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CERVICAL VERTEBRAL CANAL ENDOSCOPY IN THE HORSE

By

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ABSTRACT

CERVICAL VERTEBRAL CANAL ENDOSCOPY IN THE HORSE

By

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Diseases of the equine cervical spinal cord remain a diagnostic challenge. In human medicine, endoscopy of the vertebral canal is used in cases where non-invasive imaging tools fail to identify the lesion.

First, an approach to the vertebral canal via the atlanto-occipital space was developed and the epidural as well as the subarachnoid space of the cervical vertebral canal were explored. Nerve roots, fat and the ventral internal vertebral venous plexus were identified in the epidural space. During endoscopy of the subarachnoid space, the spinal cord, nerve roots, blood vessels, the denticulate ligaments and the external branch of the accessory nerve were seen. Subsequently, three healthy adult horses underwent endoscopy of the epidural space (epiduroscopy) while subarachnoid endoscopy (myeloscopy) was performed in another three horses. All procedures were completed successfully, including examination of the subarachnoid and epidural space from the atlanto-occipital space to the 8th cervical nerve. All horses recovered from anesthesia. Neurologic examinations after surgery were normal in all but one horse. This horse showed transient signs of ataxia and weakness after a complicated myeloscopy.

Endoscopic examination of the epidural and subarachnoid space from the atlanto-occipital space to the 8th cervical nerve is possible and can be performed safely in clinically healthy horses.

To Mami, Ecki, Gerrit, Felix, Ruth und Lyndsey

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INTRODUCTION

This thesis is divided into 4 chapters. The first chapter is a literature review that will facilitate the understanding of the endoscopic anatomy of the equine vertebral canal that is described later in the thesis. Furthermore, will demonstrate the need for a new diagnostic tool in horses with spinal cord disease and provide an introduction into epidural and subarachnoid endoscopy in humans. At the end of this chapter, I will explain my conclusions regarding the potential clinical usefulness of cervical vertebral canal endoscopy in horses.

The second chapter describes the development of the surgical approach to the cervical vertebral canal via the atlanto-occipital space and the endoscopic anatomy of the cervical epidural and subarachnoid space in equine cadavers.

In chapter 3, the intra- and post-operative observations in 6 healthy adult horses that underwent cervical vertebral canal endoscopy are reported, including three cases of myeloscopy and three of epiduroscopy.

In chapter 4, I will draw conclusions from my work and recommend a path forward for the development of vertebral canal endoscopy in horses.

CHAPTER I

LITERATURE REVIEW

Anatomy

As in most mammals, the cervical spine of the horse consists of seven vertebrae (C1-C7). They are firmly joined together and thereby contribute to the maintenance of posture and stability of the neck while allowing flexion/extension, axial rotation and lateral bending (Clayton and Townsend 1989). Furthermore, it encloses and protects the spinal cord and accessory structures in the vertebral canal (Dyce *et al.* 2010). The following is a description of the anatomical structures of the cervical vertebral column and the associated structures that are relevant for this research project.

Cervical vertebrae

The basic form of a cervical vertebra includes the two sides of a vertebral arch, a dorsal roof and a ventral body, which together form the approximately rectangular shaped vertebral foramen. The atlas however, does not have a distinct body; it has the shape of a ring that encloses a very large vertebral foramen (Butler *et al.* 2008, Liebich and Koenig 2007). Together the cervical vertebral foramina form the *cervical vertebral canal* which extends from the foramen magnum to C7 and encloses the spinal cord, its meninges, spinal nerves, blood vessels, ligaments, fat and connective tissue (Liebich and Koenig 2007). The diameter of this canal varies greatly at different points in the cervical vertebral column, emulating the shape of an hourglass; widest at the atlas, narrows to the smallest width at C4, then widens considerably at the cervico-thoracic

junction (Getty 1975, Mayhew *et al.* 1978). However, the vertebral canal in a healthy horse is always wide enough to avoid compression of the spinal cord. On the lateral aspect of two adjacent vertebrae is a small space formed by little notches in the arches, the *inter-vertebral foramen,* which allows the spinal nerves to exit the vertebral canal. The dorsal aspects of the vertebral arches fit closely in between most vertebrae, leaving no or nearly no *interarcual space*. However, there are three sites where these spaces are large enough to allow access (e.g. with a needle) to the vertebral canal:

- *atlanto-occipital space*: between the occipital bone and the atlas (therefore not a real "interacual space")
- *atlanto-axial space*: between the atlas and the axis
- *lumbosacral space*: between the last lumbar vertebra and the sacrum

Articulations of the cervical vertebral column

The *atlanto-occipital joint and the atlanto-axial joint* together form a functional unit between the skull and the vertebral column that allows flexion and extension in the sagittal plane ("nodding") and rotation about a longitudinal axis ("head-shaking"). The *dorsal atlanto-occipital membrane* strengthens the dorsal joint capsule of the atlanto-occipital joint and at the same time, covers the space between the occiput and the atlas (atlanto-occipital space) (Dyce *et al.* 2010). The *inter-vertebral articulations* of the remaining cervical vertebrae consist of symphyses between the bodies and the synovial joints of the articular processes (so called "articular facets"). The bodies are connected by inter-vertebral fibro-cartilage disks, which consist of a dense fibrous peripheral part (annulus fibrosus) and a soft and elastic central part (nucleus pulposus). The latter is

maintained under pressure and spreads the compressive forces, to which the vertebral column is subjected, over a wider part of the vertebra. The thickness of the inter-vertebral disks largely contributes to the flexibility of the spine. The articular facets are conventional synovial joints. In the cervical region these articular surfaces are large and situated almost horizontally, enabling the horse to not only flex and extend but also to rotate the neck (Dyce *et al.* 2010, Getty 1975, Liebich and Koenig 2007).

Tendons and Ligaments *(Dyce et al. 2010, Liebich and Koenig 2007)*

A variety of ligaments connects the vertebrae with each other, including long (spanning several vertebrae) and short (connecting two adjacent vertebrae) ligaments. The interarcuate ligaments (ligamenta flava) fill the interarcual spaces and are the only short ligaments of importance for this project. Relevant long ligaments are:

- the *dorsal longitudinal ligament* that runs on the floor of the vertebral canal from the axis to the sacrum and is attached to the intervertebral disks and the vertebrae
- the *nuchal ligament* consists of a funicular and a lamellar part. The funicular part is a cord like structure, situated in the dorsal midline, extends from the external occipital protuberance to the summits of T3-T5 and then continues to the supraspinous ligament. It is an elastic band, supporting the extensor muscles of the neck during head movements of locomotion (Gellman and Bertram 2002).

Spinal cord

The equine spinal cord extends from the medulla oblongata at the foramen magnum to the level of the second sacral vertebra.

Outer structure/anatomy: It can be described as a cylinder with slight dorsal-ventral flattening, with certain regional variations in shape and diameter. Along its entire length, the spinal cord can be divided into two symmetric halves by the *dorsal grove* and the *ventral median fissure*. Afferent nerve fibers enter the spinal cord through the *dorsal lateral sulcus* of both sides (*dorsal spinal nerve roots*), while efferent nerve fibers exit the spinal cord through the shallow and indistinct *ventral lateral sulcus* (ventral spinal nerve roots). One dorsal and the correlating ventral spinal nerve root together form a *spinal nerve*. The spinal nerves exit the vertebral canal via the inter-vertebral foramina and therefore their number usually coincides with the number of vertebrae, e.g. there are 18 thoracic vertebrae and 18 thoracic spinal nerves. However, there are eight *cervical spinal nerves*. The first exits the vertebral canal through the lateral vertebral foramen of the atlas followed by seven nerve roots exiting through the inter-vertebral foramina, with the 8th cervical nerve passing through the inter-vertebral foramen between C7 and T1 (Dellmann and McClure 1975, Koenig and Liebich 2007). The *external branch of the accessory nerve* (XI) arises from the cervical spinal cord at the level of the 5th cervical spinal nerve. It then continues cranially on the dorso-lateral surface of the spinal cord, continuously receiving more nerve fibers and therefore increasing in size until it eventually passes through the foramen magnum (Boehme 2004b).

Internal structure/anatomy: A transverse section of the cervical spinal cord reveals an

oval shape with obvious dorso-ventral flattening at the level of the cervical enlargement, where the spinal cord measures about 25mm (transverse) by 12mm (dorso-ventral) in diameter. The *grey matter* is located centrally, roughly resembling a capital "H" or a butterfly in shape with each lateral part consisting of a *dorsal and ventral horn/column.* The grey matter consists of cell bodies and processes of neurons and glia cells. The shape of the grey matter divides the surrounding *white matter* into three pairs of funiculi: the dorsal pair between the dorsal horns of the grey matter, the lateral pair on both sides of the grey columns and the ventral pair between the ventral grey horns. These funiculi are composed of ascending and descending nerve fibers.

Functionality of the spinal cord: A brief review of the essentials of the functionality of the spinal cord is necessary to understand certain diseases in the horse that originate in the cervical vertebral canal.

- *Somatic efferent pathways*: Somatic motor activity is regulated by lower and upper motor neurons. The *lower motor neurons* are located in the ventral grey column throughout the entire spinal cord with their axons reaching the skeletal muscles via the spinal nerves. Abnormalities of the general somatic efferent lower motor neuron generally cause signs of muscle weakness (paresis or paralysis, reduced or missing reflexes, hypo- or atonia, neurogenic atrophy). The *upper motor neuron* is the CNS motor system that is responsible for voluntary movement, the maintenance of tone against gravity and the regulation of posture. It is traditionally divided into the pyramidal and extra-pyramidal system. The *pyramidal system* predominantly consists of neurons whose cell bodies are located in the motor area of the cerebral cortex and axons that descend through the white matter of the cerebrum and brain stem. They represent

an uninterrupted monosynaptic cortico-spinal pathway from the cerebrum to the spinal cord. The pyramidal system is well developed in animals that are able to perform finely skilled movements, e.g. with their thoracic limbs, like primates or raccoons. In the horse, the pyramidal system is poorly developed, only making considerable contribution to the facial muscles and lip movements. The *extra-pyramidal system,* in contrast, comprises various multi-synaptic pathways that originate from different nuclei in the cerebral cortex (multi-neuronal, multi-synaptic, cortico-spinal pathway). This system is of much greater importance in the domestic animal, as it is responsible for maintenance of posture and the execution of intended movements by ensuring coordinated muscle activity. The pyramidal and the extra-pyramidal system overlap anatomically and function together as both are controlled by the cerebellum (de Lahunta 1983, Koenig and Liebich 2007).

- *Somatic afferent pathways*: The principal sensory systems of the body include the system for recognition of pain (nociception) and the system for detection of body position (propioception). *General propioception* pathways are formed by chains of neurons with synapses at different levels of the nervous system and can be divided into those that conduct impulses from the pelvic or the thoracic limbs. Furthermore, they can be differentiated into pathways belonging to the conscious propioception system (three neurons per chain) or the unconscious propioception system (two neurons per chain). Knowing the course of these pathways is essential to understanding clinical signs of certain diseases, like the Cervical Vertebral Stenotic Myelopathy (CVSM). The following pathways are located in the white matter of the spinal cord and make up the funiculi that have been described above (de Lahunta 1983, Masty 2008).

- conscious pathway for pelvic limbs: fasciculus gracilis (dorsal funiculi)
- un-conscious pathway for pelvic limbs: dorsal and ventral spinocerebellar tracts (lateral funiculi, superficial to the spinocerebellar tracts of the thoracic limbs)
- conscious pathway for thoracic limbs: fasciculus cuneatus (dorsal funiculi)
- un-conscious pathway for thoracic limbs: cuneo-cerebellar tract (dorsal funiculi) and the rostral spino-cerebellar tract (lateral funiculi)

Blood supply

The arterial blood supply of the cervical spinal cord is provided by *segmental arteries* that originate from the vertebral artery and enter the vertebral canal via the inter-vertebral foramina. They then divide into dorsal and ventral branches that follow the spinal nerves to the surface of the spinal cord. Together the branches form three continuous arteries that run along the spinal cord: two dorso-lateral spinal arteries and the ventral spinal artery. The *ventral spinal artery* lies in the ventral median fissure while the dorso-lateral arteries follow the dorso-lateral sulci, where the dorsal nerve roots emerge. These arteries communicate and form plexuses within the pia mater (on the surface of the spinal cord). The *spinal veins* follow the arteries on the surface of the spinal cord and through the vertebral foramina, to open into the *ventral internal vertebral venous plexus,* which is located in the epidural space. This plexus runs on the floor of the cervical epidural space and consists of two channels (located at 5 and 7 o'clock) that are connected by transverse branches (Gold *et al.* 2008, Koenig and Liebich 2007).

Meninges

The spinal cord is enclosed by three soft tissue membranes, called the meninges (from the outermost to the deepest layer): the dura mater, the arachnoid mater and the pia mater. The latter two are delicate tissue layers, also known as the *leptomeninges* (leptos [Greek] = thin, delicate), in comparison to the dura mater (durus [Latin] = hard, tough). The *spinal dura mater* forms a moveable tube within the vertebral canal. On the outside, the dura mater is separated from the periosteal lining of the vertebral canal by the epidural space. On the inside (towards the spinal cord) the dura mater is closely attached to the arachnoid mater. In the literature, especially in older anatomy books, a space between the two meninges is described. However, more recently the existence of this *subdural space* in healthy living animals and humans has been questioned. It has been demonstrated that it only forms in cadavers or due to pathologic processes (hematomas, etc.) and in fact, is located between different layers of the dura mater and not between the dura and the arachnoid. Therefore, the subdural space is called an "artificial" or "potential" space (Boehme 2004a, Haines *et al.* 1993). The inside of the *arachnoid mater* or just the *arachnoid* is connected to the pia mater with numerous trabeculae and filaments, creating the appearance of a spider web. The space between the arachnoid and the pia mater is called the *subarachnoid or leptomeningeal space* (due to its location between the two leptomeninges) and contains the cerebrospinal fluid (CSF, *liquor cerebrospinalis*). The well-vascularized *pia mater* is directly attached to the surface of the spinal cord and surrounds all spinal nerves and blood vessels that enter or exit the CNS. On the lateral sides of the spinal cord the pia mater is thickened, forming the *denticulate ligament*. Extensions of the denticulate ligament cross the

subarachnoid space and attach to the dura mater, thereby suspending the spinal cord in the CSF.

Epidural space

The epidural space, located between the periosteum of the vertebral canal and the dura mater, is mostly occupied by lose connective tissue and fat. In people and primates, analysis of the fat has shown it consists of uniform fat cells enclosed in a fine membrane. This can explain the semifluid consistency, which facilitates movement of the dura mater relative to the wall of the vertebral canal. Additional anatomical characteristics of the epidural space include spinal nerve roots that cross the epidural space on their way to the intervertebral foramina and the ventral internal vertebral venous plexus (Boehme 2004a, Hogan and Toth 1999).

Subarachnoid space and liquor cerebrospinalis/cerebrospinal fluid

The subarachnoid space is filled with CSF and surrounds the entire cervical spinal cord. It contains the trabeculations between the pia and subarachnoid mater, the nerve fibers that enter and exit the spinal cord, the blood vessels that supply the spinal cord, the denticulate ligament and the external branch of the accessory nerve (Boehme 2004a). The CSF is a clear and colorless fluid that represents a plasma ultrafiltrate. It is produced by the choroid plexuses and modified ependymal cells of the lateral, third and fourth ventricles as well as by the pia and arachnoid mater and the blood vessels in the

pia and arachnoid mater. It then flows through the apertures of the fourth ventricle to move in either a rostral (over the hemispheres) or caudal direction (into the vertebral canal). The CSF gets absorbed in the subarachnoid villi or leaves the subarachnoid space via the dural reflexions of the spinal nerve roots or even via the cranial nerves (Di Chiro *et al.* 1972, Hayes 1987). The CSF has a number of functions, including protection (physical and chemical buffer) and nourishment of the spinal cord and brain. Furthermore, in conjunction with the cerebral blood flow, it helps to regulate the pressure changes that occur within the bony calvarium (intracranial pressure): the intracranial pressure (ICP) is generated by the brain parenchyma, the CSF and blood in the intracranial vessels. In a healthy conscious horse the ICP is 2 ± 4mmHg (measured in the intracranial subarachnoid space) while the CSF pressure at the lumbosacral site has been reported to be 22.6 ± 5.5 mmHg (Brosnan *et al.* 2002a, Mayhew *et al.* 1977). Laboratory examination of the CSF reveals a specific gravity of 1.004-1.008, a protein of 10-120 mg/dl, less than 10 leukocytes and less than 50 erythrocytes per ml (Andrews 2004, Furr and Andrews 2008). Collection of CSF can be performed at the atlanto-occipital or the lumbosacral space. The site of collection should be chosen depending on the location of the lesion, addressing the caudal flow of CSF. For example, it is more likely that an intracranial lesion will be reflected by CSF collected from the atlanto-occipital space while pathologic changes in the spinal cord will be better diagnosed by analysis of CSF that has been collected at the lumbo-sacral space (Andrews 2004, Hayes 1987).

Selected diseases of the equine cervical spinal cord

Cervical vertebral stenotic myelopathy (also cervical vertebral malformation/malarticulation, cervical vertebral compressive myelopathy, Wobblers syndrome, equine sensory ataxia)

The disease was first described in 1939 (Dimock and Errington 1939) and has since been shown to be the most common non-infectious cause for spinal ataxia in horses (Papageorges *et al.* 1987, Reed *et al.* 1981, Tyler *et al.* 1993) with 1.3-2% of all Thoroughbreds being affected (Oswald *et al.* 2010, Rooney 1977). However, a variety of other breeds, including Quarterhorses, Arabians, Appaloosas and Warmbloods have been diagnosed with this disease as well (Hahn 2004, Mayhew *et al.* 1978).

