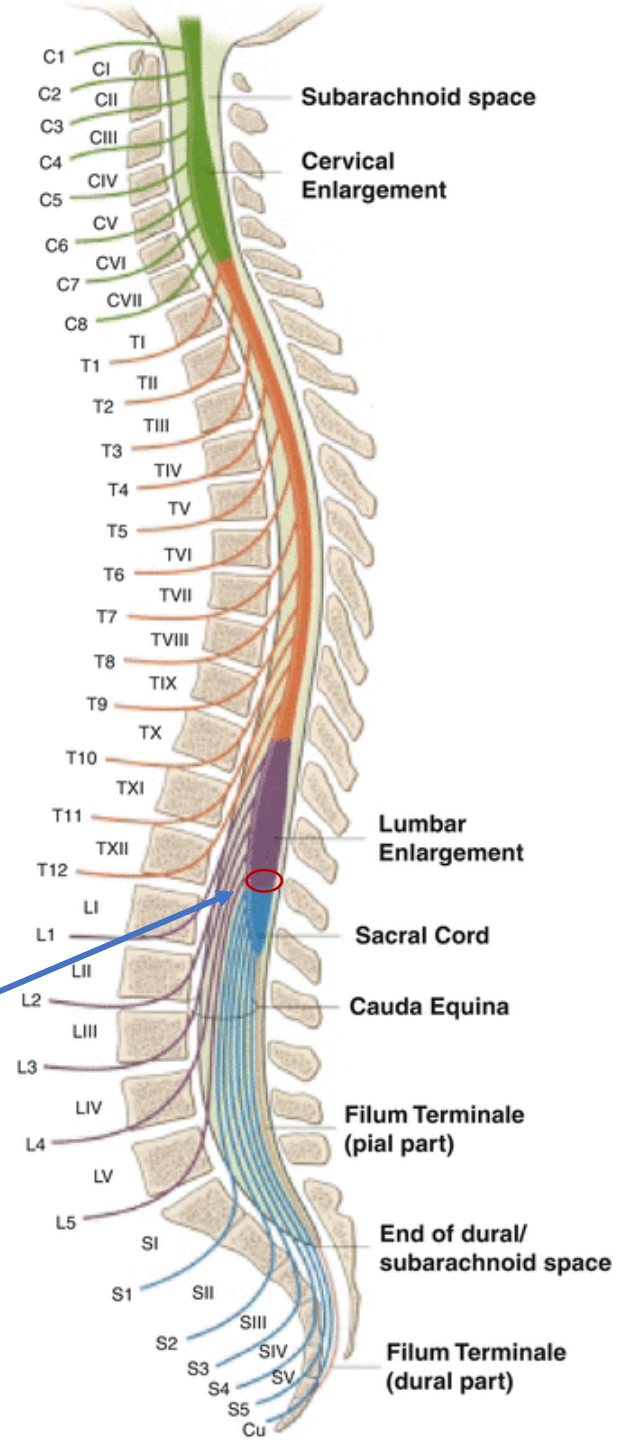
Cauda equina & conus medullaris syndrome

- Clinico-anatomical review

Anatomy

- Spinal cord terminates
  - Newbrons : L3 vertebra
  - Adults : Mostly L1-L2 IVD* (L1 – L3)
- Conus medullaris :
  - T12-L1 IVD to L1-L2 IVD (T11-12 IVD ~ L4)
  - Upper border is usually poorly defined
  - Consists of S2 to S5 and the coccygeal segments.
- Epiconus:
  - Just rostral extent of the conus medullaris
  - L4 to S1 segments

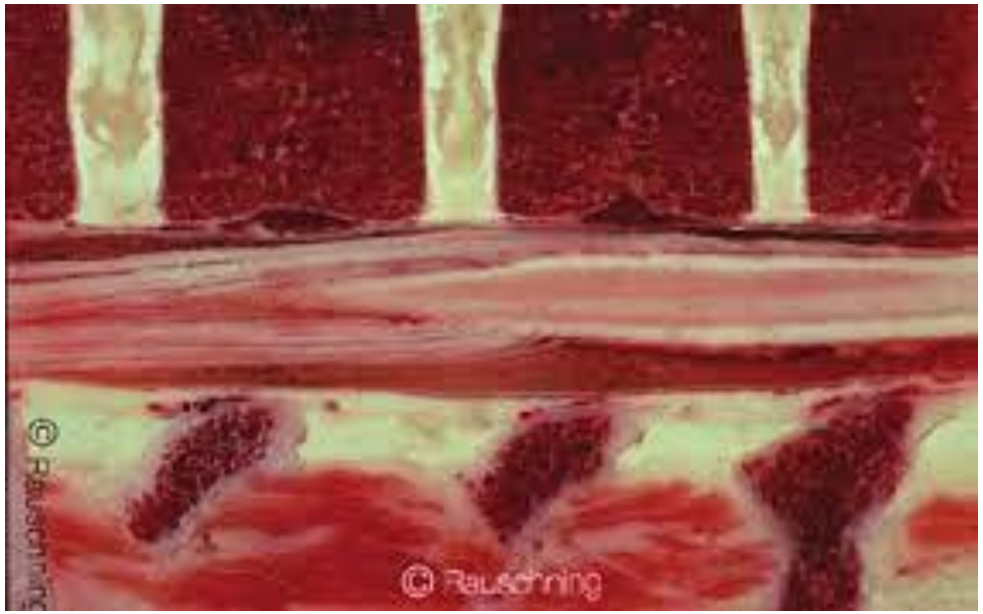


*IVD (intervertebral disc)

