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REVIEW

The Conus Medullaris: A Comprehensive Review

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ABSTRACT

The position of the conus medullaris within the vertebral canal varies. Given its role in sensory and motor function, a comprehensive understanding of the conus medullaris is necessary. PubMed and Google Scholar were used to review the literature on the conus medullaris. Pathological states and traumatic injury relating to the conus medullaris should be studied further. Spine Scholar 1:93-96, 2017

INTRODUCTION

The conus medullaris (Fig. 1), also known as the medullary cone, is the distal end of the spinal cord. Its location varies, and in adults it tapers at approximately the first or second lumbar vertebra, ranging from T11 and L3 (Neel, 2016). Derived from the neural tube, the structure ascends in the vertebral canal because the growth rates of the spinal cord and the vertebral column differ during development (Salbacak et al., 2000).

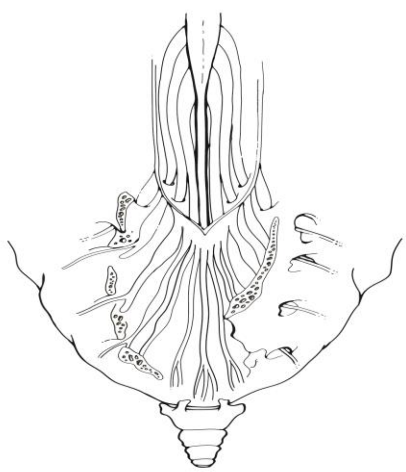

Figure 1: Schematic drawing of the conus medullaris and distal nerve roots in relation to the sacrum.

The conus contains the sacral and coccygeal segments of the spinal cord (Taylor and Coolican, 1988). Criteria for recognizing the conus on computed tomography (CT) scans have been published by Grogan et al. (1984). The radiological properties of the structure have been studied through magnetic resonance imaging (MRI) (Saifuddin et al., 1997). Injury to the conus can cause bladder, bowel, and sexual dysfunction as well as sensorimotor deficits (Taylor and Coolican, 1988). Spinal cord lesions can have serious consequences and it is necessary to understand how the conus medullaris can be affected by such lesions. Therefore, the objective of this review is to examine the embryology, anatomy, blood supply, imaging, pathology, and surgical procedures pertaining to the conus medullaris. A review was conducted using the search engines PubMed and Google Scholar to locate articles on the conus medullaris.

Embryology

The spine develops in three stages: gastrulation, primary neurulation, and secondary neurulation (Rufener et al., 2009). During gastrulation, which occurs during the second or third week of development, the bilaminar disc is converted to a trilaminar disc. Primary neurulation involves the region of the fourth to sixth pairs of somites, where the notochord and the overlying ectoderm interact to form the neural plate during weeks three and four (Saker et al., 2016). The neural plate folds and closes by day 22-23 to become the neural tube and is split into a cranial and a caudal section, the caudal one-third subsequently developing into the spinal cord. The distal neural tube later undergoes canalization, during which vacuolization and apoptosis occur. Around day 27, secondary neurulation begins below the level of somites 32-34, which later develop into the third through fifth sacral vertebrae. Distal to the posterior neuropore, the caudal cell mass (a remnant of Hensen's node) forms a secondary neural tube through vacuolar fusion. Around day 52 this structure undergoes retrogressive differentiation, in which the caudal neural tube regresses and develops into the spinal cord caudal to S2, forming the tip of the conus medullaris, filum terminale, and cauda equina. At the terminal end of the neural tube the ventriculus terminalis forms. The tail regresses through a process involving apoptosis. The walls of the ventriculus terminalis and the pia mater develop into the filum terminale.

The spinal cord and the vertebral column are the same length during stage 23 of embryonic development, the spinal cord reaching the last coccygeal vertebra (Neel, 2016). It then ascends through the spinal canal as its growth rate is exceeded by that of the vertebral column. During later fetal stages it is located between the L3 and S5 vertebrae; at 40 weeks, near full term, it is located between the L1 and L3 vertebrae; and in children between one and seven years it is located between the T12 and L3 vertebrae (Saker et al., 2016; Neel, 2016).

Anatomy

The spinal cord extends from the medulla oblongata and terminates caudally as the conus medullaris. It is located within the superior two-thirds of the vertebral canal and is enveloped by the three meninges: the dura mater, arachnoid mater, and pia mater. The location of the conus medullaris varies. On average, it terminates at the level of the middle third of the body of L1, and has been recorded as terminating as high as the middle third of the body of the T11 vertebra and as low as the middle third of the body of the L3 vertebra in adults (Neel, 2016).