Pathogenesis

Cervical vertebral stenotic myelopathy (CVSM) refers to the constant or intermittent impingement of bone and soft tissues on the cervical spinal cord that is caused by a narrowing of the cervical vertebral canal, often in combination with malformation or malarticulation of one or more of the seven cervical vertebrae. Even though the site(s) of compression can be located anywhere from C1 to T1, it is most commonly identified between C3 and C7 (Papageorges *et al.* 1987, Powers *et al.* 1986). The disease occurs in two categories, although a continuum exists.

Type 1 CVSM is a developmental orthopedic disease that tends to occur in young growing horses (usually < 2 years of age). The underlying anatomical abnormalites in this type of CVSM are malformations of the cervical vertebrae that result in stenosis of

the vertebral canal, angular deformity, caudal extension of the dorsal aspect of the vertebral arch, osteochondrosis and physitis. The malarticulation of the affected vertebrae causes compression especially when the neck of the horse is *flexed.* The site of compression is usually located in the mid-cervical region (C3-C5) (Hahn 2004, Mayhew 2008a, Wagner *et al.* 1987).

Type 2 CVSM is seen in older horses and appears to be an acquired/traumatic disease. It is caused by osteoarthritis of the articular processes (facet joints) in the caudal neck (C6-T1) and results in direct impingement of the articular and periarticular soft tissues on the spinal cord (including synovial cysts). The arthritis further results in cranial and caudal extension of the craniodorsal vertebral arch, decreasing the diameter of the vertebral canal. The stenosis in these cases is usually worsened by *extending* the neck (Gerber *et al.* 1980, Mayhew 2008a).

A further differentiation is made between dynamic and static spinal cord compressions. *Dynamic compression* is defined by intermittent spinal cord compression that occurs when the neck, and thereby the cervical vertebrae, are flexed (more cranial cervical vertebrae) or extended (more caudal cervical vertebrae). *Static compression,* on the other hand, causes permanent compression of the cervical spinal cord, independent of the neck position.

The typical changes in the spinal cord can be described as lesions in the white matter of the spinal cord, with a remarkable loss of myelin in almost all funiculi. The lateral funiculi seem to be especially susceptible to degeneration by compression, while the dorsal funiculi are sometimes spared (de Lahunta 1983, Reed *et al.* 2008).

Clinical signs

The clinical signs include ataxia (usually symmetrical), weakness and dysmetria. The owners of affected horses will frequently report an "increasing clumsiness" (Hahn 2004, Powers *et al.* 1986, Tyler *et al.* 1993). In horses with moderate signs, the animals will show circumduction of pelvic limbs when walked in small circles, dragging of the toes and inability to counterbalance a tail pull while being walked. The stride of the thoracic limbs is frequently hypometric and stiff.

The ataxia in the thoracic limbs is usually less severe compared to the pelvic limbs, which can be explained by the more superficial spinocerebellar tracts of the pelvic limbs when compared to the tracts of the thoracic limbs (see above). In general, the clinical signs can be explained by disturbance of ascending propioception pathways (ataxia) and descending upper motor neuron pathways (paresis) (Blythe 1987, de Lahunta 1983).

Diagnosis

A presumptive diagnosis can be made based on the history and clinical signs and with the help of *lateral radiographs* of the cervical vertebral column (neutral, flexed and extended position). Typical radiographic findings in horses with CVSM are:

- malalignment between adjacent vertebrae (subluxation)
- osteoarthritis of the facet joints
- enlargement of the caudal vertebral epiphysis of the vertebral body
- osteochondrosis changes of the facet joints

- extension of the dorsal aspect of the vertebral arch over the cranial physis of the adjacent caudal vertebra

Even though subjective assessment of these radiographs can be helpful, the diagnosis of CVSM must not be solely based on it (Papageorges *et al.* 1987, Reed 2007). The value of straight lateral cervical radiographs can be substantially increased when using sagittal ration measurements. The *intra-vertebral sagittal ratio* is calculated as the ratio of the minimal sagittal diameter of the vertebral foramen to the maximum sagittal diameter of the cranial aspect of the vertebral body (measured perpendicular to the vertebral canal). A ratio below 52% for C4, C5 and C6 and below 56% for C7 indicates narrowing of the vertebral canal and points towards a diagnosis of CVSM (Moore *et al.* 1994). However, the method does not reliably identify the site of compression (Hahn *et al.* 2008, Reed 2007, van Biervliet 2006).

More recently the *inter-vertebral sagittal ratio* has been proposed to be a more dependable tool for the identification of CVSM (Hahn *et al.* 2008). This value is the ratio of the minimal distance from the most cranial aspect of the vertebral body to the most caudal aspect of the vertebral arch of the adjacent cranial vertebra to the maximal sagittal diameter of the cranial vertebral body of the more caudal vertebra. The idea of using this ratio is based on the observation that the spinal cord in CVSM cases is usually compressed at the articulation of two adjacent vertebrae. In a first study evaluating this technique, the authors were able to reliably diagnose CVSM and identify the correct location of spinal cord compression. For each horse, the site of compression concurred with the site of the smallest inter-vertebral sagittal ratio. However, no reference values have been established for the general horse population because there is

overlapping of the ratios between horses with and without CVSM. Furthermore, lateral (transverse) compression is not uncommon in horses with CVSM which could not be diagnosed using this technique (Hahn *et al.* 2008).

Positive contrast cervical myelography is currently the diagnostic tool of choice to not only diagnose CVSM but also identify the site of compression (Hudson and Mayhew 2005, Papageorges *et al.* 1987). Myelography is generally performed with the horses under general anesthesia in lateral recumbency using non-ionic, water-soluble contrast agents (iopamidol, iohexol). The injection of the contrast into the subarachnoid space is performed via the atlanto-occipital space after an equal amount of CSF has been withdrawn. Lateral radiographs in neutral, flexed and extended neck position are taken. Dorso-ventral views to evaluate the vertebral canal for potential transverse compression can be added. Two different criteria for the assessment of the lateral myelographic radiographs are commonly used. The first method considers the reduction of the dorsal contrast column to less than 2mm as indicative for spinal cord compression in this location (Mayhew *et al.* 1978). The second system uses a $\geq$ 50% decrease of opposing dorsal and ventral dye columns compared to a midvertebral site cranial or caudal to the lesion for this purpose (Papageorges *et al.* 1987). These criteria have been the source of debate for a while (Reed *et al.* 2008) and in a more recent study, it was shown that neither one offers an acceptable combination of sensitivity and specificity, especially in the mid cervical sites. It is likely that the reduction of the dorsal column has to be up to >70% to avoid false positive diagnoses of spinal cord compression (van Biervliet *et al.* 2006b, van Biervliet *et al.* 2004b).

In human medicine, computed tomography and magnetic resonance imaging are the

recommended imaging modalities in cases where simple procedures fail to provide a diagnosis in cases of spinal cord disease (Haig and Tomkins 2010, NorthAmericanSpineSociety 2007). The use of *contrast enhanced computed tomography* (CECT) for horses with CVSM has been investigated in equine cadavers (Moore *et al.* 1992). While CECT provided additional information about severity and location of the stenosis, it identified a compressive lesion that could not be confirmed by histopathology (2 falsely identified lesions with myelography in the same study). Another limitation of CT (and MRI) is the inability to examine the entire cervical vertebral column in an adult horse due to the limited scanner bore width of the available machines (Gold *et al.* 2008).

Treatment

The *medical treatment* aims at reduction of cell edema and therefore reducing the compression at the site of vertebral canal stenosis. A variety of NSAIDS and corticosteroids as well as dimethyl sulfoxide have been described. While this medical therapy may provide transient improvement, especially if acute deterioration due to secondary trauma is seen, compression of the spinal cord will continue and so will clinical signs (Hahn 2004). Horses less than one year of age might benefit from changes in management (Donawick *et al.* 1993).

Surgical treatment is possible and throughout the last two decades several publications have shown successful outcome after anterior interbody fusion (DeBowes *et al.* 1984, Moore *et al.* 1993, Wagner *et al.* 1979). The surgery consists of implantation of

fenestrated stainless steel baskets or more recently of a threaded stainless steel Kerf cylinder implant (Seattle Slew Implant) between the two cervical vertebrae that need to be stabilized. The new Kerf cylinder implant has reduced the number of post-surgical complications that occurred due to implant migration (Grant *et al.* 2003). While it is frequently recommended to perform the surgery only in horses with no more than two compression sites, triple level anterior interbody fusion has been performed and horses showed decreased neurologic signs after surgery (Grant *et al.* 2007). The aim of surgery is to stop the repetitive trauma to the spinal cord, which is caused by the narrowing of the cervical vertebral canal. Therefore, in cases where surgical treatment is considered, exact identification of the compression site is crucial. Following the procedure, an improvement of 1-2 out of 5 neurologic grades can be expected, making this treatment especially appealing to moderately ataxic horses (Moore *et al.* 1993, Reed *et al.* 2008).

Neoplasia in the cervical vertebral canal

Neoplasia of the equine spinal cord is a rare occurrence (Mayhew 2008b). In a large study that reviewed 450 cases with neurologic disease, only 8 horses were diagnosed with neoplasia of the CNS, with 5 of the lesions located in the vertebral canal (Tyler *et al.* 1993). Depending on their anatomical location in relation to the spinal cord, it can be differentiated between (van Biervliet *et al.* 2006a):

- extradural extramedullary tumors, which are located outside the meninges in the vertebral canal (in the epidural space)
- intradural extramedullary tumors that are inside the meninges (between the spinal cord and the dura mater) but not invading the spinal cord

- intradural intramedullary tumors that are within the spinal cord.

The neoplasias are generally extradural metastases of non-neural origin, including lymphosarcomas (Zeman *et al.* 1989), melanomas (Rodriguez *et al.* 1998, Schott *et al.* 1990), hemangiosarcomas (Berry 1999) and squamous cell carcinomas (Tyler *et al.* 1993). Undifferentiated sarcomas in the vertebral canal were recently identified as the primary tumor in two horses (Van Biervliet *et al.* 2004a).

The onset of clinical signs can be acute, making trauma the primary differential in many cases. Frequently, an ante mortem diagnosis is not possible, even when advanced imaging modalities (including CT, MRI and nuclear scintigraphy) and CSF analysis are used (van Biervliet *et al.* 2006a).

Cervical spinal cord and vertebral injury

The most common cause of neurologic disease in horses is trauma. In a study that included 450 horses with neurologic signs, 119 cases were due to traumatic injury of the nervous system, 60 of these were diagnosed with spinal cord trauma (Tyler *et al.* 1993). In 55% of horses in this group, the cervical spinal cord was involved. Even though all cases could be associated with a traumatic incident, it was not always clear if neurologic disease was preceding the event. Most of the spinal cord injuries were the consequence of fractures and subluxations of the vertebrae, however necropsy examination revealed 5 cases where no bony damage could be identified, making an ante-mortem diagnosis difficult.

In general, diagnosis of cervical spinal cord injury can be made using radiographs as vertebral involvement is very common. However, in a small number of cases standard

and advanced diagnostic imaging modalities are not able to detect (radiographs, myelography, scintigraphy) or reach the lesion, if it is located in the caudal aspect of the neck (due to bore width of currently available CT and MRI scanners) (Nout 2008).

Cervical vertebral epidural hematomas

Cervical vertebral epidural hematomas (CVEH) have only been described twice in the literature. An older study from Germany reported four cases that all spontaneously resolved. However, the diagnosis was solely based on clinical findings and the lack of other abnormalities (von Oberregierungsrat and von Geheimrat 1966).

A more recent publication describes four horses with CVEH in the caudal aspect of the cervical vertebral canal (C6-C7) (Gold *et al.* 2008). All horses presented with ataxia, paresis and neck pain. Even though no history or evidence of recent trauma was reported, two horses had radiographic evidence of CVSM and another horse had fallen twice within the last 12 months. The origin of the hematomas could not be determined (neither the reason for the bleeding nor the actual vessel involved) but the localization within the epidural space suggested the ventral internal vertebral venous plexus to be the source of the bleeding.

Three of the 4 horses in this study were euthanized and the diagnosis of CVEH was made during necropsy. The remaining horse had signs of vertebral canal narrowing on myelographic radiographs that disappeared within nine months, suggesting a resolved epidural hematoma had caused the neurologic signs. The authors emphasize that MRI or CT are the diagnostic tools of choice in horses with CVEH but that it is very difficult or impossible to fit the caudal cervical column in the scanners.

Epidural and subarachnoid endoscopy in humans

History of vertebral canal endoscopy

The first report of endoscopic examination of the vertebral canal was published by Michael Burman in 1931 (Burman 1931). In his pioneering work he described the endoscopy of eleven spines that were removed from freshly deceased human cadavers. Using a rigid arthroscope he was able to see the dura mater, the spinal cord with blood vessels on its surface and parts of the cauda equina. However, the large size of the instrument did not allow application of the procedure in clinical patients. Within the next few years smaller rigid endoscopes were developed, allowing in vivo examination of the vertebral canal and its contents (Stern 1936). The smaller "spinascopes" and "myeloscopes" were used in clinical cases and the results of a series of 400 endoscopies of the lower vertebral canal were published (Pool 1942). A variety of abnormalities were described in this report, including neuritis, herniated nucleus pulposus, hypertrophied ligamentum flavum, primary and metastatic neoplasias, blood vessel abnormalities and adhesive arachnoiditis. The myeloscopy, performed with the patient awake and in a sitting position, provided information that could not be gained by any other imaging modality at that time. Despite these findings and the fact that no serious complications were noted, no further reports about vertebral canal endoscopy can be found for the next twenty years (Saberski and Brull 1995).

In the 1960s a group in Japan revived subarachnoid and epidural endoscopy in patients with lower back pain. Using rigid fiber-optic endoscopes with an external diameter of 3.1mm, originally manufactured for otolaryngeal or arthroscopic examinations (Ooi *et al.* 1981, Ooi *et al.* 1977, Saberski and Brull 1995) they described and photographically

documented the anatomy and pathology of the lumbo-sacral vertebral canal in 208 patients. The findings included spinal cord trauma, meningoceles, osteoarthritis and tuberculous spondylitis. However, only small aspects of the vertebral canal could be investigated with the rigid instruments (Ooi *et al.* 1977).

The development of small flexible fiber-optic endoscopes finally allowed exploration of the entire length of the epidural and subarachnoid space (Shimoji *et al.* 1991). The external diameters of the instruments ranged from 0.5 to 1.4 mm and were small enough to be inserted through a Tuohy needle (blunt hypodermic needles that are used to enter the epidural space). As in the previous reports, the patients did not receive any sedation or anesthesia, allowing communication with the surgeon during the examination. Immediate discontinuation of the procedure was possible if the patient reported any negative side effects. The authors describe that the view in the epidural space was better after the subarachnoid space had been examined. This is likely due to the fact that the leaking CSF from the subarachnoid space helped in distending the epidural space, as no fluids could be injected via the endoscope (Shimoji *et al.* 1991).

The most recent instruments are equipped with a working channel that allows injection of fluid into the epidural space and are enclosed in a steerable catheter. The ability to accurately move the tip of the endoscope in combination with a new approach through the sacral hiatus, greatly improved the diagnostic and therapeutic value of the endoscopic explorations (Jain *et al.* 2004, Saberski and Kitahata 1996, Schuetze 2008).

Epiduroscopy

Computed tomography and MRI are the most commonly used imaging modalities in complicated cases of spinal cord disease in humans but even these sophisticated tools have limitations. Endoscopy of the epidural space can provide important information in such challenging cases. Following the diagnostic part of the endoscopy, the endoscope can be used to administer drugs under visual control or to break down epidural adhesions and thereby initiate therapy (Gorchesky 1999, Haig and Tomkins 2010, North American Spine Society 2007, Saberski and Kitahata 1996).

Technique of epidural endoscopy: The procedure can be performed with the patient in a prone position, entering the vertebral canal through the sacral hiatus or in a lateral position for the lumbosacral approach (Dezawa *et al.* 2005, Ooi *et al.* 1977). The procedure should be performed in a surgery suite with the patient draped and the insertion site for the endoscope prepared in a sterile manner. After the skin and the underlying tissues at the site of approach have been injected with a local anesthetic (lidocaine, articaine, mepivicaine) a Tuohy needle is inserted into the sacral canal and its position confirmed by injection of a contrast medium (iohexol) under fluoroscopic monitoring. Subsequently, a guide wire is introduced through the Tuohy needle into the epidural space and the needle is removed. The skin at the introduction site, with the guide wire in situ, is incised using a scalpel blade to allow replacement of the Tuohy needle with a dilator and introducer sheath. The dilator is removed and the fiberoptic endoscope with the steerable sleeve introduced into epidural space. A gentle flow of saline is needed for lubrication of the instrument and to push away structures from the

lens to gain and maintain vision. The procedure can then be documented with still images and by video (Geurts *et al.* 2002, Gupta and Richardson 2009, Schuetze 2006, 2010).

Diagnostic indications for epiduroscopy: Epiduroscopies of the spinal epidural space are performed for a variety of reasons, including examination of epidural masses or collection of tissue samples. The main indication however, is chronic lumbar radiculopathic pain (pain that originates from a nerve root) that often occurs after failed back surgery and is appreciated as "lower back pain" (Beltrutti *et al.* 2006, Deniel and de Antoni 1998, Richardson *et al.* 2008, Schuetze 2008, 2010). Part of this examination is the so called "epidural pain provocation test". For this test, the endoscope is used to gently touch potentially affected nerve roots. While contact with nerve roots relevant to the patient's pain elicits a valuable response, the same manipulation on non-inflamed nerve roots only causes mild discomfort. This emphasizes the importance of a fully awake and compliant patient for certain aspects of this procedure.

Therapeutic indications for epiduroscopy: In addition to the diagnostic value of epidural endoscopy, the procedure can be used for therapeutic purposes at the same time, including (Beltrutti *et al.* 2006, Schuetze 2006, 2008):

- targeted application of medication
- lysis of scar tissue (adhesiolysis)
- epidural catheter placement
- implantation of stimulation electrodes
- adjunct in minimally invasive surgery

- retrieval of foreign body

- post-surgical assessment.