- *Nene Y, Jilani TN. StatPearls 2022*

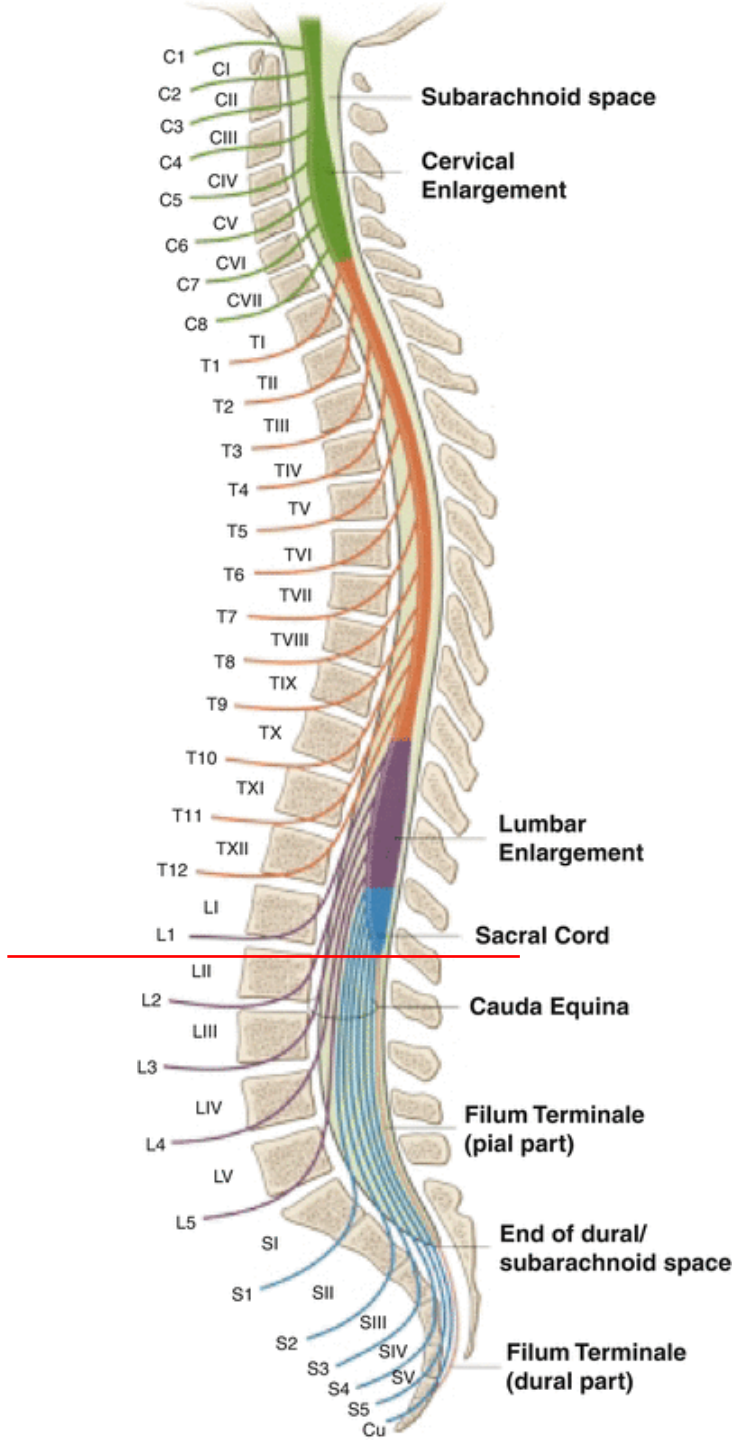
Conus medullaris

- At the T12–L1 disc space, the spinal cord began to taper and the L1–L5 nerve roots formed a peripheral rim. Only 10–15% of the spinal cord remained uncovered by nerve
- AP⌀5 to 8 mm
- Transverse⌀8 to 11 mm



- *Kingwell SP et al. Neurosurg Focus 2008*

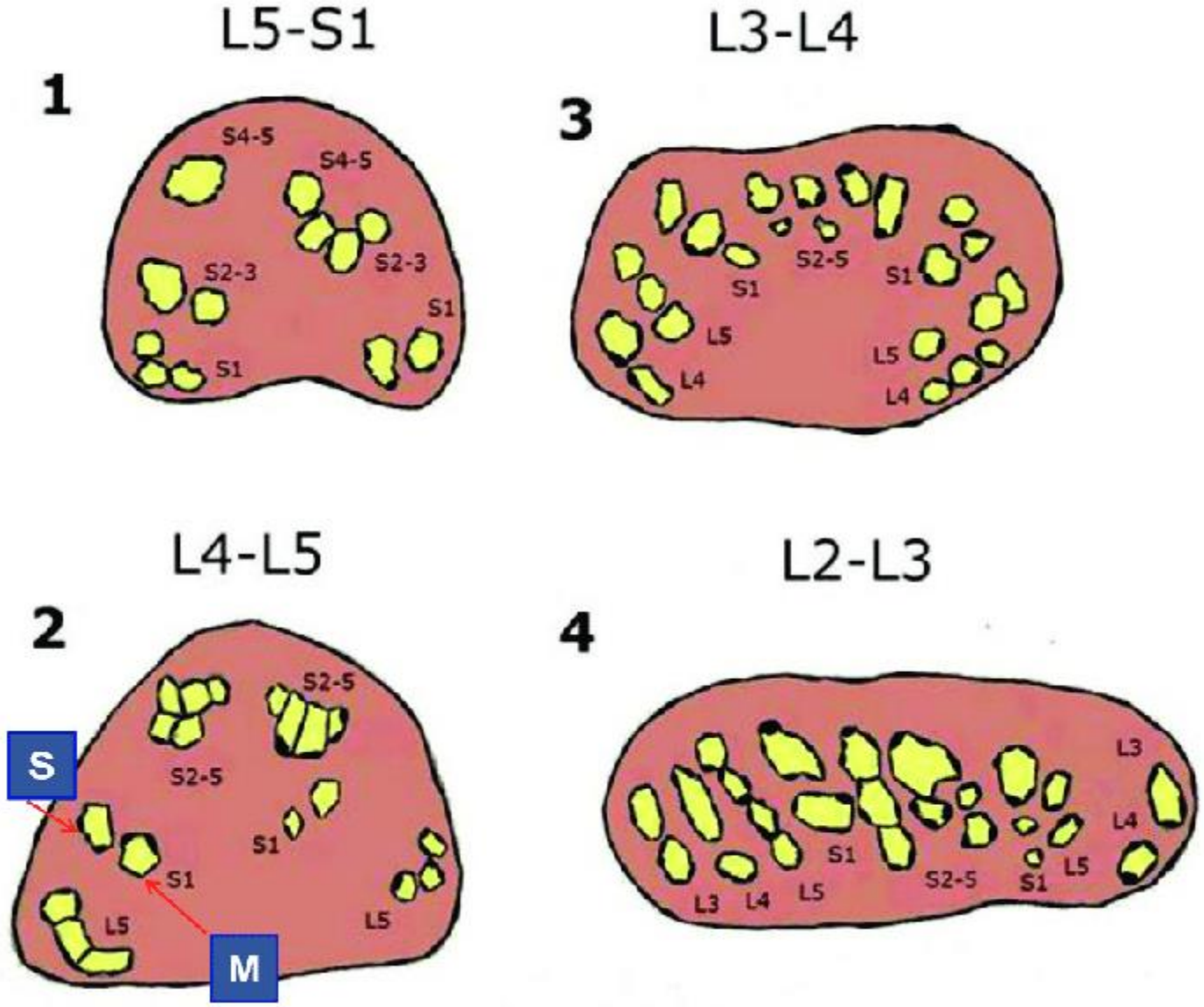
- Cauda equina
  - Nerve roots of L2~S5 and Coccygeal segment
  - Myotome of leg : L2 ~ S2
  - Dermatome of leg : L2 ~ S3
  - Bladder : S2-4, pelvic nerve
  - Ext. urethral sphincter : S2-4, pudendal nerve
  - Perineum and ext. genital area sensory
    : S2-4, pudendal nerve
- Filum terminale
  - pia mater of the tapering end of the conus
  - fibrous tissue about 20 cm in length