The conus medullaris has been reported to reach its adult position by two years of age (Wilson and Prince, 1989). The filum terminale, approximately 20 cm long in adults, is a filament of connective tissue and pia mater that descends from the apex of the conus medullaris (Neel, 2016). The spinal cord has varying transverse widths, which include cervical and lumbar enlargements and a tapered conus medullaris. Its external surface contains fissures and sulci. The left and right sides are separated by a ventral median fissure and a posterior median sulcus and septum. The central canal resides in a commissural band of nervous tissue between the two halves.

The conus medullaris contains segments from S2 to coccygeal 1 (Ebner et al., 2009). It is connected to the epiconus (L3-S1 segments) superiorly and the filum terminale (L3-coccygeal 1) inferiorly. The ventriculus terminalis, which lies within the distal conus, is an ependyma-lined cavity surrounded by glial clusters.

Blood Supply

The blood supply to the conus medullaris includes the anterior spinal artery and the right and left posterior spinal arteries, with smaller radicular contributions (Bosmia et al., 2015). The anterior spinal artery traverses the anterior median sulcus of the spinal cord, while the posterior spinal arteries descend posterior to the spinal cord and medial to the posterior nerve roots. These anterior and posterior spinal arteries join at the lower aspect of the conus to form a "conus basket" complex with extensions along the filum terminale. The artery of Desproges-Gotteron, also known as the cone artery, is an anatomical variant that arises from the internal iliac artery and is usually located between L2 and L5 (Novy et al., 2006). It usually supplements the artery of Adamkiewicz when it arises at higher levels, between T5 and T8 (Bosmia et al., 2015).

Imaging

Grogan et al. (1984) studied the characteristics of CT scans of the conus medullaris in healthy patients. They found that the conus has a distinctive oval configuration, an anterior sulcus, and a posterior promontory on CT imaging. Additionally, they found that the lengths of the anteroposterior and transverse diameters were 5-8 mm and 8-11 mm, respectively. Grogan et al. noted that intramedullary processes affected the observed dimensions and configuration.

Saifuddin et al., used T1-weighted, midline, sagittal, spin-echo MRI studies to identify the tip of the conus medullaris. The location of the conus on MRI scans was examined and compared with cadaveric data to assess the reliability of the MRI scans and the variation in position of the conus in a healthy adult population. The authors found that the average position of the structure on MRI scans was at the lower third of the L1 vertebra, ranging from the middle third of T12 to the upper third of L3, which corresponded to data from cadaveric studies.

Pathology

Lower spinal cord lesions such as those of the conus medullaris and cauda equina can cause bilateral deficits with pain in the back extending into the sacral segments and to the legs (Neel, 2016). Early features of these lesions include loss of bladder and erectile function. Fasciculation and muscle atrophy can occur in the legs, and there can be sensory loss involving the perineum and other lumbar and sacral dermatomes. Lower spinal cord lesions can result from congenital abnormalities such as spina bifida, lipomata or split cord malformations, and the conus medullaris extending below the lower border of L1 often with a tethered filum terminale. Prolapsed intervertebral discs can also affect the conus medullaris and cauda equina. Infarction of the conus medullaris can lead to cauda equina syndrome (Anderson and Willoughby, 1987; Ohbu et al. 1990). Conus medullaris syndrome can be caused by injury to the T12-L2 vertebrae and involves damage to neural structures from the T12 spinal cord segment to the S5 nerve root (Brouwers et al., 2017). The condition is usually caused by intradural tumors or vascular lesions (Neel, 2016). Symptoms of conus medullaris syndrome include symmetric saddle anesthesia, symmetric motor deficit and earlier atonic urinary bladder and sphincter dysfunction.

Tethered cord syndrome is associated with spinal dysraphism and tends to refer to a low conus medullaris although in some cases, the conus is found to lie at a normal level i.e., tethered cord with normal conus (Neel, 2016). The anatomical variations in conus medullaris position make the definition of 'abnormally low' unclear; it could be either below the L1-2 disc space or below the lower border of the L2 vertebra. There may be a short filum terminale more than 2 mm wide or an intradural lipoma. Children with tethered cord syndrome can present with foot deformities, neurological deficits, spinal deformities, and cutaneous findings such as lumbar capillary angioma. Adults can present with perianal pain and leg weakness. Tubbs and Oakes (2004) investigated tethered cord syndrome in patients whose conus medullaris was located at 'normal' anatomical position. The authors believed that there was a subset of tethered cord patients in whom the apex of the conus lies in the normal range, and suggested that tethered cord syndrome is better viewed as tautness of the cord rather than solely distal elongation resulting in a caudally displaced conus medullaris.