Epidural adhesiolysis is the endoscopic breakdown of fibrotic tissue that surrounds nerve roots in the (usually lumbar) epidural space. Epidural fibrosis is not an uncommon occurrence in patients that underwent back surgery, especially in cases that require re-intervention after lumbar discectomy or where dural tears, nerve root injury and bleeding have occurred during the initial procedure (Fritsch *et al.* 1996, Manchikanti *et al.* 2005). Furthermore, adhesions in the epidural space have been described after the application of intrathecal contrast agents, disc herniation, epidural hemorrhage or infection (Cooper *et al.* 1995, Manchikanti *et al.* 2005).

Adhesiolysis should only be performed for "symptomatic nerves", while nerves that are not considered to be involved in the patient's pain should be left alone. The procedure must be carried out gently and with a cooperative patient. If the latter reports any signs of paresthesia, the procedure has to be discontinued. Smaller adhesions can be broken down just by the injection of saline, while the tip of the endoscope is used to address more solid scar tissue. Additionally, adhesiolysis with a diode laser has been successfully used to free nerve roots from the scar tissue (Richardson *et al.* 2008, Schuetze 2006). Frequently, an injection of corticosteroids is performed once the adhesiolysis has been completed (see below).

The success rate and the usefulness of adhesiolysis are controversial. While several reports have shown immediate and long lasting pain relief in patients with chronic and refractory pain, other studies did not find this treatment superior to injection of corticosteroids in the epidural space without endoscopic guidance (Hayek *et al.* 2009,

Manchikanti *et al.* 2005, Saberski and Kitahata 1995, Veihelmann *et al.* 2006),
The injection of local anesthetics, corticosteroids and hyaluronic acid into the epidural space under endoscopic control is usually performed after the adhesiolysis has been completed. When compared to the injection into the epidural space without endoscopic support, this procedure allows *targeted injection of drugs* to the affected nerve roots (Geurts *et al.* 2002, Igarashi *et al.* 2004). Advocates of the procedure emphasize this as an advantage and provide data that demonstrate superior short and long-term outcomes (Geurts *et al.* 2002, Igarashi *et al.* 2004, Trescot *et al.* 2007) whereas other publications do not show an advantage of targeted over untargeted epidural injections (Dashfield *et al.* 2005).

Complications of epiduroscopy: Complications with epidural endoscopy are uncommon and usually minor (Gorchesky 1999, Hayek *et al.* 2009) but a small number of serious complications can occur if the procedure is not carried out with care and patience. *Injection of high fluid volumes* in a relatively short period of time can lead to excessive hydrostatic epidural pressures which result in increased CSF and intracranial pressures, epidural hematomas and retinal hemorrhage leading to visual deficiencies (Gill and Heavner 2005, Manchikanti and Singh 2002). To avoid this, it has been recommended to limit the injection of fluid into the epidural space to 1ml every 1-2 seconds (Gill and Heavner 2005). *Puncture of the dura mater* can occur during the approach to the epidural space. This is not expected to cause complications in every case but orthostatic headache and temporary CSF leakage might occur after surgery (Hayek *et al.* 2009, Manchikanti *et al.* 1999). If the surgeon fails to recognize this mistake, severe

complications during surgery are possible: adhesiolysis is occasionally performed using hypertonic saline (10%) (Heavner *et al.* 1999, Manchikanti *et al.* 2001) and the injection of hypertonic saline into the subarachnoid space can cause cardiac arrhythmia, myelopathy and paralysis (Boswell *et al.* 2005). *Transient post-surgical complications* include pain at the insertion site of the endoscope, lower limb pain and sensory deficits. A more serious complication that requires treatment with antimicrobials and possibly hospitalization is infection of the surgical site and the epidural space (Hayek *et al.* 2009, Trescot *et al.* 2007, Veihelmann *et al.* 2006).

Myeloscopy

Endoscopy of the spinal subarachnoid space is less common than endoscopy of the spinal epidural space (Richardson *et al.* 2008). It is often performed by neurosurgeons, while epidural endoscopy is usually offered by "pain specialists" and anesthesiologists. Since Pool's report of 400 clinical cases of subarachnoid endoscopy in 1942 (Pool 1942) no other study with an equally large case number has been published. However, there are a few articles that describe the application of flexible fiber-endoscopes in clinical cases. The positioning of the patient and the *approach* itself are very similar to epiduroscopy procedures, though penetration of the dura mater is necessary in order to enter the subarachnoid space (Shimoji *et al.* 1991, Tobita *et al.* 2003). Some surgeons choose to perform myeloscopy under general anesthesia (Warnke and Mourgela 2007), while others prefer to do the procedure in conscious patients. This depends, apart from the preference of the surgeon, largely on the purpose of the procedure and the compliance of the patient (Uchiyama *et al.* 1998). *Indications* for

myeloscopy include cases of (often chronic) back pain in which the cause could not be identified by the use of non-invasive imaging modalities (Dezawa *et al.* 2005, Uchiyama *et al.* 1998). Other reasons include the further evaluation of subarachnoid masses, including the collection of tissue samples (Curry 2008), the treatment of previously diagnosed adhesive arachnoiditis (Warnke and Mourgela 2007) and surgical removal of intradural arachnoid cysts (Endo *et al.* 2010). The *complications* are usually limited to neck pain and discomfort at the insertion site during the endoscopy and "post lumbar-puncture headache" (orthostatic headache) but mild fevers and even meningitis have been documented. (Shimoji *et al.* 1991, Uchiyama *et al.* 1998, Warnke and Mourgela 2007).

Recently, the introduction of flexible video-endoscopes with an external diameter of less than 3mm (Warnke *et al.* 2007) has increased the interest in subarachnoid endoscopy of the spinal cord again. New publications describe the endoscopic anatomy of and surgical approaches to the lower subarachnoid space with these instruments and first studies document the use of flexible videoendoscopes with superior image quality in clinical cases (Fujimoto *et al.* 2005, Warnke *et al.* 2003, Warnke *et al.* 2001a, Warnke *et al.* 2001b).

First experiences in animals

Prior to the use of vertebral canal endoscopy in humans, the techniques were performed in a variety of laboratory animals (Saberski 2008). The results were not published and no information about the feasibility and safety of vertebral canal endoscopy in domestic animals was available until recently. Franz *et al.* describe the endoscopic anatomy of

the epidural space in the sacro-coccygeal area of adult cows and the safety of the procedure in healthy animals. The authors were able to identify the anatomical structures in the epidural space (epidural fat, dura mater, blood vessels) and complete the epiduroscopy in six standing cows without complications.

Conclusion

Modern imaging modalities allow identification of many pathologic changes involving the cervical spinal cord in the horse. However, there are some diseases that cannot be diagnosed reliably and accurately. In humans, endoscopy of the spinal epidural and subarachnoid spaces has proven to provide useful information in inconclusive cases and offer minimally invasive treatment options. While the procedure will need to be adjusted to the horse and its specific diseases, I am confident that endoscopy of the equine vertebral canal is possible and can provide important information in patients with CVSM and other diseases of the cervical spinal cord.

In the next chapter I will describe the surgical approach to the cervical vertebral canal and the endoscopic anatomy of the cervical epidural and subarachnoid space in equine cadavers.

CHAPTER 2

ENDOSCOPIC ANATOMY OF THE CERVICAL VERTEBRAL CANAL IN THE HORSE: A CADAVER STUDY

Summary

Reason for performing study: Localization of spinal cord compression in horses with cervical vertebral stenotic myelopathy is inexact. Vertebral canal endoscopy has been used in humans to localize spinal cord lesions and has the potential to become a useful diagnostic technique in horses.

Objective: To establish a surgical approach via the atlanto-occipital space to the cervical vertebral canal in equine cadavers and describe the endoscopic anatomy of the cervical epidural and subarachnoid spaces.

Methods: The cadavers of 25 adult horses were used to assess three surgical methods to approach the cervical vertebral canal, including two minimally invasive and one open technique. Once the approach had been made, a flexible video-endoscope was inserted into the epidural space (epiduroscopy) or the subarachnoid space (myeloscopy) and advanced caudally until the inter-vertebral space between C7 and T1 was reached.

Results: The epidural and subarachnoid spaces could not be accessed reliably using the minimally invasive techniques. Furthermore, damage to the nervous tissues was a frequent complication with these procedures. The open approach allowed successful insertion of the video-endoscope in the epidural and subarachnoid

spaces in all horses and no inadvertent damage was observed. Anatomical structures that could be seen in the epidural space included the dura mater, nerve roots, fat and the ventral internal vertebral venous plexus. In the subarachnoid space, the spinal cord, nerve roots, blood vessels, the denticulate ligaments and the external branch of the accessory nerve were seen.

Conclusions: Using the open approach, epiduroscopy and myeloscopy over the entire length of the cervical vertebral canal are possible in the adult horse.

Potential Relevance: Cervical vertebral canal endoscopy may become a valuable tool to localize the site of spinal cord injury in horses with cervical vertebral stenotic myelopathy and might aid in the diagnosis of other diseases of the cervical spinal cord.

Introduction

Cervical vertebral stenotic myelopathy (CVSM), the principal differential for equine cervical spinal cord disease, is characterized by stenosis of the cervical vertebral canal that causes compressive myelopathy (de Lahunta and Glass 2009). Lesions can occur anywhere from the first cervical to the first thoracic vertebra, but are usually located between C3 and C7 (Papageorges *et al.* 1987, Powers *et al.* 1986, Tyler *et al.* 1993). CVSM is predominantly seen in male horses that are less than 3 years old (Papageorges *et al.* 1987, Powers *et al.* 1986, Tyler *et al.* 1993). Furthermore, Thoroughbreds and Quarterhorses are over-represented, with an estimated 2% of all Thoroughbreds being affected (Powers *et al.* 1986, Rooney 1977, Tyler *et al.* 1993). Because surgery can be a treatment option for horses with CVSM, it is important to differentiate this disease from other conditions causing cervical spinal cord disease (Moore *et al.* 1994). Additionally, for the surgical procedure to be successful, it is imperative to identify the exact location of the compression site. While several diagnostic imaging modalities are available to evaluate the cervical vertebrae and associated structures in horses, there are limitations to all of them.

Intra-vertebral sagittal ratio diameters measured from standard lateral cervical radiographs have been used to identify stenosis of the vertebral canal. However, this method does not reliably detect the specific site of compression (Moore *et al.* 1994). More recently, inter-vertebral sagittal ratio diameters have been investigated in horses with CVSM and reported results are promising. Although the compression could be localized using this procedure in a small number of animals, further studies are

necessary to validate this technique (Hahn *et al.* 2008). Myelography reliably identifies the site of compression in the caudal neck (C6-C7) but is frequently inaccurate in other regions of the cervical vertebral column (Hudson and Mayhew 2005, Papageorges *et al.* 1987, van Biervliet *et al.* 2004b). In human medicine, magnetic resonance imaging (MRI) and computed tomography (CT) are the diagnostic tools of choice for lesions of the cervical spinal cord (Holmes and Akkinepalli 2005, Muchow *et al.* 2008). In the adult horse however, it is usually not possible to examine the caudal cervical vertebrae and associated structures using MRI or CT because of the large size of the animal and the limitations of the scanner bore width (Moore *et al.* 1992, van Biervliet *et al.* 2006b). These limitations of MRI and CT are not exclusive for CVSM but apply to all pathological conditions of the caudal neck in horses (Gold *et al.* 2008).

The use of endoscopy has proven invaluable in many areas of veterinary medicine, including arthroscopy and laparoscopy. Endoscopy of the vertebral canal in humans was introduced by Burman in 1931. Since then, the instruments and endoscopic procedures have consistently improved. Currently, the procedure allows direct viewing of a variety of pathological changes within the vertebral canal, including compression and injury of the spinal cord, arachnoiditis and tumors. It is particularly beneficial when the results of other imaging modalities are inconclusive (Geurts *et al.* 2002, Tobita *et al.* 2003, Uchiyama *et al.* 1998). Additionally, vertebral canal endoscopy is used as a minimally invasive treatment in patients with conditions producing back pain, including chronic radiculopathic pain or failed back-surgery syndrome. Reported complications of the endoscopic procedures are rare and usually minor (Dezawa *et al.* 2005, Tobita *et al.* 2003, Uchiyama *et al.* 1998).

The anatomy of the mammalian vertebral canal allows for endoscopic examination of two different spaces: the epidural (epiduroscopy) and the subarachnoid space (myeloscopy). The epidural space is located between the dura mater and the surrounding vertebrae. It mainly contains fat, and lymphatic and blood vessels (including the ventral internal vertebral venous plexus). Furthermore, the nerve roots that originate from the spinal cord pass through the epidural space to leave the vertebral canal via the inter-vertebral foramina. The subarachnoid space contains the CSF and is located between the arachnoid mater and the pia mater. Anatomic structures within this space include the spinal cord, nerve roots, blood vessels (Figure 1) (Boehme 2004a).

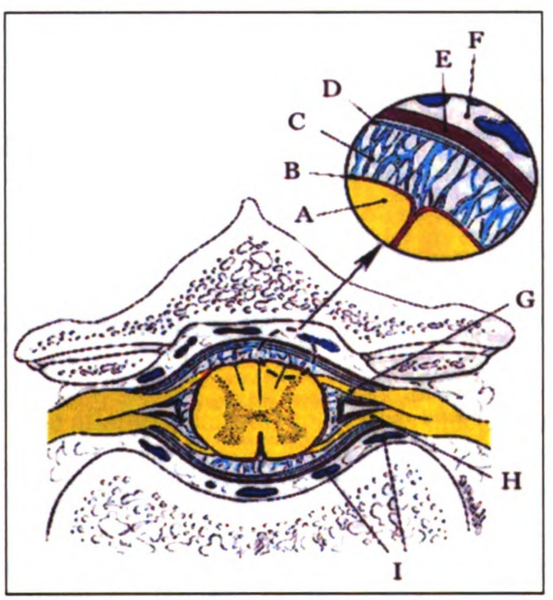

Figure 1: Schematic cross section of the vertebral canal at the level of an inter-vertebral foramen. Top of the picture is dorsal. A = spinal cord; B = pia mater; C = subarachnoid space; D = arachnoid mater; E = dura mater; F = epidural space, G = dorsal nerve root; H = ventral nerve root; I = ventral internal vertebral venous plexus (modified from *E.C.B. Hall-Craggs, Anatomy as a Basis for Clinical Medicine*, Williams and Wilkins, 1995. With permission.)

Endoscopy of the vertebral canal has been performed in a small number of horses (Dr. M. Nowak, personal communication), but the results have not been published.

The objective of this study is to establish a practical approach to the cervical vertebral canal in equine cadavers and describe the endoscopic anatomy of the epidural and subarachnoid space.

Material and methods

Horses

The cadavers of 25 horses of various breeds (10 mares, 15 geldings, mean age 15.1 years, age-range 2-25 years) weighing a mean of 505 kg (445-580 kg) were used. Horses had been euthanized for reasons other than this study and none of the animals had a history of neurologic disease or problems related to the cervical vertebral column. The study was approved by the Institutional Animal Care and Use Committee at Michigan State University.

Surgical approaches

The atlanto-occipital space was elected to be the entry site into the cervical vertebral canal. After the horses had been euthanized, they were placed in right lateral recumbency with the head flexed in a ninety degree angle. In this position, the atlanto-occipital space is located at the level of the cranial edge of the wings of the atlas (Mayhew 1975). In preparation for the procedure, an area extending about 30 cm caudal from the base of the ears and 15 cm to either side of the dorsal midline was clipped and cleaned. Three different surgical techniques (*procedures 1-3*) were tested, all using the above-mentioned landmarks to access the cervical vertebral canal: two minimally

invasive procedures (optical trocar and endovascular dilator/introducer system) and one open approach. The ability to insert the endoscope and explore the epidural and subarachnoid spaces without causing damage to the spinal cord was used as the main criterion to assess each approach. For all procedures, a flexible video-endoscope with a working length of 110 cm and an external diameter of 4.9 mm was used (GIF-N180, Olympus America Inc., Melville, NY, USA).

Procedure 1(3 horses)

A stab incision was made on the dorsal midline of the neck with a #10 scalpel blade at the level of the cranial edge of the wings of the atlas, incising the skin, subcutaneous tissues and the nuchal ligament. Then, a 7 French size endovascular dilator with a surrounding sheath (introducer)[1] was inserted into the incision and advanced into the subarachnoid space. Placement of the dilator/introducer was confirmed by the appearance of CSF at the end of the instrument. A wire guide was then advanced through the dilator into the subarachnoid space and was used as a guide for serial dilation until a 22 French introducer was in place. At this point the endoscope could be advanced through the introducer into the subarachnoid space. As the appearance of CSF was needed to confirm the placement of the endovascular dilator/introducer system, we did not attempt to access the epidural space using this technique.

Procedure 2 (10 horses)

The incision was made as described above and an optical trocar enclosed within a sleeve was then introduced into the incision. This trocar[2] has a blunt rounded clear window at the distal tip that includes a crescent-shaped blade which cuts about 1 mm of tissue beyond the visual field when the trigger is pulled. After that, the blade retracts, and the trocar can be advanced. The trocar accommodates the endoscope, allowing direct viewing of the tissues through the clear window in the end of the trocar. The crescent-shaped blade was used to dissect the tissues until the dorsal atlanto-occipital membrane was cut. Then, the trocar and endoscope were removed, leaving the sleeve in place. Next, the endoscope was inserted into the sleeve and advanced into the epidural space. In order to perform a myeloscopy, the trocar was advanced until the dura mater and the closely attached arachnoid mater were incised, and the endoscope was advanced into the subarachnoid space in a similar manner.