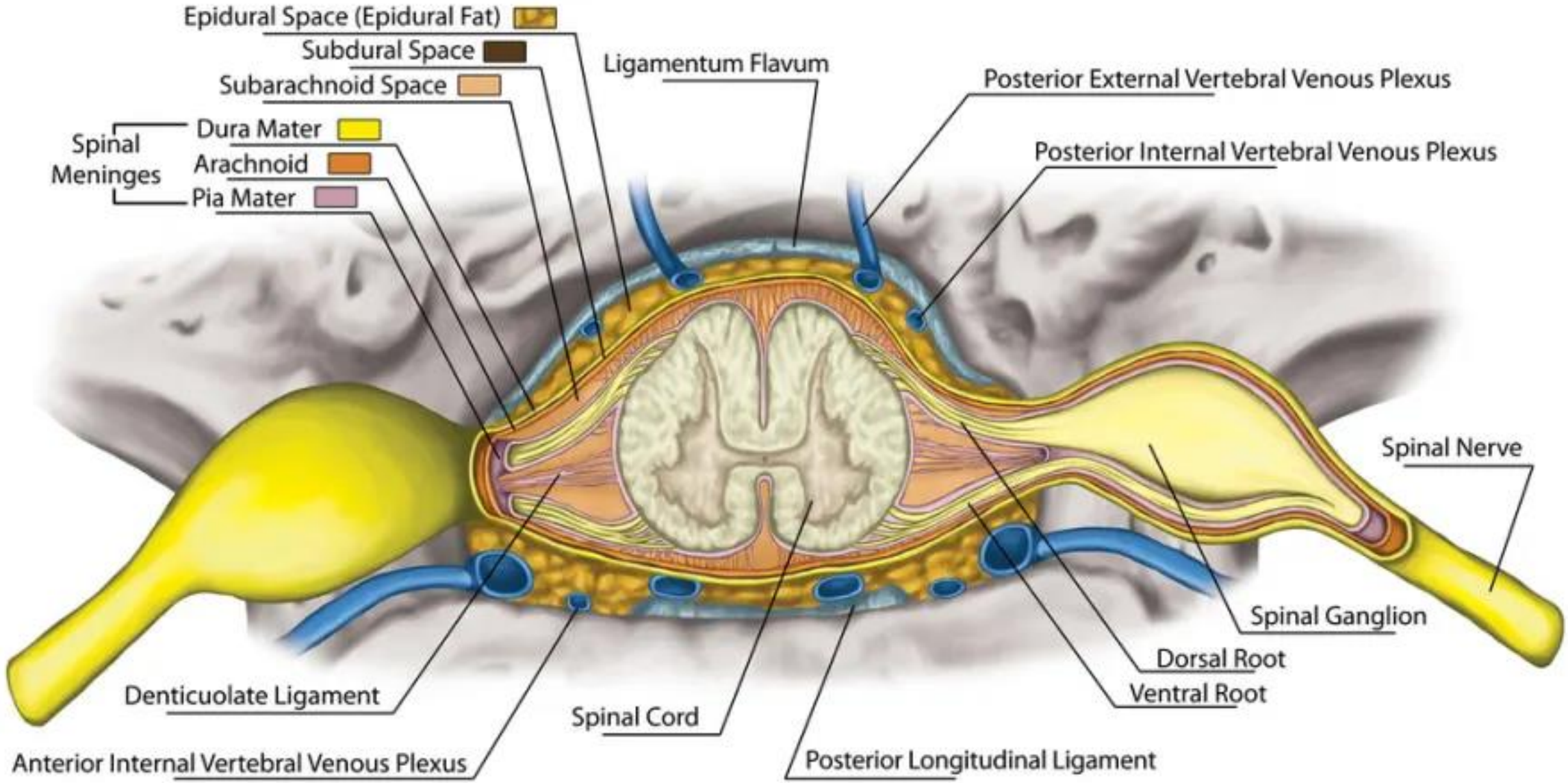
Motor sensory and reflex components of lumbar and sacral roots

Nerve level	Motor innervation	Sensory innervation	Reflexes
L2	Hip flexors, thigh adductors	Upper thigh	
L3	Quadriceps, knee extensors	Anterolateral thigh	
L4	Knee extensors and foot dorsiflexors	Anteromedial calf	Patella, knee
L5	Foot and toe dorsiflexors (extensor hallucis longus)	Lateral calf, dorsum of foot	
S1,2	Foot and toe plantar flexors	Lateral side of foot, sole of foot	Ankle
S2, S3, S4, S5	Sphincters	Perianal and saddle	Bulbocaverno-sus