Traumatic injury to the conus medullaris can impair bowel, bladder, and sexual functions. Taylor et al. (1988) demonstrated that after a four-year follow-up in 18 patients with traumatic conus injuries (most frequently due to a L1 burst fracture), all patients could walk on discharge but four required external support. All patients regained regular bladder habits but lost some degree of bladder sensation. There was a correlation between the degree of bladder control and urinary tract infection. Bowel control was preserved but decreased. Eleven out of 16 males could undertake intercourse with variable adequacy, and potency was linked to the degree of genital sensation.

There are many intramedullary lesions of the conus medullaris. Neoplastic lesions include glial tumors such as ependymoma, astrocytoma, glioblastoma multiforme, and ganglioma; non-glial tumors such as hemangioblastoma and primitive neuroectodermal tumor; and other malignancies such as lymphoma, primary melanoma, and metastases (Ebner et al., 2009). Non-neoplastic lesions include granulomatous lesions such as tuberculoma and sarcoidosis. Other non-neoplastic causes include bacterial abscess, parasitic infestations (schistosomiasis and cysticercosis), vascular lesions (cavernoma, spinal vascular malformations, and amyloid angiopathy), demyelinating lesions (multiple sclerosis), and dysembryogenetic lesions (lipoma, cystic lesion of the ventriculus terminalis, epidermoid cyst, dermoid cyst, and teratoma).

Intramedullary spinal tumors occur in the conus medullaris in approximately 10% of cases. Han et al. (2008) reviewed 26 patients who underwent surgery for primary conus medullaris tumors. The patients exhibited the following symptoms: leg pain (80.8%), lower back pain (69.2%), sensory change (69.2%), bladder and bowel change (57.7%), motor weakness (46.2%), and pain or sensory change in the saddle area (50.0%). Myxopapillary ependymoma was the most common tumor, occurring in 50.0% of patients. Other tumor types included hemangioblastoma (11.5%), lipoma (11.5%), astrocytoma (11.5%), primitive neuroectodermal tumor (7.7%), capillary hemangioma (3.8%), and mature teratoma (3.8%). Symptoms such as severe perineal pain and genital pain probably resulted from sacral nerve root compression. Conus tumors can cause sacral and lumbar nerve root compression and therefore should be considered for the differential diagnosis of cauda equina syndrome or sciatica due to degenerative lumbar diseases. Urinary symptoms are commonly the only early symptoms, and urinary dysfunction tends to appear as the tumor progresses. Uchiyama et al. (2004) found that 91% of patients with conus medullaris tumors exhibited urodynamic abnormalities. In addition, 58% of patients had voiding symptoms, especially decreased urge to void (50%), detrusor sphincter dyssynergia (42%), and detrusor areflexia on voiding (32%).

The artery of Desproges-Gotteron, an anatomical variant, can be involved in vascular injury and arteriovenous fistulas. A case study by Balblanc et al. (1998) showed that lumbar manipulation for L4-L5 disc herniation can cause compression of the artery, leading to vascular complications of the conus medullaris and cauda equina. Another case study by Reis et al. (2007) depicted a patient with L5-S1 disc herniation and conus medullaris syndrome possibly caused by compression of the artery. Tubbs et al. (2011) described a case of arteriovenous malformation involving the artery in an adult female with bladder incontinence and intermittent pain radiating down the right posterior thigh and foot. The patient underwent transarterial embolization and had no evidence of recurrent arteriovenous malformation on two-year follow-up. A case by Cohen et al. (2013) described a patient with a perimedullary arteriovenous fistula of the conus medullaris involving the artery of Desproges-Gotteron and a thoracic radiculomedullary artery. The patient presented with urinary difficulty and severe sudden-onset right lumbar pain that evolved to severe paraparesis and compromised sphincter muscles. Conus arteriovenous malformations can be treated by microsurgery and/or embolization (Ozpinar et al., 2017). In a review of tumors of the conus medullaris by Han et al. (2008), gross total or complete tumor resection was achieved in 80.8% of the patients. Tumor resectability was affected by the histopathological type, and the difficulty in distinguishing tumor from neural tissue limited complete resection. The complete tumor resection rate for ependymoma and hemangioblastoma was approximately 90%, and 50-76% for low grade astrocytomas. Ebner et al. (2009) noted the importance of early tumor detection and resection of the filum terminale attached to the tumor. Intraoperative electrophysiological monitoring reduces surgical morbidity and involves using motor-evoked potentials of lower limb muscles and the external anal sphincter.

CONCLUSION

The conus medullaris is important in motor and sensory function of the lower body. Therefore, it is necessary to study pathological states and traumatic injury involving the conus, especially with regard to anatomical variations.

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The authors report no conflict of interest concerning the material or methods used in the findings specified in this paper.

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