Procedure 3 (12 horses)

A 15 cm long skin incision was made on the dorsal midline centered at the level of the cranial edge of the wings of the atlas. Once the nuchal ligament (funiculus nuchae) could be palpated, the dissection was continued on the left side of the nuchal ligament by separating it from the left splenius capitis and left semispinalis capitis muscles. The intact nuchal ligament was then pushed to the right of midline using self-retaining retractors, exposing the aponeurosis between the right and left rectus capitis dorsalis major and minor muscles. The dissection was continued along the midline until the

dorsal atlanto-occipital membrane could be seen. This membrane was then incised on the midline, opening the epidural space. To perform an epiduroscopy, the endoscope was introduced into the epidural space in a cranio-dorsal to caudo-ventral direction, sliding the endoscope along the cranial edge of the incision. The endoscope was then slowly advanced caudad along the dorsal aspect of the dura mater. To perform a myeloscopy the dura mater and the underlying arachnoid mater were incised for 1.5 cm. Two simple interrupted sutures were placed, dividing the incision in the dura mater into three sections of equal length using #4-0 silk on a reverse cutting needle. After the endoscope had been inserted into the subarachnoid space at the same angle as described for epiduroscopy, the pre-placed sutures were gently tightened to minimize CSF loss.

Epiduroscopy

Once the endoscope was inserted into the epidural space, the latter was carefully distended using gentle irrigation with normal saline via the working channel, allowing the anatomical structures to be seen. Using the 2-way angulation capability of the endoscope, the dorsal, ventral and the lateral aspects of the epidural space were explored. Lateral radiographs were taken to confirm the placement of the video-endoscope when nerve roots were identified at the inter-vertebral spaces. Distance markers on the endoscope at the level of the dorsal atlanto-occipital membrane were also recorded. Once the 8^{th} cervical nerve had been reached, the endoscope was slowly withdrawn and the incision closed. In cadavers in which the minimally invasive techniques were used, only the subcutaneous tissue and the skin were closed. The open

approach incision was closed in four layers, including the rectus capitis dorsalis major muscles, the incision between the nuchal ligament and the splenius capitis as well as the subcutaneous tissues and skin.

Myeloscopy

Before the subarachnoid space was entered with any of the described techniques, the surgery table was tilted into a 20 degree reverse Trendelenburg position, thereby elevating the head above the caudal aspect of the horse. This decreased the pressure of CSF in the cerebello-medullary cistern and thus reduced the loss of CSF when the meninges were incised. Once the dura and arachnoid mater were opened, the endoscope was carefully introduced in the subarachnoid space. While avoiding contact with the nervous tissues and the blood vessels, the trabeculations between the pia mater and the arachnoid mater were slowly broken down by the advancing endoscope. As described for the epiduroscopy, we viewed the whole circumference of the spinal cord, and radiographs were taken to confirm the location of the end of the endoscope in relation to the inter-vertebral spaces until the 8^{th} cervical nerve was reached (Figure 2). Again, distance markers on the endoscope at the level of the dura mater were recorded. Then the endoscope was removed, and when the open approach was used the dura mater was closed with #4-0 silk in a simple continuous pattern. Now the table was brought back to a horizontal position to check for leakage of CSF. Subsequently, the incision was closed as described for the epiduroscopy. The technique for closure of the minimal invasive approaches was identical to the one described for the epidural endoscopy.

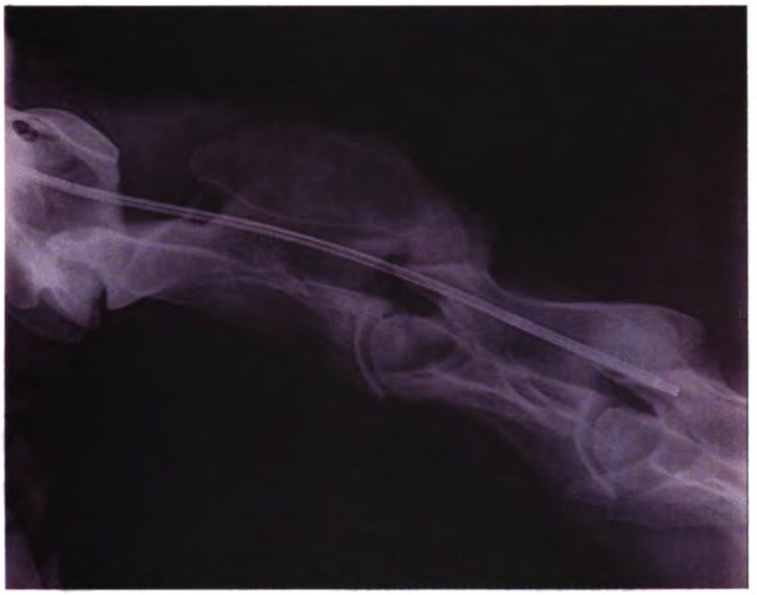

Figure 2: Lateral radiograph of the cranial cervical vertebrae in a horse during myeloscopy. The video-endoscope is dorsal to the spinal cord. The tip of the endoscope is located at the level of the 4th cervical nerve (between C3 and C4), and the cm marking on the endoscope at the level of the dura mater read 30 cm.

Necropsy examination

We used two different methods to identify potential damage to the spinal cord, nerve roots and blood vessels within the cervical vertebral canal. Evaluation of the videos recorded during endoscopy was used to assess the tissues caudal to the endoscope insertion site, and gross necropsy examinations were performed to examine the spinal cord at the insertion site of the endoscope.

Results

Procedure 1

The approach to the subarachnoid space with the endovascular dilator/introducer technique was attempted in three horses. It was obvious that the procedure caused substantial damage to the spinal cord as soon as the endoscope was inserted. Necropsy

examination revealed macroscopic damage to the spinal cord in all horses. The damage appeared to be caused by the tip of the dilator. This technique was not pursued further.

Procedure 2

The optical trocar was employed in ten horses. In four of these we gained access to the epidural and subarachnoid spaces, and examination of the videos recorded during endoscopy, and necropsy examination failed to reveal damage to the nervous tissues. In the remaining six horses, the following complications were encountered. In three horses we were unable to either identify or enter the epidural or subarachnoid space, as the dorsal atlanto-occipital membrane and the dura mater look very similar when viewed via the endoscope. In the remaining three we were able to enter the spaces, but significant damage to the nervous tissues could be seen with the endoscope. Thereafter, this technique was abandoned.

Procedure 3

The open approach was performed in 12 horses, and access to the epidural and subarachnoid space was gained in all cases. No visible damage to the spinal cord was observed during endoscopic exploration. The dorsal atlanto-occipital membrane could easily be identified as a fibrous tissue layer that connects the cranial edge of the atlas to the caudal margin of the foramen magnum. Once the membrane was incised along its sagittal plane the white dura mater and epidural fat could be seen (Figure 3). Epiduroscopy and myeloscopy were performed as described below. The sequence of the

procedures was randomized. The following results represent the findings that were obtained using the open approach.

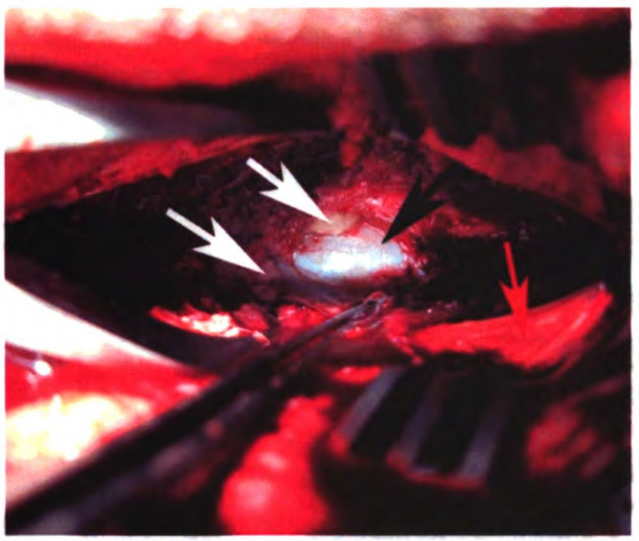

Figure 3: Open approach to the atlanto-occipital space, cranial is to the right. The dorsal atlanto-occipital membrane has been incised, opening the epidural space, exposing epidural fat (white arrows) and the dura mater (black arrow). Note the retracted nuchal ligament (red arrow) to the right side of midline.

Epiduroscopy

The endoscope was easily introduced into the dorsal aspect of the epidural space and was slowly advanced caudally. Saline was injected when necessary to obtain a view of the anatomical structures. About 200 ml of saline were needed to complete the procedure. The dura mater was used as a landmark to maintain orientation. The endoscope could be directed to the lateral and ventral aspects of the spinal cord, allowing 360° exploration of the epidural space from the first to the 8th cervical nerve root. We were able to see the following epidural structures: fat, connective tissue, dorsal and ventral nerve roots crossing the epidural space, and the ventral internal vertebral venous plexus (Figure 4). Nerve roots were seen at the level of every inter-vertebral space. The distance between two nerve roots (cranial to caudal) was 10-12 cm in all

horses.

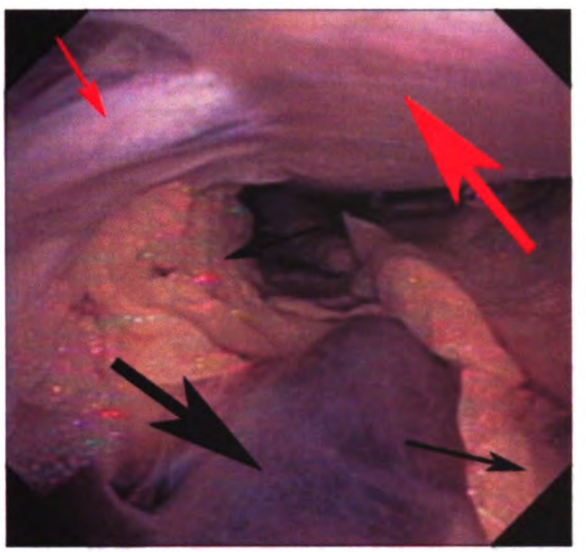

Figure 4: Epiduroscopy. The epidural space ventral to the spinal cord, looking caudally. Top of the picture is dorsal. Fluid has been injected through the biopsy channel, allowing the anatomical structures to be seen. The video-endoscope is at the level of an inter-vertebral space, indicated by the presence of a right ventral nerve root (small red arrow). Note the ventral internal vertebral venous plexus (large black arrow), the ventral aspect of the dura mater (large red arrow) and epidural fat (small black arrows).

Myeloscopy

After incision of the dura and the arachnoid mater, CSF escaped. As soon as the endoscope was inserted into the subarachnoid space and the pre-placed sutures were tightened, the CSF leakage was greatly reduced. Once the endoscope was introduced into the subarachnoid space, the instrument was advanced caudally along the dorsal aspect of the spinal cord. The endoscope could also be positioned on the lateral and ventral aspects of the spinal cord, allowing 360° exploration of the subarachnoid space. The following anatomical structures could reliably be identified: the trabeculations between the pia and the arachnoid mater; dorsal and ventral nerve roots with the associated blood vessels; blood vessels within the pia mater; dorsal median and lateral sulci; the denticulate ligaments; the external branch of the accessory nerve. Orientation

within this fluid filled space was noticeably easier than in the epidural space (Figure 5,6,7). In contrast to the epidural space, the nerve roots in the subarachnoid space divide in a fanlike fashion before entering or leaving the spinal cord; therefore, the nerve roots spread out over a longer distance (Figure 7). Of course, the distance between the centers of two nerve roots is the same as we reported for the epidural space.

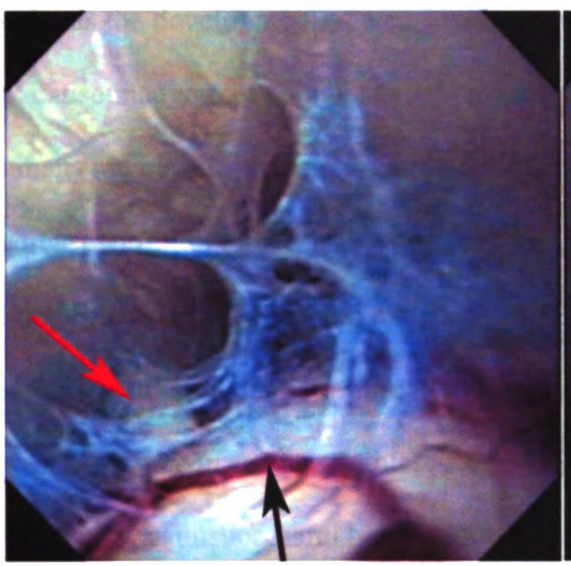

Figure 5: Myeloscopy during insertion of the endoscope. Subarachnoid space dorsal to the spinal cord, looking caudally. Top of the picture is dorsal. Note the arachnoid mater/dura mater dorsally and the pia mater covered spinal cord ventrally. Intact trabeculations cross the subarachnoid space connecting the pia mater with the arachnoid mater. Note a right dorsal nerve root (red arrow) and blood vessels within the pia mater (black arrow).

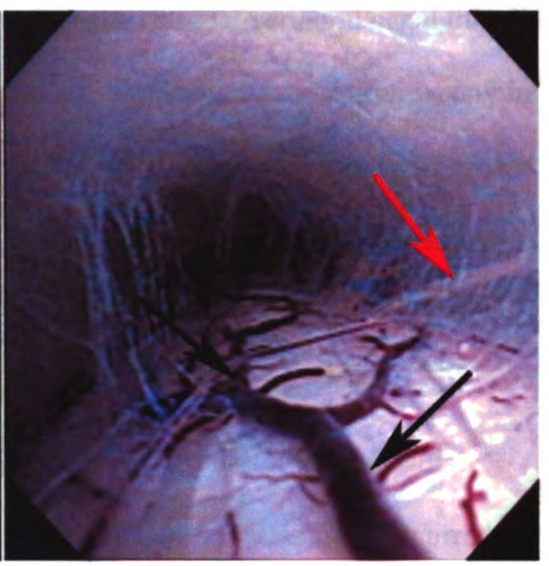

Figure 6: Myeloscopy during withdrawal of the endoscope. Subarachnoid space dorsal to the spinal cord, looking caudally. Top of the picture is dorsal. The arachnoid mater/dura mater is dorsal and the pia mater covered spinal cord is ventral. Some of the trabeculations have been broken down by the endoscope, improving viewing. Note a left dorsal nerve root (red arrow) and blood vessels within the pia mater (black arrow).

Discussion

In humans, epidural and subarachnoid endoscopies are performed to diagnose vertebral canal conditions, including compression of the spinal cord (Tobita *et al.* 2003, Uchiyama *et al.* 1998). The purpose of the study reported here was to assess if cervical vertebral canal endoscopy (CVCE) was feasible in horses. The first step toward this goal was the development of a surgical approach to the cervical vertebral canal that did not cause inadvertent damage to the nervous tissues. Myeloscopy and epiduroscopy in humans are performed using minimally invasive techniques, because these approaches decrease morbidity after surgery of the cervical vertebrae and associated structures (Benglis *et al.* 2008, Saberski and Kitahata 1995, Uchiyama *et al.* 1998). For this reason, we attempted two minimally invasive approaches.

In *procedure 1* an endovascular dilator/introducer system was used. This technique was unsuccessful because substantial damage to the spinal cord occurred during penetration of the dura mater. Considerable force was necessary to advance the larger size dilators/introducers into the atlanto-occipital space, making it difficult to control the tip of the dilator during entry. Entrance into the subarachnoid space was confirmed by the appearance of fluid at the end of the dilator. Therefore, this procedure could not be used to identify entrance into the epidural space. Consequently, this approach was abandoned and an optical trocar was evaluated.

In *procedure 2* we used the Visiport® optical trocar, which allowed access to the subarachnoid and epidural space in 4 out of 10 cases without causing visible damage to the nervous tissue. However, various problems were encountered in the remaining six horses. It is necessary to press the trocar against the tissues in order for the crescent-

shaped blade to incise these tissues. When incising the dura mater, this pressure puts the dura mater in direct contact with the underlying spinal cord and consequently poses the risk of inadvertently cutting into the nervous tissue. This complication was observed in 3 horses. Another concern was the high resistance that was experienced during dissection through the nuchal ligament and the muscle layers, making meticulous movements of the trocar difficult. Additionally, the inability to close the dura mater once the procedure was completed resulted in CSF loss.

The open technique (*procedure 3*) was superior to both minimally invasive procedures and met our requirements for a surgical approach to the atlanto-occipital space: it allowed access to the cervical vertebral canal in all cases without causing visible damage to the nervous tissues. The 15 cm long incision made it possible to identify the important anatomical structures and their relationships. This allowed exact placement of the incision in the dorsal atlanto-occipital membrane, as well as the dura and arachnoid mater, and gentle, controlled insertion of the endoscope into the vertebral canal. This is particularly important when introducing the endoscope into the subarachnoid space. Another advantage of the open approach was the ability to place sutures in the dura mater that allowed sealing of the dura mater around the endoscope during myelosopy and closure of this layer after the endoscopy had been completed, thereby minimizing CSF loss.

Once a surgical approach had been developed, we assessed the ability of CVCE to allow viewing of anatomical structures within the subarachnoid and epidural space over the entire length of the cervical vertebral canal (atlanto-occipital space to C7/T1). The 110 cm working length of the endoscope made it possible to explore the

vertebral canal to and beyond C7 in all horses. Indeed, we were able to easily identify each spinal nerve and inter-vertebral space by reading the distance markers on the endoscope at the level of the incision into the atlanto-occipital membrane (epiduroscopy) or the dura mater (myeloscopy). With a 4.9 mm external diameter, the endoscope was small enough to be easily advanced within the epidural and the subarachnoid spaces. Video-endoscopes have a larger minimal external diameter when compared with fiberoptic instruments. Thus, the latter are used in humans for epiduroscopy and myeloscopy (Geurts *et al.* 2002, Tobita *et al.* 2003, Uchiyama *et al.* 1998). However, the larger size of horses allowed us to use a video-endoscope, which provides superior picture quality when compared to fiberoptic endoscopes.