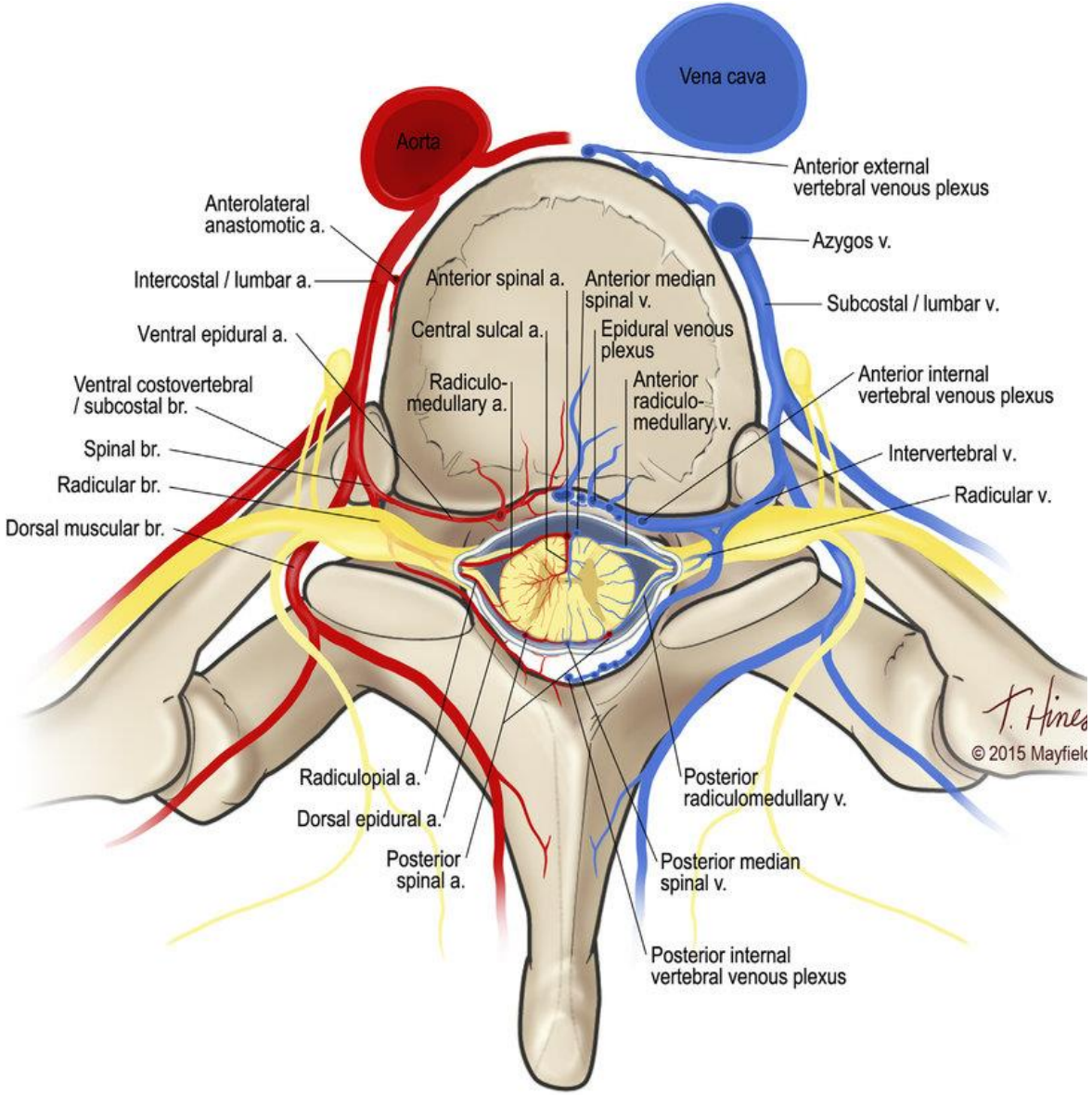
- *Lavy C. et al 2009 BMJ*

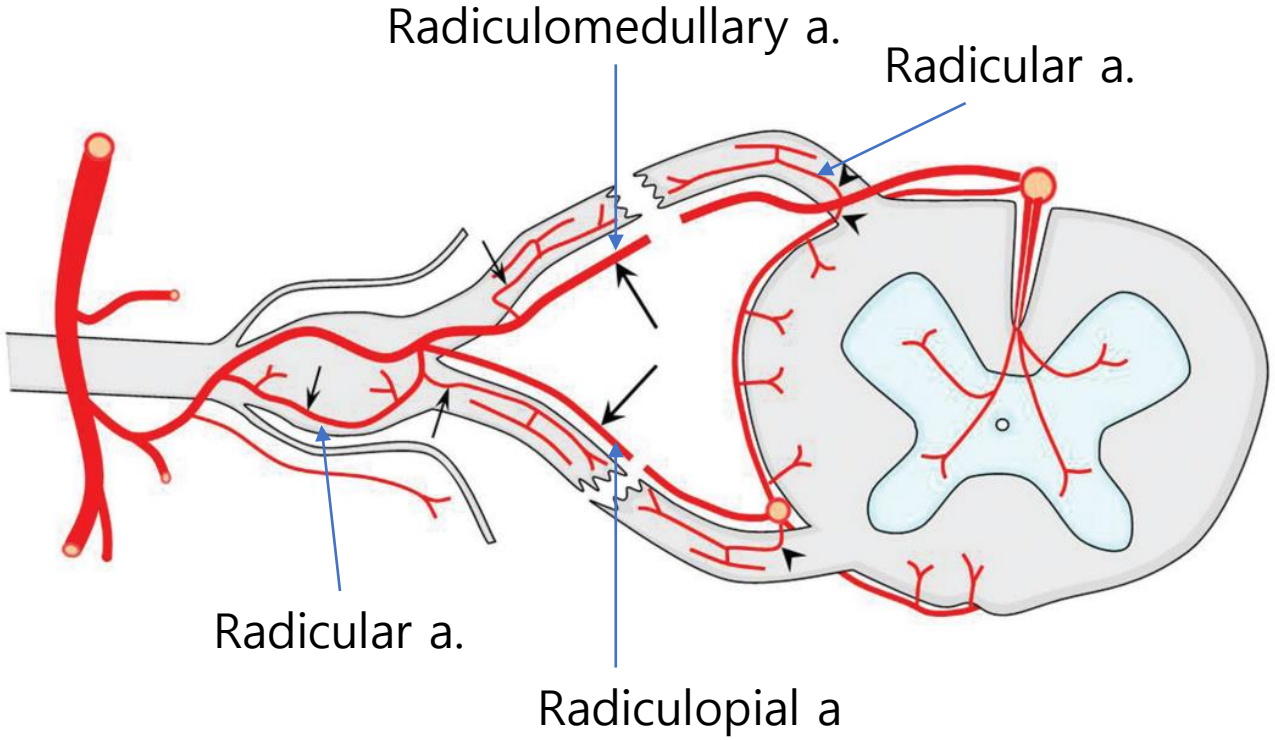


- *Judita Orendáčová et al. 2001, Progress in neurobiology*


Epidural Space (Epidural Fat)
Subdural Space
Subarachnoid Space
Spinal Meninges
Dura Mater
Arachnoid
Pia Mater
Ligamentum Flavum
Posterior External Vertebral Venous Plexus
Posterior Internal Vertebral Venous Plexus
Spinal Nerve
Spinal Ganglion
Dorsal Root
Ventral Root
Denticuolate Ligament
Spinal Cord
Anterior Internal Vertebral Venous Plexus
Posterior Longitudinal Ligament

