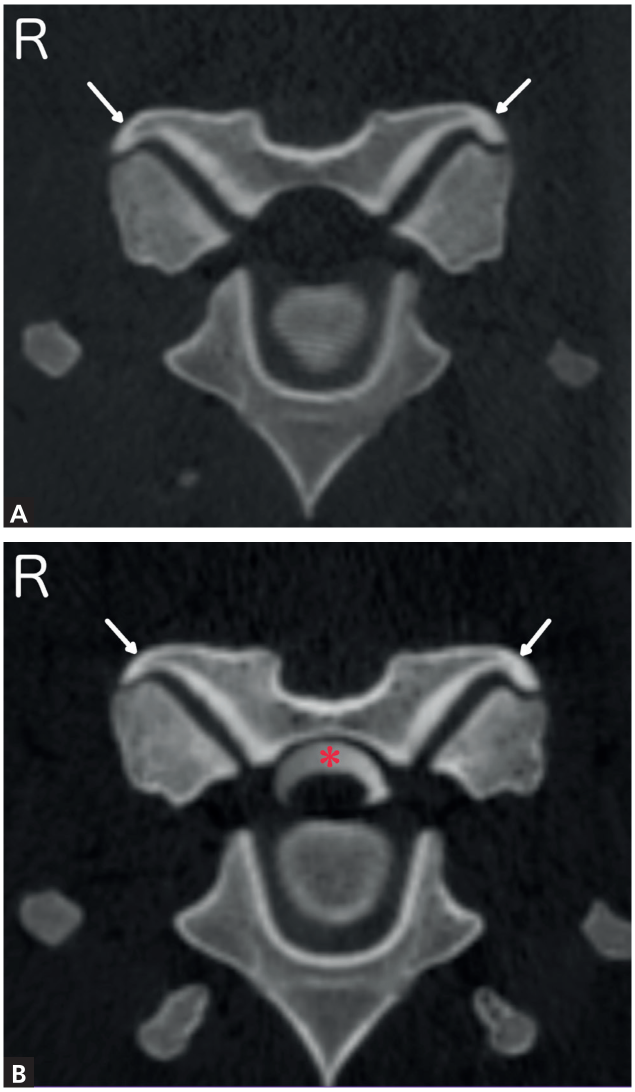

Figure 8. Transverse CT images at the level of the C4-C5 articular process joints pre- (A) and post- (B) myelogram. Note the large periarticular osteophytes (white arrows). This allows for evaluation of signs indicating dorsolateral spinal cord compression (not seen here). The red asterisk indicates contrast medium in the subarachnoid space.

even in cases of trauma, as bony disruption can be detected.

Use of ultrasonography to guide cervical CFS centesis both at the atlanto-occipital space and between C1 and C2, has been described as a rapid and straight forward procedure in standing sedated horses (Pease et al, 2012; Depecker et al, 2014), and in this region, the occipital condyles and atlanto-occipital joint can be evaluated also.

Nuclear scintigraphy

Nuclear scintigraphy can be used to assess the vertebral bodies and articular process joints, and can be a helpful tool to evaluate for signs suggestive of DJD, or in horses where a fracture is suspected but radiography has not identified such a lesion.

Importantly, in cases with narrowing of the vertebral canal alone, nuclear scintigraphy may not demonstrate any abnormalities, thus, in the author's opinion, false negatives can occur.

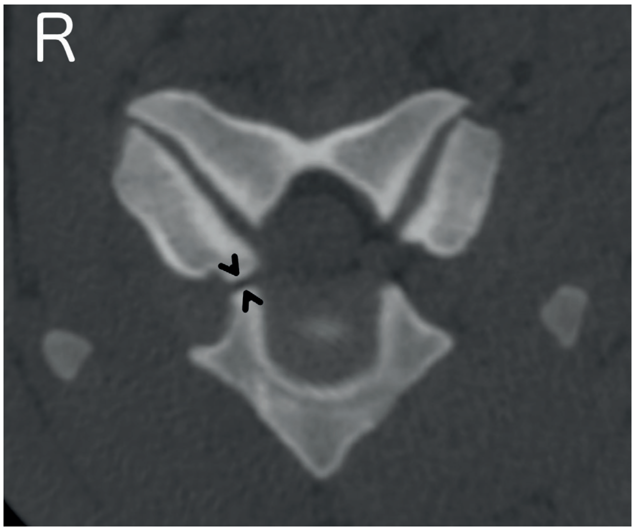

Figure 9. Transverse CT image at the level of the C5-C6 articular process joints. Black arrowheads indicate narrowed intervertebral foramina on the right, secondary to marked unilateral enlargement of the articular process joints.

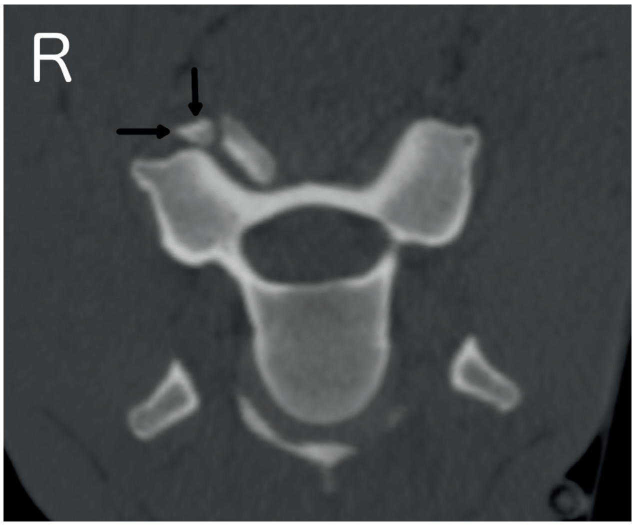

Figure 10. Transverse computed tomography image at the level of the C5-C6 articular process joints. Black arrows indicate solitary bony fragment on the right, consistent with osteochondrosis dissecans.

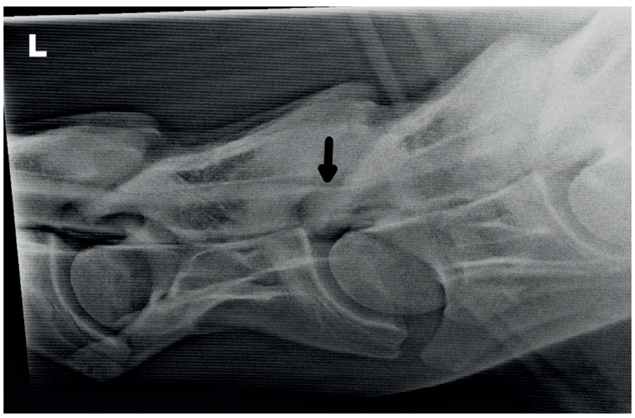

Figure 11. Laterolateral myelographic image of the caudal cervical spine. Black arrow indicates focal narrowing of the dorsal contrast media column, suggestive of spinal cord compression at this site.

Summary

While radiographic examination of the spine remains the most frequent method of evaluation of this complex anatomical region, other imaging techniques can be employed on a case-by-case basis with some specific benefits. Advanced imaging can provide information that cannot be obtained using conventional techniques; however this is associated with increasing cost and often also requirements for general anaesthesia. EQ

Conflicts of interest: none.

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