Approaching the epidural space and performing epiduroscopy was easier than the equivalent procedure in the subarachnoid space, because the dura mater is not opened, thereby avoiding direct contact with the spinal cord and CSF loss. However, the visual field in the epidural space is limited to the amount of fluid that is injected. Immediately after insertion of the endoscope and injection of fluid, we were able to see the dorsal surface of the dura mater, connective tissue and fat in all horses. In order to maintain orientation when advancing the endoscope, the dorsal surface of the dura mater was kept in view. Once the first inter-vertebral space between C1 and C2 was reached (approximately 10 cm from the point of insertion) the dorsal nerve roots were seen. When the endoscope was advanced caudally, dorsal nerve roots were seen at each inter-vertebral space. The ventral aspect of the epidural space was also examined and features the ventral nerve roots, the ventral surface of the dura mater, connective tissue, fat and the ventral internal vertebral venous plexus.

Endoscopy of the subarachnoid space (myeloscopy) was more complex. The approach included opening of the dura and subarachnoid mater with a scalpel blade, carrying the risk of inadvertent damage to the underlying spinal cord and allowing CSF leakage. To reduce the chance of damaging the spinal cord, the pre-placed sutures were used to elevate the dura and the closely attached arachnoid mater during the incision. After the endoscope was introduced into the subarachnoid space, mild tension was placed on the sutures to minimize loss of CSF. Too much tension made it difficult to advance the endoscope through the incision. The loss of CSF was further reduced by placing the horses in a reverse Trendelenburg position. The presence of CSF in the subarachnoid space made the picture quality better and increased the field of view, when compared to the epidural space. This facilitated identification of anatomical structures and made orientation within the space easier. The trabeculations between the pia mater and the arachnoid mater partially obscured the view when the scope was advanced caudally. In contrast, when the endoscope was retracted, the trabeculations were partially broken down, allowing a better look at the anatomical structures (Figure 6,7). Structures that were easily identified included nerve roots, the spinal cord, blood vessels, dorsal sulci on the surface of the spinal cord, denticulate ligaments and the external branch of the accessory nerve (Figure 7). Myeloscopy may carry a higher risk than epiduroscopy, because of the abundance of blood vessels and the potential to directly touch the spinal cord and nerve roots with the endoscope.

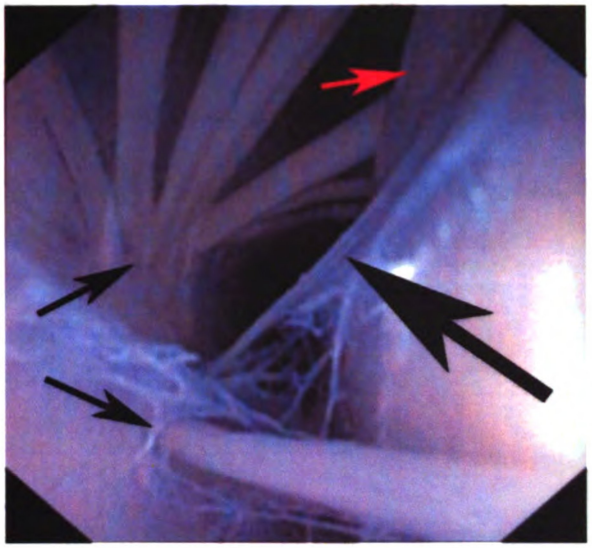

Figure 7: Myeloscopy. Right lateral aspect of the subarachnoid space, looking caudally. Top of the picture is dorsal. Note the right dorsal and ventral nerve roots (small black arrows), the denticulate ligament (large black arrow) and the external branch of the accessory nerve (small red arrow).

The present study demonstrates that myeloscopy and epiduroscopy are possible in adult horses and that the subarachnoid and epidural spaces can be explored over the entire length of the cervical vertebral canal. The open approach was the most appropriate method to gain access to the atlanto-occipital space. Although anatomical structures could be seen in greater detail and the orientation was easier in the subarachnoid space, myeloscopy is more complex than epiduroscopy. CVCE may become a valuable tool to localize the site of compression in horses with CVSM and aid in the diagnosis of other diseases and/or lesions of the spinal cord that cannot be seen using other imaging modalities. Studies in living horses are now necessary to evaluate the safety and efficacy and of epiduroscopy and myeloscopy.

In the third chapter I will describe the intra- and post-surgical observations in healthy adult horses that underwent CVCE, either epiduroscopy or myeloscopy.

Manufacturers' address

[1]Check-Flo® Introducers, Cook Medical Incorporated, IN, USA

[2]Visiport™ Plus RPF, Autosuture Covidien, MA, USA

CHAPTER 3

CERVICAL VERTEBRAL CANAL ENDOSCOPY IN THE HORSE: INTRA- AND POST-OPERATIVE OBSERVATIONS

Summary

Reason for performing study: Despite modern medical imaging, it is not possible to reliably identify the exact location of spinal cord compression in horses with cervical vertebral stenotic myelopathy. Vertebral canal endoscopy has been successfully used in humans and a technique for cervical vertebral canal endoscopy (CVCE) has been described in equine cadavers.

Objective: To determine the feasibility and safety of CVCE in healthy adult horses.

Methods: Six healthy adult horses were included in the study. Under general anesthesia, a flexible video-endoscope was introduced via the atlanto-occipital space into the epidural space (epiduroscopy, horses 1-3) or the subarachnoid space (myeloscopy, horses 4-6) and advanced to the 8th cervical nerve. After surgery, neurologic examinations were performed and lumbosacral cerebrospinal fluid was analyzed in horses that had undergone myeloscopy.

Results: All procedures were completed successfully and all horses recovered from anesthesia. Anatomical structures in the epidural space (including the dura mater, nerve roots, fat) and subarachnoid space (including the spinal cord, blood vessels, nerve roots, external branch of the accessory nerve) were identified. During

epiduroscopy, a significant increase in mean arterial pressure was recognized, when repeated injections of electrolyte solution in the epidural space were performed. In one horse of the myeloscopy group, subarachnoid hemorrhage and pneumorrhachis occurred, resulting in transient post-operative ataxia and muscle fasciculations. No complications during or after myeloscopy were observed in the other horses. CSF analysis indicated mild inflammation on day 7 with values approaching normal 21 days after surgery.

Conclusions: Endoscopic examination of the epidural and subarachnoid space from the atlanto-occipital space to the 8^{th} cervical nerve is possible and safe in healthy adult horses.

Potential relevance: CVCE might allow accurate identification of the site of compression in horses with cervical vertebral stenotic myelopathy and aid diagnosis of other lesions within the cervical vertebral canal.

Introduction

Vertebral canal endoscopy was first described in human cadavers (Burman 1931). Only a few years later, the procedure was described in 400 clinical patients that suffered from lower back pain. A variety of findings, including herniation of the nucleus pulposus, chronic adhesive arachnoiditis and tumors within the vertebral canal were documented (Pool 1942). In the following decades, the equipment and the surgical procedure improved continuously and today epidural endoscopy (epiduroscopy) and subarachnoid endoscopy (myeloscopy) are not only used to diagnose, but also to treat a number of conditions, including chronic back pain (Manchikanti *et al.* 2005, Manchikanti and Singh 2002, Tobita *et al.* 2003, Uchiyama *et al.* 1998, Warnke and Mourgela 2007).

More recently magnetic resonance imaging (MRI) and computed tomography (CT) have revolutionized the diagnosis of conditions associated with the spinal cord in humans. Therefore, they are the recommended diagnostic tools in cases where simple procedures are insufficient (Haig and Tomkins 2010, North American Spine Society 2007). However, even these techniques have limitations and, in a small number of inconclusive cases, vertebral canal endoscopy can add important diagnostic information (Tobita *et al.* 2003).

In horses, CT and MRI can acquire high-quality images of the head and cranial neck but cannot be used to image the caudal neck (Gold *et al.* 2008). This is of interest because cervical vertebral stenotic myelopathy (CVSM), the most common cause of ataxia in horses, occurs frequently in the caudal cervical vertebral canal (Papageorges *et al.* 1987, Powers *et al.* 1986, Reed *et al.* 1981).

The standard diagnostic imaging modality in cases of CVSM is myelography.

While this procedure is useful in recognizing vertebral canal stenosis, it frequently fails to identify the exact site of spinal cord compression (Hudson and Mayhew 2005, van Biervliet *et al.* 2004b). Precise localization of the compression is critical when surgical treatment is contemplated (Moore *et al.* 1993).

Additionally, the caudal equine neck can be the site of other conditions, such as epidural hematomas and tumors, which cannot be diagnosed ante-mortem with the imaging tools currently available (Gold *et al.* 2008). It is possible that cervical vertebral canal endoscopy (CVCE) will prove to be useful for accurate identification of these lesions.

In a previous paper, we showed that endoscopy of the cervical epidural and subarachnoid space of adult cadaveric horses is possible and anatomical structures in both spaces can be clearly seen. The purpose of his study was to assess the feasibility and safety of CVCE, including epiduroscopy and myeloscopy under general anesthesia, in healthy adult horses.

Material and methods

Horses

Six horses (4 mares, 2 geldings; mean age 11.2 years, age-range 4-20 years) weighing a mean of 506 kg (430-658 kg) were used in the study. There were three Thoroughbreds, one Standardbred, one Appaloosa and one Paint horse. The horses had no history of neurologic disease or problems related to the cervical vertebral canal. Furthermore, clinical and neurologic examination (Hahn *et al.* 1999) and a complete blood count failed to reveal any abnormalities. The study was approved by the Institutional Animal Care and Use Committee at Michigan State University.

Pre-surgical medication, anesthesia and recovery

Food was withheld from each horse for 6 hours prior to general anesthesia. Five minutes after sedation with intravenous (i.v.) xylazine hydrochloride (0.5mg/kg), methadone (0.1 mg/kg) was given i.v. Anesthesia was induced with i.v. guaifenesin (50 mg/kg)/thiopental (4 mg/kg) and the horses were intubated with 24-26 mm cuffed endotracheal tubes. Subsequently the horses were placed in right lateral recumbency on an equine hydraulic surgery table and anesthesia was maintained by use of isoflurane in oxygen at 1.8% (1.5 times the averaged equine minimal alveolar concentration of isoflurane) (Steffey *et al.* 1977) measured with an inhalant gas analyzer[1]. Lactated Ringer's Solution was administered IV at a rate of 5 ml/kg/h.

Throughout general anesthesia, the following parameters were measured every five minutes: Heart rate (HR), respiratory rate, systolic, mean (MAP) and diastolic arterial

pressure, measured end tidal carbon dioxide, end tidal isoflurane concentration and body temperature. Every 15 minutes an arterial blood gas analysis was performed, including arterial partial pressure of carbon dioxide ($PaCO_2$) and oxygen (PaO_2), pH, oxygen saturation (SaO_2) and electrolytes (Na^+, Ca^{2+}, K^+).

After completion of the procedure horses were positioned in right lateral recumbency in a padded 16 m^2 recovery stall. The head of horses that had undergone myeloscopy was kept in a slightly elevated position. This was done to decrease the pressure of CSF at the dura mater incision site. Once breathing became spontaneous, xylazine (0.2 mg/kg IV) was administered. After this, the recovery was observed and videotaped. Horses did not receive any assistance, unless they were unable to rise up or serious injury had to be avoided. Recovery was graded using a previously described scoring system (Table 1, (Mama *et al.* 1996)]).

Surgery

One hour prior to surgery, all horses received chloramphenicol[2] orally (50mg/kg) (Gronwall *et al.* 1986) and flunixin-meglumin[3] intravenously (1.1 mg/kg). Horses 1-3 underwent epiduroscopy, while myeloscopy was performed in horses 4-6. Access to the cervical vertebral canal was gained via the atlanto-occipital space. A 15-cm long skin incision was made on the dorsal midline, centered at the level of the cranial edge of the wings of the atlas.

Score	Definition
5 – Excellent	A single coordinated effort to stand with minimum to no ataxia
4 – Good	A single attempt to stand with some ataxia
3 – Fair	A quiet recovery with more than one attempt to stand
2 – Marginal	Uncoordinated attempts to stand with or without minor injuries such as superficial lacerations
1 – Poor	Multiple uncoordinated attempts to stand with life threatening injury

Table 1: Scoring system for recovery of horses after CVCE (after Mama *et al.* 1996)

With the exception of the nuchal ligament, which was separated from the left splenius capitis and left semispinalis capitis muscles and then retracted to the right side, all tissue layers were dissected in the midline, avoiding trauma to the muscles and thereby minimizing bleeding. This deep midline dissection included division of the right and left rectus capitis dorsalis major and minor muscles (Prange *et al.* 2010). For all procedures, a flexible video-endoscope with a working length of 110 cm and an external diameter of 4.9 mm was used (GIF-N180, Olympus America Inc., Melville, NY, USA).

Epiduroscopy: Once the dorsal atlanto-occipital membrane had been exposed, the endoscope was inserted into the epidural space. Irrigation with Plasma-Lyte®A^4 via the working channel of the endoscope was used to carefully distend the epidural space. This was necessary to see the anatomical structures and to allow gentle advancement of the endoscope caudally. Once the cm-markings on the endoscope indicated that the instrument had been introduced for 70 cm and the roots of the 8^{th} cervical nerve were seen, the endoscope was slowly withdrawn. The incision was closed in four layers, including the rectus capitis dorsalis major muscles, the incision between the nuchal ligament and the splenius capitis as well as the subcutaneous tissues and skin. The deep layers were sutured in a simple interrupted pattern using #2-0 polydioxanone, while the

skin was closed using a #0 polydioxanone in a continuous vertical mattress pattern. The skin incision was covered with an antimicrobial incise drape (3M™ Ioban™ 2 Antimicrobial Incise Drape). The total amount of Plasma-Lyte®A during the procedure was documented.

Myeloscopy: Before surgery, a CSF sample was collected from the lumbosacral area and submitted for cytology (Mayhew 1975). The surgical approach was made as described for epiduroscopy. Once the epidural space had been opened, the surgery table was tilted 20 degrees, elevating the head above the caudal aspect of the horse (reverse Trendelenburg position).This decreased the pressure of CSF in the cerebello-medullary cistern before opening the subarachnoid space. Then, the dura and the arachnoid mater were incised for a length of 1.5 cm and two simple interrupted sutures (#4-0 silk) were pre-placed, dividing the incision in the dura mater into three sections of equal length. The endoscope was then inserted into the subarachnoid space between the sutures which were gently tightened and clamped in position using a rubber stint and hemostats to minimize CSF loss during myeloscopy. Gentle irrigation with Plasma-Lyte®A via the working channel of the endoscope was used to enhance the view if it was obscured by the trabeculations in the subarachnoid space. The endoscope was advanced until the roots of the 8th cervical nerve were seen. Then the endoscope was slowly withdrawn, and the dura mater closed with #4-0 silk in a simple continuous pattern. At this point, horses were brought back into a horizontal position and the incision in the dura mater was checked for CSF leakage. The remainder of the incision was closed as described above.

Post-surgical phase: All horses received oral chloramphenicol for three days (50 mg/kg, q6h) and oral phenylbutazone[5] (2.2 mg/kg, q12h) for 7 days after surgery and were kept on stall rest for 21 days. A neurologic examination was performed daily for 7 days after recovery from the procedure, then weekly for another two weeks. In the horses that underwent myeloscopy, CSF was collected 7 and 21 days after surgery through the lumbosacral space and submitted for cytology. Skin sutures were removed 14 days after surgery. Horses after myeloscopy were fed from an elevated hay net for the first 14 days after the procedure.

Variables between groups were compared using a two-tailed t-test, a multiple measurements ANOVA with post-hoc Bonferroni correction was used for analysis of time-dependent data during anesthesia. Significance was set at $p \leq 0.05$.

Results

The surgical approach allowed access to the atlanto-occipital space in all horses and exposure of the relevant anatomic structures, including the dorsal atlanto-occipital membrane and the dura mater, was excellent. In three cases, intravenous injection of 200mg of thiopental was necessary when the nuchal ligament was retracted as the horses showed a sudden decrease in anesthetic depth. All CVCE procedures were successful, including introduction of the endoscope in the epidural and subarachnoid spaces and advancement of the instrument to the 8th cervical nerve.

Epiduroscopy

After the endoscope was introduced into the epidural space, the instrument was slowly advanced caudally, keeping the dura mater in the visual field. Plasma-Lyte®A was gently injected via the working channel to obtain a view of the anatomical structures. An average of 225 ml (200-275 ml) of electrolyte solution was necessary to complete the endoscopic procedure. In addition to the anatomical structures that can be seen in the epidural space of equine cadavers (fat, connective tissue, dorsal and ventral nerve roots crossing the epidural space, and the ventral internal vertebral venous plexus), small blood vessels on the surface of the dura mater and within the connective tissue and fat were apparent in the live horses. The angulation capabilities of the endoscope and slow rotation of the instrument around its long axis allowed 360 degree exploration of the epidural space, while the anatomical landmarks were used to identify the location of the tip of the endoscope in relation the spinal cord during the procedure. The average time necessary to complete the endoscopic examination of the epidural space, insertion to withdrawal of the endoscope, was 23 min (20-25 min, Table 2).

	Horses	Endoscopy Time (min)	Length of General Anesthesia (min)	Recovery Score
Epiduroscopy	#1	25	124	3
	#2	20	132	4
	#3	24	105	5
	Mean	23	120.3	4
Myeloscopy	#4	29	125	3
	#5	24	125	4
	#6	29	119	not scored
	Mean	27.3	123	3.5

Table 2: Time of general anesthesia, CVCE procedure and recovery scores

Complications during epiduroscopy

An increase in MAP and a decrease in HR were recognized at 15-20 minutes after beginning of the epiduroscopies. While the decrease in HR was not statistically significant, the MAP changes at 20 minutes were significantly higher when compared to measurements obtained at other times during the procedure ($p = 0.009$). These observations were linked with repeated injections of Plasma-Lyte®A into the epidural space via the working channel of the endoscope at the level of the 7th and 8th cervical nerve (Table 3, Figure 8).