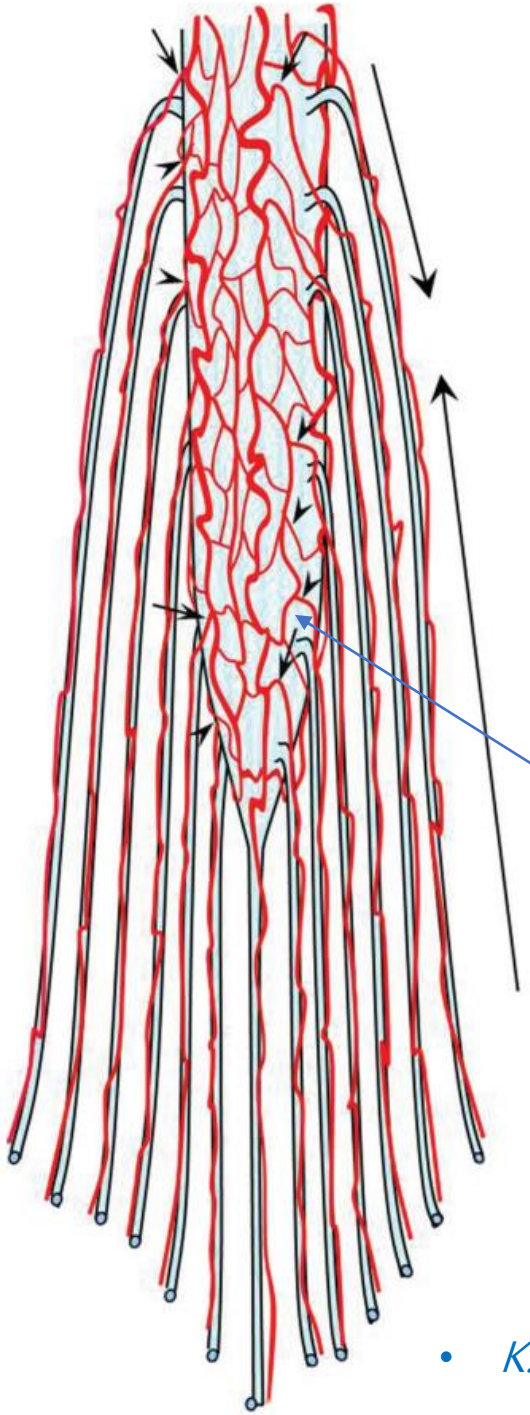
Arterial supply to the intradural cauda equina nerve roots





- *Shawn M. Vuong, Seminars in Ultrasound CT and MRI · 2016*
- *K. Namba et al. Neurol Med Chir, June, 2016*