		-5	0	5	10	15	20	25	30	35
Epiduroscopy	HR	41 ± 3.6	41.3 ± 3.2	41 ± 3.5	42 ± 4.1	33.3 ± 7.9	43 ± 4.9	35.7 ± 3.2	37.3 ± 2.9	38.7 ± 3.3
	MAP	78.7 ± 8.4	71.7 ± 2.7	72 ± 4.2	76. 7 ± 4.2	87. 3 ± 9.8	107.7 ± 16.6	67.3 ± 5.6	66 ± 3	72.7 ± 7.5
Myeloscopy	HR	37.3 ± 4.9	33.3 ± 4.5	35.3 ± 6.4	39 ± 9.5	39 ± 8.5	39.3 ± 8.3	37.3 ± 6.8	36.7 ± 5.7	36.3 ± 6.9
	MAP	91.7 ± 5.4	71 ± 4.2	81.7 ± 6.6	89 ± 12.9	83.7 ± 9.2	84 ± 8.7	78 ± 6.8	73.7 ± 4.3	78 ± 7.2

Table 3: HR and MAP of horses during myeloscopy and epiduroscopy. 0 indicates beginning of the endoscopy procedures, i.e., when the endoscope was inserted. Mean values and standard error of the mean.

Myeloscopy

Insertion of the endoscope into the subarachnoid space was a critical step of the procedure and required slow and meticulous movements in order to avoid injury to the spinal cord or the subarachnoid blood vessels. During the subsequent endoscopic exploration of the subarachnoid space, contact of the tip of the endoscope with blood

vessels and nervous tissues was avoided. The reverse Trendelenburg position and the pre-placed, clamped sutures in the dura mater limited the loss of CSF during the procedure. Injection of Plasma-Lyte®A during myeloscopy was necessary when the trabeculations between the pia mater and the arachnoid mater impaired the view. On average, 211 ml (range 165-260 ml) of electrolyte solution were needed for a myeloscopy. The view and thereby the orientation within the fluid-filled subarachnoid space was easier when compared to the epidural space, but 360 degree exploration of the space had to be carried out with more caution, as direct trauma to the spinal cord and the associated blood vessels can occur. It was possible to see the following structures in very good detail: the trabeculations between the pia and the arachnoid mater; dorsal and ventral nerve roots with the associated blood vessels; blood vessels within the pia mater; dorsal median and lateral sulci; the denticulate ligaments; the external branch of the accessory nerve (Prange *et al.* 2010). The average time for the endoscopy of the subarachnoid space, insertion to withdrawal of the endoscope, was 27 min (range = 24-29 min, Table 2). Although on average myeloscopy took slightly longer than epiduroscopy, this difference was not statistically significant ($p = 0.13$). The closure of the dura mater after completion of the myeloscopy prevented leakage of CSF once the horses were back in a horizontal position.

Complications during myeloscopy

Anesthesia was uneventful in all horses (Table 3, Figure 9). No complications were encountered during the myeloscopy procedures in horses 5 and 6. In horse 4, however, a

minor bleeding occurred at the insertion site of the endoscope. The blood caused mild impairment of the endoscopic view in the cranial aspect of the vertebral canal, but did not have an effect on the examination caudal to the 4th cervical nerve (C3-C4). When the endoscope was withdrawn, no active bleeding was apparent at the insertion site, indicating that the hemorrhage stopped during myeloscopy. Due to technical difficulties with the endoscope during the endoscopy in the same horse, air was able to enter the subarachnoid space. At the time of completion of the myeloscopy, the subarachnoid air extended approximately from the atlanto-occipital space to the 6th cervical nerve (C5-C6).

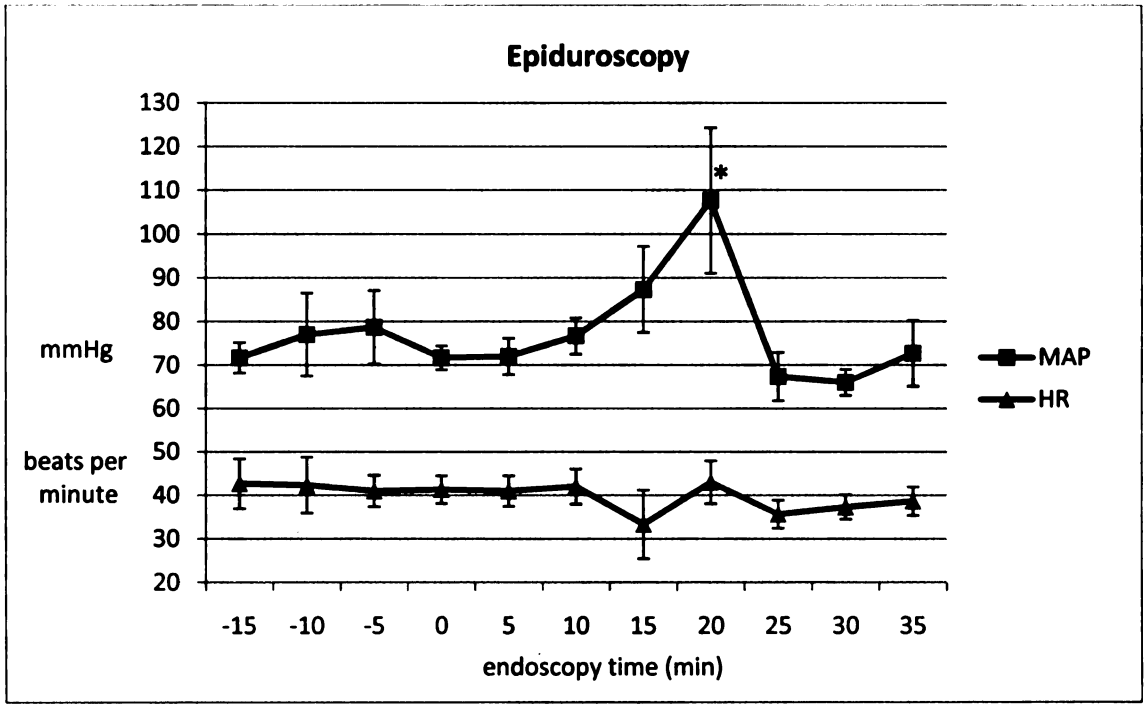

Figure 8: Mean arterial pressure and heart rate during epiduroscopy. 0 indicates beginning of the endoscopy procedures = insertion of the endoscope in the spaces. Mean values and standard error of the mean, significant results are indicated by *.

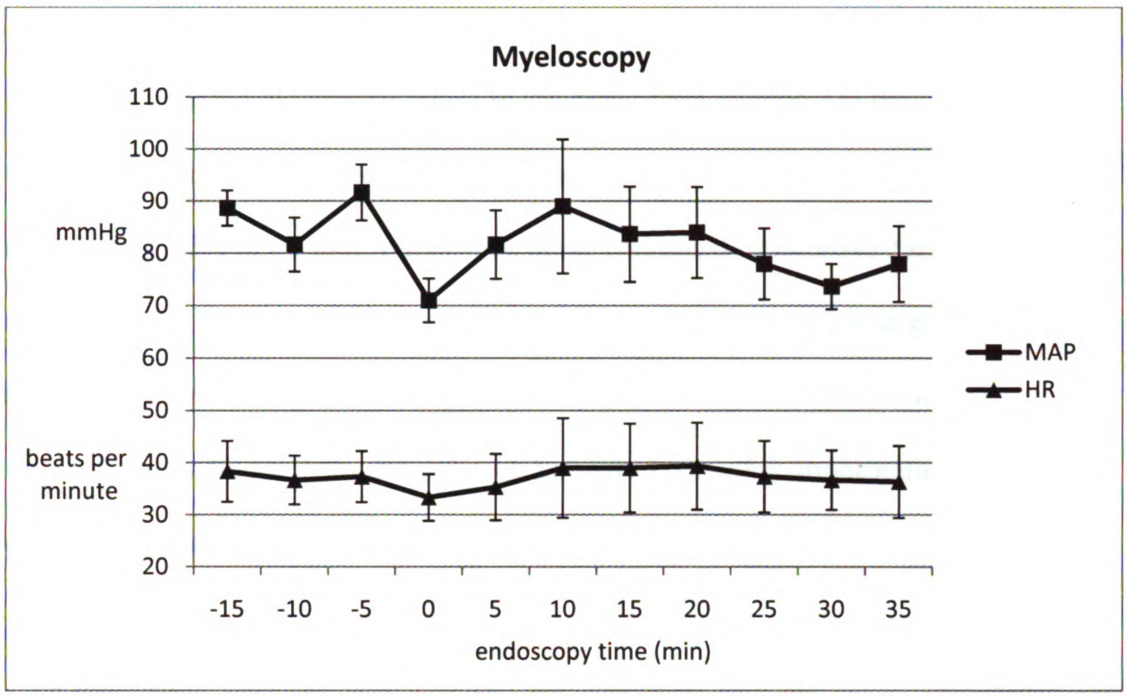

Figure 9: Mean arterial pressure and heart rate during myeloscopy. 0 indicates beginning of the endoscopy procedures = insertion of the endoscope in the spaces. Mean values and standard error of the mean.

Anesthesia and recovery

The average anesthesia time for horses undergoing epiduroscopy was 120 min (range 105-132 min) while it was 123 min (range 119-125 min) for myeloscopy ($p = 0.78$). Recovery was uneventful in five horses. The recovery of horse 6 was not scored because intervention of the anesthesiologist was necessary due to bleeding from an open i.v. catheter (Table 2).

Post-surgical phase

Neurological examinations after surgery were normal in all horses, with the exception of horse 4, where intra-operative hemorrhage and pneumorrhachis had occurred. This horse showed grade 3/4 grade ataxia and 1/4 paresis in all four limbs (Mayhew *et al.* 1978) on day 1 after surgery. Furthermore, diffuse muscle fasciculations, which became

more obvious when muscle groups were activated, were observed. Offering food, for example, increased the fasciculations in the area of the muzzle. On day 2 after surgery, the muscle fasciculations had decreased markedly, whereas the ataxia was still easily observable (2.5/4 in all four limbs). The horse continued to improve daily and on day 4 muscle fasciculations could only be seen in the triceps and ataxia was graded as 1/4 in all four legs. Seven days after the procedure the neurologic examination was normal. Beside some stiffness in the cranial neck in horse 1, no other abnormalities were observed in the other horses after CVCE.

CSF analysis

Collection of CSF at the lumbosacral space under general anesthesia was successful in horses 5 and 6, whereas no sample could be obtained from horse 4. Therefore, horse 4 was excluded from further CSF analysis. Analysis of CSF seven days after surgery showed an increase of protein in horses 5 and 6 and a mild increase in the nucleated cell count in horse 6. After 21 days, the protein concentration approached normal levels and the nucleated cell counts were back within reference ranges (Table 4).

	Horses	Day 0	Day 7	Day 21
Microprotein (g/dl)	#5	57	110	58
	#6	84	467	142
Nucleated Cell Count (/µl)	#5	3	1	8
	#6	1	45	2

Table 4: CSF analysis in horses 5 and 6 after myeloscopy

Discussion

In the study presented here, we evaluated the feasibility and safety of CVCE in healthy horses, particularly the effects of the procedures on the horses during surgery, anesthetic recovery and the post-surgical period. Epiduroscopy and myeloscopy were successfully completed in all cases.

The epiduroscopy approach was least complex because it did not require incising the dura mater. Furthermore, during epiduroscopy the dura mater is positioned between the endoscope and the spinal cord, protecting this important structure. Advancing the endoscope from the atlanto-occipital space to the 8^{th} cervical nerve was easily accomplished and anatomical structures in the epidural space were clearly identified. If space-occupying lesions had been present in the epidural space, identification and even biopsy would have been feasible. In humans, it is even possible to treat diseases in the epidural space, for example by performing epidural adhesiolysis and injecting therapeutic agents such as corticosteroids to treat inflamed nerve roots (Geurts *et al.* 2002, Trescot *et al.* 2007).

Entering the subarachnoid space required control of CSF fluid leakage. This was accomplished by pre-placement of sutures in the dura mater prior to insertion of the endoscope, clamping them to appose the incision around the endoscope, and placing the horses in the reverse Trendelenburg position. In horse 4, bleeding was encountered at the site of endoscope insertion into the subarachnoid space. Tissue injury is most likely to occur during introduction of the endoscope in the subarachnoid space. Therefore, we recommend caution during this step of the procedure. Once the endoscope had entered

the subarachnoid space, anatomic structures were easily and clearly seen and advancing the endoscope to the eighth cervical nerve root while avoiding trauma to vessels and nerves was not difficult.

Completion of the endoscopic procedures within 30 minutes and an anesthetic time of not more than 2 hours make this procedure practical. During anesthesia, no major problems were encountered, and there were no complications during anesthetic recovery related to the endoscopy. Furthermore, with the exception of one horse, animals were neurologically normal when evaluated 24 hours after surgery. These data suggest that myeloscopy and epiduroscopy can be safely performed in healthy adult horses. Studies with larger numbers of horses are needed to extrapolate this information to the general population. Also, the safety and usefulness of CVCE needs to be evaluated in horses with cervical vertebral canal diseases.

Complications during epiduroscopy

In the three horses that underwent epiduroscopy, statistically significant hypertension was recognized about 15-20 minutes after the beginning of the endoscopic procedure (Table 3, Figure 8). During the same time period, mean heart rate decreased, but this bradycardia was not statistically significant. In all cases, the observations were temporally associated with repeated injections of electrolyte solution into the epidural space at the level of the 7^{th} and 8^{th} cervical nerve. In humans, it is recommended that no more than 1 ml of fluid per 1-2 seconds is injected (Gill and Heavner 2005). Rapid injection of fluids in the epidural space can cause transient increase in epidural pressure in humans and animals, including the horse (Iff *et al.* 2009). Because the dura mater is a

moveable membrane, it transfers the increased pressure in the epidural space to the subarachnoid space, which ultimately causes increased CSF and intracranial pressure (Buffington and Nystrom 2006, Gill and Heavner 2005, Shah 1981). A possible complication of increased intracranial pressure (ICP) is the so-called 'Cushing Reflex', which leads to hypertension, bradycardia and apnea (Agrawal *et al.* 2008). We speculate that the cardiovascular observations were caused by this reflex. Future studies that include measurements of the ICP are necessary to confirm or reject this possibility. We recommend slow injection of fluids during this procedure, with monitoring of blood pressure, especially when areas of interest are being examined.

Complications during myeloscopy

There were no complications in 2 of the 3 horses. In horse 4, however, there was subarachnoid air and hemorrhage. In humans, causes for this uncommon phenomenon include trauma, respiratory conditions that cause high intrathoracic pressures and iatrogenic manipulations (Oertel *et al.* 2006). Even though the condition is usually benign and responds to treatment of the underlying cause, about 10% of the cases show neurologic signs that are attributable to the pneumorrhachis (Chaichana *et al.* 2010, Uemura *et al.* 2000). Iatrogenic damage to radicular vessels leading to subarachnoid bleeding has been reported to be as high as 26% in human patients after lumbar puncture, causing clinical signs in only a small number of these (Breuer *et al.* 1982, Park *et al.* 2007). Extensive bleeding can lead to epidural hematomas. The clinical presentation of hematomas include acute onset of pain at the level of the hemorrhage, motor paralysis and sensory deficits (Kreppel *et al.* 2003). To our knowledge, no

information about clinical signs of adult horses with subarachnoid hemorrhage or air is available in the literature. In horse 4, subarachnoid air and hemorrhage did not affect anesthesia or anesthetic recovery, but neurologic signs were observed after surgery in this case. Because both subarachnoid bleeding and pneumorrhachis occurred during myeloscopy in this horse, it is not possible to specifically identify the cause of the transient neurologic signs.

CSF loss

Standing healthy horses tolerate withdrawal of more than 100 ml CSF (Spinelli *et al.* 1968) without exhibiting clinical signs. Also, the ICP in horses changes substantially depending on the position of the head in relation to the body (Brosnan *et al.* 2002a, Brosnan *et al.* 2002b). These studies suggest that horses are able to tolerate loss of small amounts of CSF. In humans, though, CSF leakage from lesions in the dura mater (after lumbar puncture, trauma, etc.) can cause a variety of clinical signs. As these tears in the dura mater are frequently located in the lumbosacral region, intensification of the clinical signs occurs when the patient stands up. Chronic CSF leakage is known to cause orthostatic headache, nausea, neck pain or stiffness, "sagging" of the brain towards the foramen magnum and potentially herniation of the brainstem (Couch 2008, Schievink 2000). In contrast, the poll region of standing horses is the highest point of the body as long as their head is elevated. Therefore, the fluid pressure at the site of the surgical approach was low once the horses had recovered from anesthesia, decreasing the chances of CSF leakage. Feeding from hay nets encouraged horses to keep their head elevated.

Thus, pre-placement of sutures in the dura mater and the reverse Trendelenburg position during surgery, an elevated head position in anesthetic recovery, and use of elevated hay nets post-operatively appeared to be effective in preventing excessive CSF loss in our horses.

CSF fluid analysis

Samples of CSF were only collected in the horses that underwent myeloscopy, as the subarachnoid space was not opened in the epiduroscopy cases. As collection of the pre-surgical sample was unsuccessful in horse 4, the case was excluded from further CSF analysis. In the remaining 2 horses CSF protein increased, and in one horse nucleated cell count increased on day 7 after surgery. These parameters had returned towards baseline on day 21 after surgery. These data demonstrate that myeloscopy induces mild, transient inflammation not accompanied by neurologic signs.

Summary

This study demonstrates that myeloscopy and epiduroscopy are feasible and safe in healthy adult horses. Myeloscopy and epiduroscopy were completed within 30 minutes and important structures in the entire cervical vertebral canal were seen. No major complications were encountered during anesthesia and anesthetic recovery. All horses but one were free of neurologic signs after surgery. We hypothesize that myeloscopy will be the most beneficial in accurate assessment of spinal cord compression with CVSM, because the view in this fluid-filled space is more likely to allow identification

of narrowing of the vertebral canal. Future studies are needed to determine the clinical usefulness and safety of the procedure in horses with cervical vertebral canal diseases.

In chapter 4, I will briefly summarize the results of both parts of the study and outline some ideas future research projects and potential applications for CVCE in horses.

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Manufacturers' addresses

1 BSM-2353 Life Scope A®, Nihon Kohde, Tokyo, Japan

2 Viceton®, Bimeda, Inc., LeSueur, MN, USA

3 FlunixiJect®, Butler Animal Health Supply, Dublin, OH, USA

4 Plasma-Lyte® A, Baxter Healthcare Corporation, Deerfield, IL, USA

5 Phenylbutazone, Bimeda, Inc., LeSueur, MN, USA

CHAPTER 4

CONCLUSIONS AND FUTURE PERSPECTIVES

Despite the significant progress in medical diagnostic imaging over the last 40 years (Damadian 1971, Hounsfield 1973), certain diseases of the spinal cord remain an intractable challenge for physicians as well as for veterinarians. In human medicine, vertebral canal endoscopy has been used for over 60 years to provide information in cases where non-invasive imaging modalities fail to provide a diagnosis. The purpose of this research project was to investigate if cervical vertebral canal endoscopy is a safe and feasible procedure in healthy adult horses.

In the first part of the study, I developed a surgical approach to the epidural and subarachnoid space via the atlanto-occipital foramen and described the endoscopic anatomy of the cervical epidural and subarachnoid space. The second part of the study demonstrated that epiduroscopy and myeloscopy are feasible and safe in healthy adult horses. Overall, the epiduroscopies were easier to perform than the myeloscopies and seem to bear less risk for the patient. However, in cases of CVSM, it is questionable if the limited view in the epidural space will allow identification of vertebral canal stenosis whereas the excellent images obtained during myeloscopy are more likely to provide this information. The complications associated with myeloscopy appear to be higher. In particular, the risk of direct damage to the nervous tissue or subarachnoid blood vessels can cause transient and possibly even permanent neurologic signs.

A number of follow up projects are possible, but it is important to use the information gained to answer *the* question that initiated the project: "Is CVCE in general, and *myeloscopy* in particular, a reliable and accurate tool to diagnose the exact

compression site in horses with CVSM and how do neurologically compromised horses tolerate the surgery?" A basic study outline should include the following: Ten horses previously diagnosed with spinal ataxia due to CVSM (e.g. by a referring veterinarian) undergo standardized clinical, neurologic and radiographic examination, including calculation of intra- and inter-vertebral ratios. A myelogram is performed under general anesthesia and the recovery scored as described before (Mama *et al.* 1996). Neurologic status is assessed daily for 7 days, followed by weekly neurologic examinations for the subsequent three weeks. At this point, the horses are taken to surgery for myeloscopy. The site of compression is identified using distance measurements on the endoscope and is documented by video and lateral radiographs. Scoring of the recovery and the post-surgical assessment are done exactly as it was for myelography, making observations between the two procedures comparable. After 4 weeks, the horses will be euthanized and histopathology of the cervical spinal cord in areas of suspected compression sites (vertebral ratios, myelography and myeloscopy) will be done. Using histopathology as the gold standard, the value of myeloscopy for identifying clinically relevant vertebral canal stenosis can be compared to the commonly used diagnostic tool, the myelography. Furthermore, this study design would allow comparison of recovery and post-surgical course between myelography and myeloscopy in the same horses.

As the optical assessment of subarachnoid space narrowing and associated spinal cord compression during myeloscopy is subjective, it might not be reliable in cases of mild to moderate stenosis. However, these cases are the best surgical candidates and an objective measurement tool is desirable. In humans, trans-endoscopic ultrasound probes are used to evaluate the tissues in the bony calvarium during endoscopic examination of

the ventricular system of the brain (Resch 2003, Resch *et al.* 1997). Therefore, an ultrasound probe with a diameter of 6F and a cable length of 192cm is fed though and endoscope and adds a 360 degree axial view of the probe's tip position to the image of the endoscope. This "brain-radar" or "mini-CT" would allow measurements of the vertebral canal diameter and therefore provide objective data about potential sites of narrowing.

The possibilities for *epiduroscopy* are different, but not less interesting, especially as this procedure appears to be less risky as long as fluid injections during the endoscopy are performed slowly. As described in chapter 1, arthritis of the facet joints in the caudal cervical vertebrae has been associated with neurologic signs in horses, but the severity of radiographic changes does not correlate with clinical signs (Down and Henson 2009). This is partially due to the accompanying soft tissue pathology that can cause the actual impingement on the nerve roots and/or the spinal cord (e.g. synovial cysts). Epidural endoscopy could identify soft tissue abnormalities and allow targeted drug application and drainage of cysts. The latter could be done by trans-endoscopic cystocentesis, the use of trans-endoscopic diode or Nd:YAG lasers. Trans-endoscopic lasers have been applied in horses for ablation of upper respiratory cysts (Tate 2004) and in humans for epidural adhesiolysis (Ruetten *et al.* 2002). While the avoidance of thermal damage to the surrounding tissues would be challenging, the reports of successful epidural adhesiolysis in humans are encouraging.

In addition, epiduroscopy could be used to place an epidural catheter in a desired location, for example next to the spinal nerve roots that supply the brachial plexus in horses that underwent a painful procedure in a front limb (e.g. fracture repair). This

catheter would remain in the epidural space after endoscope removal, allowing targeted administration of drugs to this nerve root over a course of several days, reducing the risk of laminitis in the opposite limb.

BIBLIOGRAPHY

Agrawal, A., Timothy, J., Cincu, R., Agarwal, T. and Waghmare, L. B. (2008) Bradycardia in neurosurgery. *Clin Neurol Neurosurg* 110, 321-327.

Andrews, F. M. (2004) Cerebrospinal Fluid Evaluation. In: *Equine Internal Medicine*, Eds: Reed, S. M., Bayly, W. M. and Sellon, D. C., Elsevier, St. Louis. pp 542-546.

Beltrutti, D., Groen, G. J., Saberski, L. R., Sander-Kiesling, G., Schuetze, G. and Weber, G. (2006) Consensus Paper. In: *Consensus Conference of the WISE*, Eds, World Initiative of Spinal Endoscopy, Graz, Austria

Benglis, D. M., Guest, J. D. and Wang, M. Y. (2008) Clinical feasibility of minimally invasive cervical laminoplasty. *Neurosurg Focus* 25, E3.

Berry, S. (1999) Spinal cord compression secondary to hemangiosarcoma in a saddlebred stallion. *Can Vet J* 40, 886-887.

Blythe, L. L. (1987) Neurologic examination of the horse. *Vet Clin North Am Equine Pract* 3, 255-281.

Boehme, G. (2004a) Huellen des Zentralnervensystems In: *Lehrbuch der Anatomie der Haustiere-Band IV, Nervensystem, Sinnesorgane, Endokrine Druesen*, 4 edn., Eds: Nickel, R., Schummer, A. and Seiferle, E., Paul Parey, Berlin. pp 198-208.

Boehme, G. (2004b) Rueckenmark. In: *Lehrbuch der Anatomie der Haustiere-Band IV, Nervensystem, Sinnesorgane, Endokrine Druesen*, edn., Eds: Nickel, R., Schummer, A. and Seiferle, E., Paul Parey, Berlin. pp 28-62.

Boswell, M. V., Shah, R. V., Everett, C. R., Sehgal, N., McKenzie Brown, A. M., Abdi, S., Bowman, R. C., 2nd, Deer, T. R., Datta, S., Colson, J. D., Spillane, W. F., Smith, H. S., Lucas, L. F., Burton, A. W., Chopra, P., Staats, P. S., Wasserman, R. A. and Manchikanti, L. (2005) Interventional techniques in the management of chronic spinal pain: evidence-based practice guidelines. *Pain Physician* 8, 1-47.

Breuer, A. C., Tyler, H. R., Marzewski, D. J. and Rosenthal, D. S. (1982) Radicular vessels are the most probable source of needle-induced blood in lumbar puncture: significance for the thrombocytopenic cancer patient. *Cancer* 49, 2168-2172.

Brosnan, R. J., LeCouteur, R. A., Steffey, E. P., Imai, A. and Kortz, G. D. (2002a) Direct measurement of intracranial pressure in adult horses. *Am J Vet Res* 63, 1252-1256.

Brosnan, R. J., Steffey, E. P., LeCouteur, R. A., Imai, A., Farver, T. B. and Kortz, G. D. (2002b) Effects of body position on intracranial and cerebral perfusion pressures in isoflurane-anesthetized horses. *J Appl Physiol* 92, 2542-2546.

Buffington, C. W. and Nystrom, E. U. (2006) Hydrodynamics of the spinal epidural space in pigs determined by constant-flow methods. *Reg Anesth Pain Med* 31, 100-104

Burman, M. S. (1931) Myeloscopy or the direct visulization of the spinal canal and its contents. *J Bone Joint Surg Am* 13, 695-696.

Butler, J. A., Colles, C. M., Dyson, S. J., Kold, S. E. and Poulos, P. W. (2008) The Spine. In: *Clinical Radiology of the Horse*, edn., Eds: Butler, J. A., Colles, C. M., Dyson, S. J., Kold, S. E. and Poulos, P. W., Wiley-Blackwell, Chichester, West Sussex, United Kingdom

Chaichana, K. L., Pradilla, G., Witham, T. F., Gokaslan, Z. L. and Bydon, A. (2010) The clinical significance of pneumorachis: a case report and review of the literature. *J Trauma* 68, 736-744.

Clayton, H. M. and Townsend, H. G. (1989) Kinematics of the cervical spine of the adult horse. *Equine Vet J* 21, 189-192.

Cooper, R. G., Freemont, A. J., Hoyland, J. A., Jenkins, J. P., West, C. G., Illingworth, K. J. and Jayson, M. I. (1995) Herniated intervertebral disc-associated periradicular fibrosis and vascular abnormalities occur without inflammatory cell infiltration. *Spine (Phila Pa 1976)* 20, 591-598.

Couch, J. R. (2008) Spontaneous intracranial hypotension: the syndrome and its complications. *Curr Treat Options Neurol* 10, 3-11.

Curry, D. J. (2008) email communication.

Damadian, R. (1971) Tumor detection by nuclear magnetic resonance. *Science* 171, 1151-1153.

Dashfield, A. K., Taylor, M. B., Cleaver, J. S. and Farrow, D. (2005) Comparison of caudal steroid epidural with targeted steroid placement during spinal endoscopy for chronic sciatica: a prospective, randomized, double-blind trial. *Br J Anaesth* 94, 514-519.

de Lahunta, A. (1983) *Veterinary Neuroanatomy and Clinical Neurology*, edn., Saunders, Philadelphia.

de Lahunta, A. and Glass, E. (2009) Veterinary Neuroanatomy and Clinical Neurology. In: *Veterinary Neuroanatomy and Clinical Neurology*, 3 edn., Eds: de Lahunta, A. and Glass, E., Saunders, St. Louis, Missouri. pp 285-318.

DeBowes, R. M., Grant, B. D., Bagby, G. W., Gallina, A. M., Sande, R. D. and Ratzlaff, M. H. (1984) Cervical vertebral interbody fusion in the horse: a comparative study of bovine xenografts and autografts supported by stainless steel baskets. *Am J Vet Res* 45, 191-199.

Dellmann, H. D. and McClure, R. C. (1975) Equine Nervous System. In: *Sisson and Grossman's The Anatomy of the Domestic Animals*, edn., Eds: Getty, R., W. B. Saunders Company, Philadelphia, London, Toronto. pp 633-702.

Deniel, J. and de Antoni, M. D. (1998) Lumbar epidural endoscopy in lateral stenosis. In: *International Intradiscal Therapy Society Eleventh Annual Meeting*, edn., Eds, International Intradiscal Therapy Society.

Dezawa, A., Kitagawa, T., Katoh, K., Shibuya, I. and Kusano, S. (2005) Intraspinal Examination with a Spinal Fiberscope (Myelofiberscope). pp 131-139.

Di Chiro, G., Stein, S. C. and Harrington, T. (1972) Spontaneous cerebrospinal fluid rhinorrhea in normal dogs. Radioisotope studies of an alternate pathway of CSF drainage. *J Neuropathol Exp Neurol* 31, 447-453.

Dimock, W. W. and Errington, B. J. (1939) Incoordination of equidae: Wobblers. *J Am Vet Med Assoc* 95, 261-267.

Donawick, W. J., Mayhew, I. G. and Galligan, D. T. (1993) Results of a low-protein, low-energy diet and confinement on young horses with wobbles. In: *39th annual convention of the American Association of Equine Practitioners*, Lexington, KY.

Down, S. S. and Henson, F. M. (2009) Radiographic retrospective study of the caudal cervical articular process joints in the horse. *Equine Vet J* 41, 518-524.

Dyce, K. M., Sack, W. O. and Wensing, C. J. G. (2010) The Locomotor Aparatus. In: *Textbook of Veterinary Anatomy*, edn., Eds: Dyce, K. M., Sack, W. O. and Wensing, C. J. G., Saunders, St. Louis. pp 32-99.

Endo, T., Takahashi, T., Jokura, H. and Tominaga, T. (2010) Surgical treatment of spinal intradural arachnoid cysts using endoscopy. *J Neurosurg Spine* 12, 641-646.

Franz, S., Dadak, A. M., Moens, Y., Baumgartner, W. and Iff, I. (2008) Use of endoscopy for examination of the sacral epidural space in standing cattle. *Am J Vet Res* 69, 894-899.

Fritsch, E. W., Heisel, J. and Rupp, S. (1996) The failed back surgery syndrome: reasons, intraoperative findings, and long-term results: a report of 182 operative treatments. *Spine (Phila Pa 1976)* 21, 626-633.

Fujimoto, T., Giles, B. P., Replogle, R. E., Fujimoto, H., Miller, S. L. and Purdy, P. D. (2005) Visualization of sacral nerve roots via percutaneous intraspinal navigation (PIN). *AJNR Am J Neuroradiol* 26, 2420-2424.

Furr, M. and Andrews, F. M. (2008) Cerebrospinal fluid and the blood brain barrier. In: *Equine Neurology*, Eds: Reed, S. M. and Furr, M., Blackwell, Ames. pp 33-46.

Gellman, K. S. and Bertram, J. E. A. (2002) The equine nuchal ligament 2: passive dynamic energy exchange in locomotion. *Vet Comp Orthop Traumatol* 15, 7-14.

Gerber, H., Fankhauser, R., Straub, R. and Ueltschi, G. (1980) [Spinal ataxia in the horse, caused by synovial cysts in the cervial spinal cord]. *Schweiz Arch Tierheilkd* 122, 95-106.

Getty, R. (1975) Equine Osteology. In: *Sisson and Grossman's The Anatomy of the Domestic Animals*, edn., Eds: Getty, R., W. B. Saunders Company, Philadelphia, London, Toronto. pp 255-348.

Geurts, J. W., Kallewaard, J. W., Richardson, J. and Groen, G. J. (2002) Targeted methylprednisolone acetate/hyaluronidase/clonidine injection after diagnostic epiduroscopy for chronic sciatica: a prospective, 1-year follow-up study. *Reg Anesth Pain Med* 27, 343-352.

Gill, J. B. and Heavner, J. E. (2005) Visual impairment following epidural fluid injections and epiduroscopy: a review. *Pain Med* 6, 367-374.

Gold, J. R., Divers, T. J., Miller, A. J., Scrivani, P. V., Perkins, G. A., VanBiervliet, J. and de LaHunta, A. (2008) Cervical vertebral spinal hematomas in 4 horses. *J Vet Intern Med* 22, 481-485.

Gorchesky, M. S. (1999) Spinal Endoscopy. In, 1999 edn., Eds, Duval County Medical Society.

Grant, B. D., Bagby, G. W., Rantanen, N. and Trostle, S. S. (2003) The Thirteenth Annual American College of Veterinary Surgeons Symposium to be held October 9-12, 2003, in Washington, DC. *Veterinary Surgery* 32, 479-500.

Grant, B. D., Huggons, N., Bagby, G. W., Reed, S. M. and Robertson, J. T. (2007) Review of Surgical Treatment of Triple Level Cervical Cord Compression (12 Cases). In: *53rd Annual Convention of the American Association of Equine Practitioners,* International Veterinary Information Service, Orlando. pp 60-63.

Gronwall, R., Brown, M. P., Merritt, A. M. and Stone, H. W. (1986) Body fluid concentrations and pharmacokinetics of chloramphenicol given to mares intravenously or by repeated gavage. *Am J Vet Res* 47, 2591-2595.

Gupta, S. and Richardson, J. (2009) Epiduroscopy for low-back pain and radiculopathy. In: *Interventional Pain Management - A Practical Approach*, Eds: Baheti, D. K., Bakshi, S., Gupta, S. and Gehdoo, R. P., Jaypee Brothers Medical Publishers, Maryland Heights.

Hahn, C. N. (2004) Cervical vertebral malformation. In: *Equine internal medicine*, Eds: Reed, S. M., Bayly, W. M. and Sellon, D. C., Saunders, St. Louis. pp 603-606.

Hahn, C. N., Handel, I., Green, S. L., Bronsvoort, M. B. and Mayhew, I. G. (2008) Assessment of the utility of using intra- and intervertebral minimum sagittal diameter ratios in the diagnosis of cervical vertebral malformation in horses. *Vet Radiol Ultrasound* 49, 1-6.

Hahn, C. N., Mayhew, I. G. and MacKay, R. J. (1999) Examination of the Nervous System. In: *Equine Medicine and Surgery*, Eds: Colahan, P. T., Mayhew, I. G., Merritt, A. M. and Moore, J. N., Mosby, Chicago. pp 865-883.

Haig, A. J. and Tomkins, C. C. (2010) Diagnosis and management of lumbar spinal stenosis. *JAMA* 303, 71-72.

Haines, D. E., Harkey, H. L. and al-Mefty, O. (1993) The "subdural" space: a new look at an outdated concept. *Neurosurgery* 32, 111-120.