Posterior roots



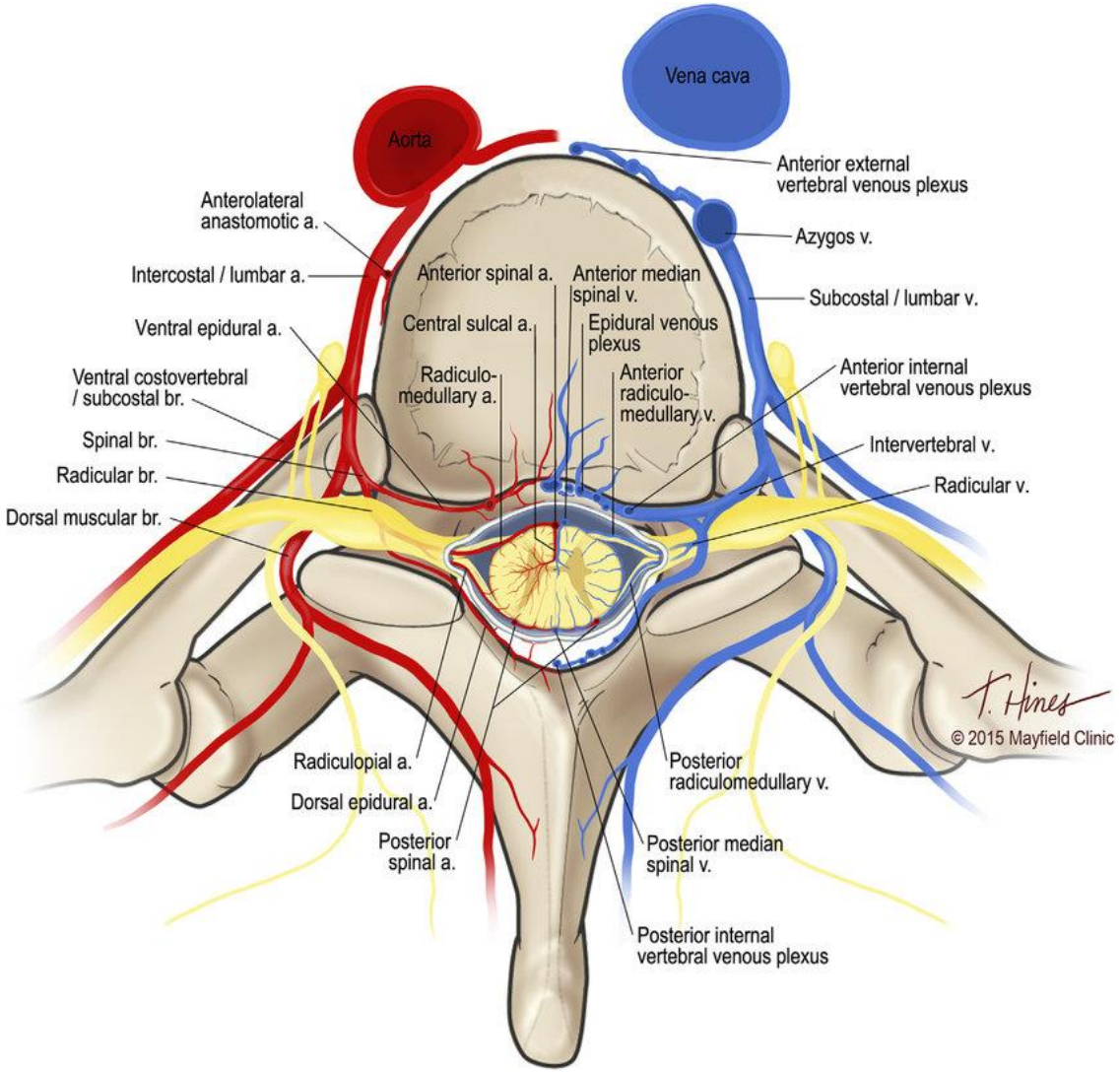
Anterior roots

Vasa corona

- *K. Namba et al. Neurol Med Chir, June, 2016*

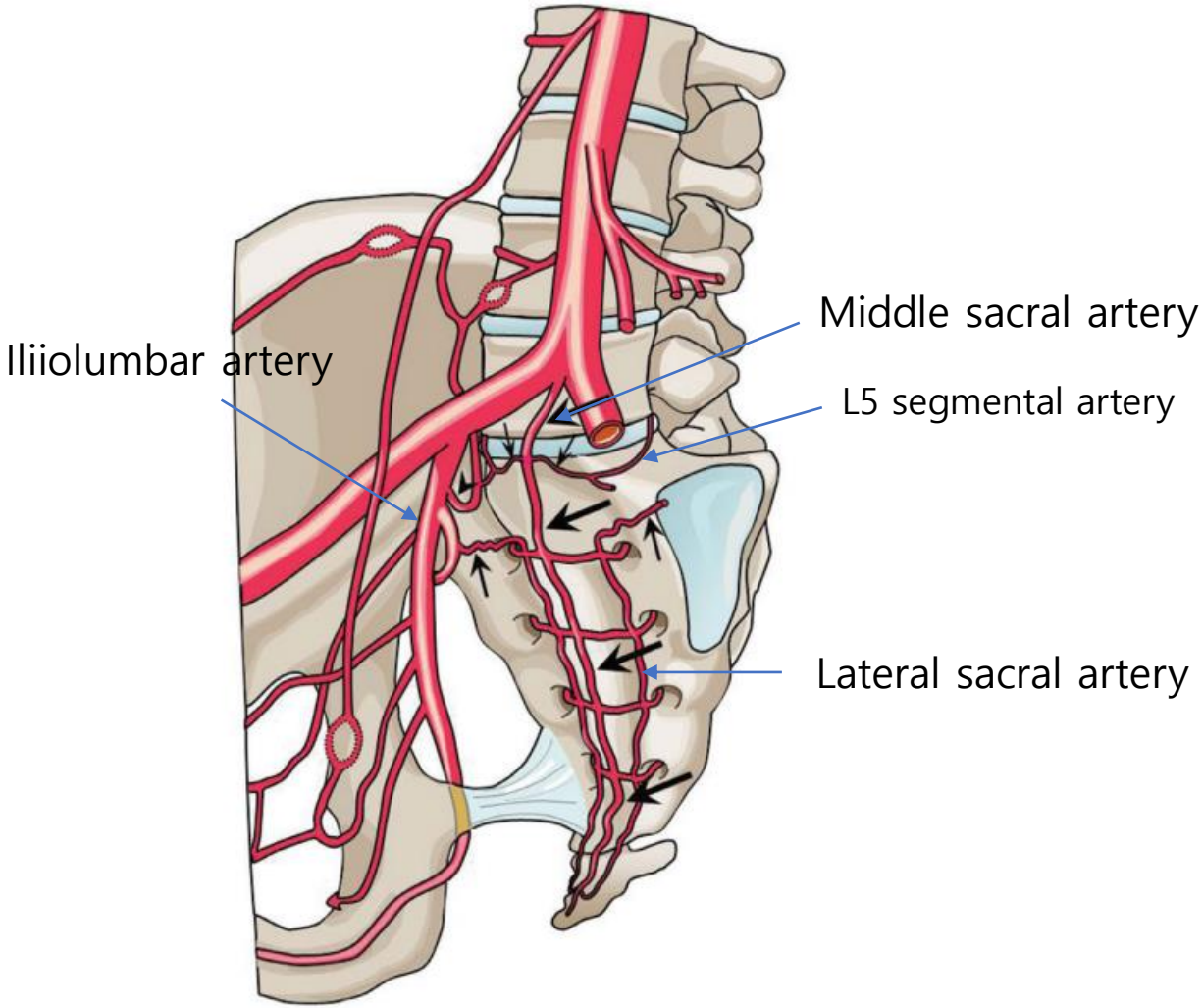
Arterial supply to the extradural cauda equina nerve roots

L1–L4 region



- *Shawn M. Vuong, Seminars in Ultrasound CT and MRI · 2016*

L5 and sacrococcygeal region



- *K. Namba et al. Neurol Med Chir, June, 2016*

Biomechanical frailty of roots compared with peripheral nerve

- Spinal nerve roots are covered by only endoneurium, comparable to pia mater of spinal cord.
- Nerve roots consisted of approximately 0.4% collagen by weight which was only one-fifth the amount estimated for nerve.
  - *LS Stodieck et al. Exp. Neurol. (1986)*
- Relative hypovascularity at the proximal portion of the cauda equina
  - *WW Parke et al. . J Bone Joint Surg Am 1981*
- Long-standing compression of spinal nerve roots is likely to induce intraneural edema which may be transferred into fibrotic scar tissue within and around the nerve roots
  - *Rydevik et al. 1984, Rydevik and Holm 1992*
- Double-level compression of the cauda equina can thus induce impairment of blood flow, not only at the compression sites, but also in the intermediate nerve segments located between two compression sites, even at very low pressures
  - *Takahashi K et al. J. Orthop. Res. 1993*

Cause of Conus medullaris symdrome (CMS)

- Trauma (thoracolumbar fractures)
  - Isolated lesion without cauda equina is rare.
- Isolated CMS is commonly because of atraumatic primary intradural pathologic conditions such as tumors or vascular lesions.
- Infection, iatrogenic (epidural anesthesia or spinal implants)
- Penetrating truma and falls

Causes of Cauda equina syndrome (CES)

- Disc herniation, L4/5, L5/S1, most common
  0.12 ~ 2% of herniated discs
- Trauma
- Spinal stenosis
- Neoplasm
- Subdural hematoma
- Ischemia – aortic dissection/thrombosis
- Infective causes with abscess formation or bony involvement
- Iatrogenic causes -manipulation, spinal anaesthesia,
  postoperative complications

Incidence

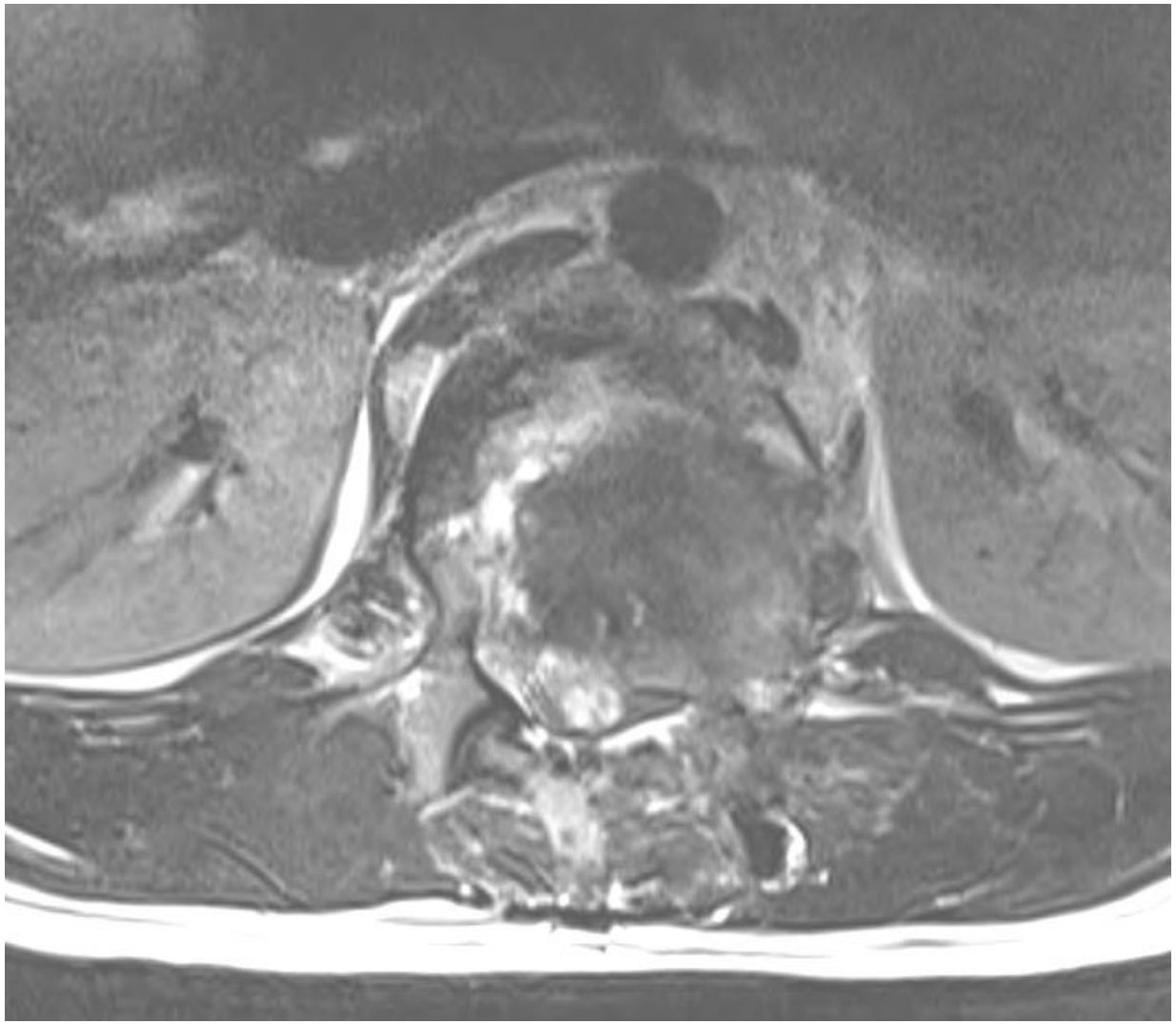
- McKinley et al. have reviewed SCI clinical syndromes in 839 patients admitted for inpatient rehabilitation
  - The incidences of CEI and CMI were 5.2 and 1.7%, respectively.

McKinley et al. J Spinal Cord Med. 2007

- 15% traumatic SCI occur in the thoracolumbar spine
- 10–38% of these injuries, the conus medullaris (CM) or cauda equina (CE) is involved

Sekhon LH, Fehlings MG. Spine 2001


FL



Clinical diagnosis of cauda equina syndrome

- Dysfunction of bladder, bowel, or sexual function
- Sensory changes in saddle or perianal area

Other possible symptoms

- Back pain (with or without sciatic-type pains)
- Sensory changes or numbness in the lower limbs
- Lower limb weakness
- Reduction or loss of reflexes in the lower limbs
- Unilateral or bilateral symptoms

- *Lavy C. et al 2009 BMJ*

Conus medullaris syndrome (CMS) vs Cauda equina syndrome (CES)

- The CM may includes both upper and lower motor neurons, whereas the CE consists solely of lower motor neurons
- From a purely anatomical perspective, CMS and CES are separate structures,
- Clinical distinction between incomplete CMS and CES based upon neurological examination alone is difficult.
  - *Tator CH. Neurosurgery 1998*
- There is no differentiation between these syndromes in the acute phase of traumatic injury
  - *Brouwers E et al. Spinal Corde 2017*
- The case in an L-1 or L-2 burst fracture when the conus is not adequately visualized on MR imaging.
  - *Kingwell SP et al. Neurosurg. Focus 2008*