Hayek, S. M., Helm, S., Benyamin, R. M., Singh, V., Bryce, D. A. and Smith, H. S. (2009) Effectiveness of spinal endoscopic adhesiolysis in post lumbar surgery syndrome: a systematic review. *Pain Physician* 12, 419-435.

Hayes, T. E. (1987) Examination of cerebrospinal fluid in the horse. *Vet Clin North Am Equine Pract* 3, 283-291.

Heavner, J. E., Racz, G. B. and Raj, P. (1999) Percutaneous epidural neuroplasty: prospective evaluation of 0.9% NaCl versus 10% NaCl with or without hyaluronidase. *Reg Anesth Pain Med* 24, 202-207.

Hogan, Q. and Toth, J. (1999) Anatomy of soft tissues of the spinal canal. *Reg Anesth Pain Med* 24, 303-310.

Holmes, J. F. and Akkinepalli, R. (2005) Computed tomography versus plain radiography to screen for cervical spine injury: a meta-analysis. *J Trauma* 58, 902-905.

Hounsfield, G. N. (1973) Computerized transverse axial scanning (tomography). 1. Description of system. *Br J Radiol* 46, 1016-1022.

Hudson, N. P. H. and Mayhew, I. G. (2005) Radiographic and myelographic assessment of the equine cervical vertebral column and spinal cord. *Equine Veterinary Education* 17, 34-38.

Iff, I., Mosing, M. and Moens, Y. (2009) Pressure profile in the caudal extradural space of standing horses before and after extradural drug administration. *Vet J* 180, 112-115.

Igarashi, T., Hirabayashi, Y., Seo, N., Saitoh, K., Fukuda, H. and Suzuki, H. (2004) Lysis of adhesions and epidural injection of steroid/local anaesthetic during epiduroscopy potentially alleviate low back and leg pain in elderly patients with lumbar spinal stenosis. *Br. J. Anaesth.* 93, 181-187.

Jain, P., Gupta, A. K. and Sood, J. (2004) Epidurography/Epiduroscopy in Pain Management. *J Anaesth Clin Pharmacol* 20, 239-243.

Koenig, H. E. and Liebich, H.-G. (2007) Nervous System. In: *Veterinary Anatomy of Domestic Animals*, Eds: Koenig, H. E. and Liebich, H.-G., Schattauer, Stuttgart. pp 489-520.

Kreppel, D., Antoniadis, G. and Seeling, W. (2003) Spinal hematoma: a literature survey with meta-analysis of 613 patients. *Neurosurg Rev* 26, 1-49.

Liebich, H.-G. and Koenig, H. E. (2007) Axial Skeleton In: *Veterinary Anatomy of Domestic Animals*, Eds: Liebich, H.-G. and Koenig, H. E., Schattauer, Stuttgart.

Mama, K. R., Steffey, E. P. and Pascoe, P. J. (1996) Evaluation of propofol for general anesthesia in premedicated horses. *Am J Vet Res* 57, 512-516.

Manchikanti, L., Boswell, M. V., Rivera, J. J., Pampati, V. S., Damron, K. S., McManus, C. D., Brandon, D. E. and Wilson, S. R. (2005) [ISRCTN 16558617] A randomized, controlled trial of spinal endoscopic adhesiolysis in chronic refractory low back and lower extremity pain. *BMC Anesthesiol* 5, 10.

Manchikanti, L., Pampati, V., Bakhit, C. E. and Pakanati, R. R. (1999) Non-endoscopic and endoscopic adhesiolysis in post-lumbar laminectomy syndrome: a one-year outcome study and cost effectiveness analysis. *Pain Physician* 2, 52-58.

Manchikanti, L., Pampati, V., Fellows, B., Rivera, J. J., Damron, K. S., Beyer, C. and Cash, K. A. (2001) Effectiveness of percutaneous adhesiolysis with hypertonic saline neurolysis in refractory spinal stenosis. *Pain Physician* 4, 366-373.

Manchikanti, L. and Singh, V. (2002) Epidural lysis of adhesions and myeloscopy. *Curr Pain Headache Rep* 6, 427-435.

Masty, J. (2008) Overview of Neuroanatomy. In: *Equine Neurology*, Eds: Reed, S. M. and Furr, M., Blackwell, Ames. pp 3-32.

Mayhew, I. G. (1975) Collection of cerebrospinal fluid from the horse. *Cornell Vet* 65, 500-511.

Mayhew, I. G. (2008a) Cervical vertebral malformation and malarticulation of horses. In: *Large animal neurology*, 2nd edn., Eds: Mayhew, I. G., Blackwell, Oxford. pp 394-404.

Mayhew, I. G. (2008b) Neoplasms and other tumors. In: *Large animal neurology*, edn., Eds: Mayhew, I. G., Blackwell, Oxford. pp 385-391.

Mayhew, I. G., deLahunta, A., Whitlock, R. H., Krook, L. and Tasker, J. B. (1978) Spinal cord disease in the horse. *Cornell Vet* 68 Suppl 6, 1-207.

Mayhew, I. G., Whitlock, R. H. and Tasker, J. B. (1977) Equine cerebrospinal fluid: reference values of normal horses. *Am J Vet Res* 38, 1271-1274.

Moore, B. R., Holbrook, T. C., Stefanacci, J. D., Reed, S. M., Tate, L. P. and Menard, M. C. (1992) Contrast-enhanced computed tomography and myelography in six horses with cervical stenotic myelopathy. *Equine Vet J* 24, 197-202.

Moore, B. R., Reed, S. M., Biller, D. S., Kohn, C. W. and Weisbrode, S. E. (1994) Assessment of vertebral canal diameter and bony malformations of the cervical part of the spine in horses with cervical stenotic myelopathy. *Am J Vet Res* 55, 5-13.

Moore, B. R., Reed, S. M. and Robertson, J. T. (1993) Surgical treatment of cervical stenotic myelopathy in horses: 73 cases (1983-1992). *J Am Vet Med Assoc* 203, 108-112.

Muchow, R. D., Resnick, D. K., Abdel, M. P., Munoz, A. and Anderson, P. A. (2008) Magnetic resonance imaging (MRI) in the clearance of the cervical spine in blunt trauma: a meta-analysis. *J Trauma* 64, 179-189.

NorthAmericanSpineSociety (2007) Clinical Guidelines for Multidisciplinary Spine Care In: *Diagnosis and Treatment of Degenerative Lumbar Spinal Stenosis* Eds, North American Spine Society, Burr Ridge

Nout, Y. (2008) Central Nervous System Trauma. In: *Equine Neurology*, Eds: Reed, S. M. and Furr, M., Blackwell, Ames. pp 305-327.

Oertel, M. F., Korinth, M. C., Reinges, M. H., Krings, T., Terbeck, S. and Gilsbach, J. M. (2006) Pathogenesis, diagnosis and management of pneumorrhachis. *Eur Spine J* 15 Suppl 5, 636-643.

Ooi, Y., Satoh, Y., Inoue, K., Mikanagi, K. and Morisaki, N. (1981) Myeloscopy, with special reference to blood flow changes in the cauda equina during Lasegue's test. *Int Orthop* 4, 307-311.

Ooi, Y., Satoh, Y., Sugawara, S., Mikanagi, K. and Morisaki, N. (1977) Myeloscopy. *International Orthopaedics* 1, 107-111.

Oswald, J., Love, S., Parkin, T. D. and Hughes, K. J. (2010) Prevalence of cervical vertebral stenotic myelopathy in a population of thoroughbred horses. *Vet Rec* 166, 82-83.

Papageorges, M., Gavin, P. R., Sande, R. D., Barbee, D. D. and Grant, B. D. (1987) Radiographic and myelographic examination of the cervical vertebral column in 306 ataxic horses. *Veterinary Radiology & Ultrasound* 28, 53-59.

Park, J. H., Shin, K. M., Hong, S. J., Kim, I. S. and Nam, S. K. (2007) Subacute spinal subarachnoid hematoma after spinal anesthesia that causes mild neurologic deterioration. *Anesthesiology* 107, 846-848.

Pool, J. L. (1942) Myeloscopy: Intraspinal Endoscopy. *Surgery* 11, 169-182.

Powers, B. E., Stashak, T. S., Nixon, A. J., Yovich, J. V. and Norrdin, R. W. (1986) Pathology of the vertebral column of horses with cervical static stenosis. *Vet Pathol* 23, 392-399.

Prange, T., Derksen, F. J., Stick, J. A. and Garcia-Pereira, F. L. (2010) Endoscopic anatomy of the cervical vertebral canal in the horse: a cadaver study. *Equine Vet J.*

Reed, S. M. (2007) Equine Cervical Myelopathy - Surgical, Medical, and Dietary Management of Affected Horses and Outcome. In: *The North American Veterinary Conference*, Eds, North American Veterinary Conference, Orlando, FL. pp 160-162.

Reed, S. M., Bayly, W. M., Traub, J. L., Gallina, A. and Miller, L. M. (1981) Ataxia and paresis in horses. Part I. Differential diagnosis. *Compendium on Continuing Education for the Practicing Veterinarian* 3, 12.

Reed, S. M., Grant, B. D. and Nout, Y. (2008) Cervical Vertebral Stenotic Myelopathy. In: *Equine Neurology*, Eds: Reed, S. M. and Furr, M., Blackwell, Iowa. pp 283-298.

Resch, K. D. (2003) Endo-neuro-sonography: first clinical series (52 cases). *Childs Nerv Syst* 19, 137-144.

Resch, K. D., Perneczky, A., Schwarz, M. and Voth, D. (1997) Endo-neuro-sonography: principles of 3-D technique. *Childs Nerv Syst* 13, 616-621.

Richardson, J., Kallewaard, J. W. and Groen, G. J. (2008) Epiduroscopy and endoscopic adhesiolysis. Eds, Bradford Royal Infirmary. pp.

Rodriguez, F., Forga, J., Herraez, P., Andrada, M. and Fernandez, A. (1998) Metastatic melanoma causing spinal cord compression in a horse. *Vet Rec* 142, 248-249.

Rooney, J. R. (1977) Disorders of the nervous system In: *Biomechanics of lameness in horses*, Eds: Rooney, J. R., Robert E. Krieger Publishing Company, Huntington, New York. pp 219-233.

Ruetten, S., Meyer, O. and Godolias, G. (2002) Application of holmium:YAG laser in epiduroscopy: extended practicabilities in the treatment of chronic back pain syndrome. *J Clin Lser Med Surg* 20, 203-206.

Saberski, L. and Kitahata, L. (1996) Persistent radiculopathy diagnosed and treated with epidural endoscopy. *Journal of Anesthesia* 10, 292-295.

Saberski, L. R. (2008) Video conference.

Saberski, L. R. and Brull, S. J. (1995) Spinal and epidural endoscopy: a historical review. *Yale J Biol Med* 68, 7-15.

Saberski, L. R. and Kitahata, L. M. (1995) Direct visualization of the lumbosacral epidural space through the sacral hiatus. *Anesth Analg* 80, 839-840.

Schievink, W. I. (2000) Spontaneous spinal cerebrospinal fluid leaks: a review. *Neurosurg Focus* 9, e8.

Schott, H. C., Major, M. D., Grant, B. D. and Bayly, W. M. (1990) Melanoma as a cause of spinal cord compression in two horses. *J Am Vet Med Assoc* 196, 1820-1822.

Schuetze, G. (2006) Epiduroscopy for diagnosis and treatment of spinal pain syndromes. In: *12th International Pain Clinic World Society of Pain Clinicians*, Eds: Beltrutti, D. and Varassi, G., World Society of Pain Clinicians, Turin, Italy. p 215

Schuetze, G. (2008) *Epiduroscopy-Spinal Endoscopy*, edn., Springer, Heidelberg.

Schuetze, G. (2010) Epiduroscopy: Method and retrospective review of 165 epiduroscopies, Schuetze, G., Schmerzzentrum Iserlohn.

Shah, J. L. (1981) Influence of cerebrospinal fluid on epidural pressure. *Anaesthesia* 36, 627-631.

Shimoji, K., Fujioka, H., Onodera, M., Hokari, T., Fukuda, S., Fujiwara, N. and Hatori, T. (1991) Observation of spinal canal and cisternae with the newly developed small-diameter, flexible fiberscopes. *Anesthesiology* 75, 341-344.

Spinelli, J., Holliday, T. and Homer, J. (1968) Collection of large samples of cerebrospinal fluid from horses. *Lab Anim Care* 18, 565-567.

Steffey, E. P., Howland, D., Jr., Giri, S. and Eger, E. I., 2nd (1977) Enflurane, halothane, and isoflurane potency in horses. *Am J Vet Res* 38, 1037-1039.

Stern, E. L. (1936) The spinascope: a new instrument for visualizing the spinal canal and its contents. *Medical Record (NY)* 143, 31-32.

Tate, J. L. P. (2004) Transendoscopic laser ablation of upper respiratory cysts in 12 horses, 1993-2003. In, 1 edn. Eds: Bartels, K. E., Bass, L. S., de Riese, W. T. W., Gregory, K. W., Hirschberg, H., Katzir, A., Kollias, N., Madsen, S. J., Malek, R. S., McNally-Heintzelman, K. M., Paulsen, K. D., Robinson, D. S., Tate, L. P., Jr, Trowers, E. A. and Wong, B. J., SPIE, San Jose, CA, USA. pp 354-358.

Tobita, T., Okamoto, M., Tomita, M., Yamakura, T., Fujihara, H., Baba, H., Uchiyama, S., Hamann, W. and Shimoji, K. (2003) Diagnosis of spinal disease with ultrafine flexible fiberscopes in patients with chronic pain. *Spine (Phila Pa 1976)* 28, 2006-2012.

Trescot, A. M., Chopra, P., Abdi, S., Datta, S. and Schultz, D. M. (2007) Systematic review of effectiveness and complications of adhesiolysis in the management of chronic spinal pain: an update. *Pain Physician* 10, 129-146.

Tyler, C. M., Davis, R. E., Begg, A. P., Hutchins, D. R. and Hodgson, D. R. (1993) A survey of neurological diseases in horses. *Aust Vet J* 70, 445-449.

Uchiyama, S., Hasegawa, K., Homma, T., Takahashi, H. E. and Shimoji, K. (1998) Ultrafine flexible spinal endoscope (myeloscope) and discovery of an unreported subarachnoid lesion. *Spine (Phila Pa 1976)* 23, 2358-2362.

Uemura, K., Behr, R. and Roosen, K. (2000) Symptomatic intraspinal air entrapment. *Br J Neurosurg* 14, 154-156.

van Biervliet, J. (2006) Diagnosis of cervical compressive myelopathy: value of radiography, myelography and ancillary diagnostics? In: *13th ESVOT Congress*, Eds: Traumatology, E. S. o. V. O. a., International Veterinary Information Service, Munich. pp 195-196.

Van Biervliet, J., Alcaraz, A., Jackson, C. A., Njaa, B., de Lahunta, A. and Divers, T. J. (2004a) Extradural undifferentiated sarcoma causing spinal cord compression in 2 horses. *J Vet Intern Med* 18, 248-251.

van Biervliet, J., de Lahunta, A. and Divers, T. J. (2006a) Sporadic Conditions Affecting the Spinal Cord: Parasitic Migration and Neoplastic Disease. *Clinical Techniques in Equine Practice* 5, 49-53.

van Biervliet, J., Mayhew, J. and de Lahunta, A. (2006b) Cervical Vertebral Compressive Myelopathy: Diagnosis. *Clinical Techniques in Equine Practice* 5, 54-59.

van Biervliet, J., Scrivani, P. V., Divers, T. J., Erb, H. N., de Lahunta, A. and Nixon, A. (2004b) Evaluation of decision criteria for detection of spinal cord compression based on cervical myelography in horses: 38 cases (1981-2001). *Equine Vet J* 36, 14-20.

Veihelmann, A., Devens, C., Trouillier, H., Birkenmaier, C., Gerdesmeyer, L. and Refior, H. J. (2006) Epidural neuroplasty versus physiotherapy to relieve pain in patients with sciatica: a prospective randomized blinded clinical trial. *J Orthop Sci* 11, 365-369.

von Oberregierungsrat, G. and von Geheimrat, F. (1966) Epidurale Haematome der Halswirbelsaeule beim Pferd. *Dtsch Tieraerztl Wochenschr* 73, 585-588.

Wagner, P. C., Bagby, G. W., Grant, B. D., Gallina, A., Ratzlaff, M. and Sander, R. (1979) Surgical Stabilization of the Equine Cervical Spine. *Veterinary Surgery* 8, 7-12.

Wagner, P. C., Grant, B. D. and Reed, S. M. (1987) Cervical vertebral malformations. *Vet Clin North Am Equine Pract* 3, 385-396.

Warnke, J. P., Di, X., Mourgela, S., Nourusi, A. and Tschabitscher, M. (2007) Percutaneous Approach for Thecaloscopy of the Lumbar Subarachnoidal Space. *Minim Invasive Neurosurg* 50, 129-131.

Warnke, J. P., Koppert, H., Bensch-Schreiter, B., Dzelzitis, J. and Tschabitscher, M. (2003) Thecaloscopy part III: first clinical application. *Minim Invasive Neurosurg* 46, 94-99.

Warnke, J. P. and Mourgela, S. (2007) [Adhesive lumbar arachnoiditis. Endoscopic subarachnoepidurostomy as a new treatment]. *Nervenarzt* 78, 1182-1187.

Warnke, J. P., Mourgela, S., Tschabitscher, M. and Dzelzitis, J. (2001a) Thecaloscopy part II: anatomical landmarks. *Minim Invasive Neurosurg* 44, 181-185.

Warnke, J. P., Tschabitscher, M. and Nobles, A. (2001b) Thecaloscopy: the endoscopy of the lumbar subarachnoid space, part I: historical review and own cadaver studies. *Minim Invasive Neurosurg* 44, 61-64.

Zeman, D., Snider, T., 3rd and McClure, J. (1989) Vertebral lymphosarcoma as the cause of hind limb paresis in a horse. *J Vet Diagn Invest* 1, 187-188.