Epiconus & Conus medullaris lesion

- In case of cord injury, a secondary damage response occurs
- Neuronal cell body damage has no possibility of recovery

- Most of the CMIs were the result of trauma and 57% of these patients had ASIA Grade A or B function.
  - *McKinley et al. J Spinal Cord Med. 2007*

- More severe neurological injuries more likely to occur at the cord level
  - *Gertzbein SD et al. Spine. 1988*

- A smaller degree of canal compromise results in greater neurological dysfunction at the epiconus level than the conus medullaris and cauda equina
  - *Hashimoto T et al. Spine. 1988*

Cauda equin lesion

- Muscle weakness is generally mild, and lower limb weakness associated with CES is predominantly asymmetrical in patients with an incomplete injury
  - *Podnar S. Muscle Nerve 2007*
  - *Orendacova J et al. Prog Neurobiol 2001*
- Asymmetrical lower-extremity weakness would favor a diagnosis of CES
  - *Kingwell SP et al. Neurosurg. Focus 2008*

Prognostic point of view

- It is assumed that the regenerative capacity in lower motor neuron lesions is superior to upper motor neuron lesions, and therefore the functional outcome of CES could be better than the functional outcome of CMS.

  - *Tator CH. Neurosurgery 1998*

Definitions of traumatic conus medullaris and cauda equina syndrome: a systematic literature review

- *Brouwers E et al. Spinal Cord 2017*

- The aim of this review was to search for the exact definitions of CMS and CES in trauma literature, including the vertebral level of injury, identify neurological symptoms and differentiate between the two syndromes

- A total of 14 articles for qualitative analysis

Table 1 The definitions of CMS found in literature

Author	*Definition of the CM*
Korovessis *et al.*[32]	The lesion was considered to be mixed CMS if the bony level was at Th11–L1.
McAfee *et al.*[28]	The determination of CM injury was made on the basis of the clinical findings of a neurogenic bladder, and the loss or third, fourth and fifth sacral nerve root sensation. In patients without a clinically apparent injury of the CM, there was evidence of neural compression with hyperreflexia, clonus, spasticity and sensory deficit, in addition to compromise of the spinal canal on CT and myelography.
Kaneda *et al.*[29]	Patients with pure CMS had a lesion at vertebral level L1.
Transfeldt *et al.*[34]	It appears from this study and others that fractures at T12 and L1 (CM lesions) have a greater potential for neurologic recovery compared to SCI, especially of bladder control.
Rahimi-Movaghar *et al.*[30]	In this study, 24 patients presented with CMS. The most frequent level of bony injury was L1, followed by T12.
Harrop *et al.*[27]	The lumbar spinal cord or CM contains the anterior horn cells for the distal lumbar and sacral spinal cord segments and is surrounded by nerve roots for the upper lumbar segments. The lumbar region (Conus) was defined as L1–S5.
Kim *et al.*[31]	There were 48 fractures in the CM area (L1).
Clohisy *et al.*[33]	CM function was assessed by clinical evaluation of rectal tone, perianal sensation and the ability to spontaneously void. Out of 20 patients, 15 patients with a fracture at T12 or L1 had a CMS. All patients with a fracture at L1 had a CMS; however, not every patient with a T12 fracture had CMS.
Jelsma *et al.*[35]	In this study, 50 patients had thoracolumbar fractures and complete or incomplete CMS or CES. Patients had fractures from Th10 to L2.
Blumenkopf and Juneau[37]	The CM was observed at the th12 level in 8 patients, the L1 level in 10 patients and the L2 level in 2 patients.
Podnar[4]	Patients with pathology at the T12 or L1 levels were assumed to have CM lesions.
Gertsbein *et al.*[38]	The lesion was considered to be mixed CMS and CES if the fracture was located at Th11–L1.
Bradford and McBride[39]	The conus portion of the spinal cord is usually found between L1 and L2.
Willén *et al.*[36]	A conus lesion was identified, when there was saddle anesthesia, bladder and/or bowel disturbances or sexual problems, but no motor impairment in the lower limbs.

Abbreviations: CES, cauda equina syndrome; CMS, conus medullaris syndrome; CT, computed tomography; SCI, spinal cord injury.

The definitions of CMS found in literature

- Fracture level : T12 and L1 (T10 ~ L2)
- Neurological symptoms :
  - saddle anesthesia (S3,4,5), bladder and/or bowel disturbances or anal problems but no motor impairment in the lower limbs

- So all refer to an acute loss of sensation in the saddle region, bladder and/or bowel dysfunction and sexual dysfunction after trauma, without muscle weakness in lower extremities.

Table 2 The definitions of CES found in literature

Author	*Definition of CE*
Korovessis *et al.*[32]	The lesion was considered to be CES, if bony level was L2 or below.
Kaneda *et al.*[29]	Patients with pure CES presented a lesion at vertebral level L2 and below.
Kim *et al.*[31]	There were 59 fractures in the level of CE (L2, L3 and L4).
Podnar[4]	Patients with pathology below the L1–L2 intervertebral level were assumed to have CE lesions.
Gertsbein *et al.*[38]	The lesion was considered to be pure CES, if the bony level was L2 or below.
Bradford and McBride[39]	The CE was below L2.
Willén *et al.*[36]	In patients with signs of nerve root lesions without bladder or bowel disturbances, saddle anesthesia or sexual problems, the term used was CE lesion.

Abbreviation: CES, cauda equina syndrome.
Definition of CES was not available in the articles of McAfee *et al.*,[28] Transfeldt *et al.*,[34] Rahimi-Movaghar *et al.*,[30] Harrop *et al.*,[27] Clohisy *et al.*,[33] Jelsma *et al.*,[35] Blumenkopf and Juneau.[37]

- *Brouwers E et al. Spinal Corde 2017*

- Mixed CMS/CES cases were described with vertebral lesions between Th10 and L1, whereby no differentiation was made based on neurological function

Table 3 Neurological symptoms of CMS and CES

Symptoms	*CM*	*CE*
Low back pain, accompanied by pain radiating into one or both legs.	Yes	Yes
Muscle weakness in lower extremities	Predominantly symmetrical	Often asymmetrical
Sensory loss of all sensory modalities, typically saddle anesthesia (S3–S5)	Predominantly symmetrical	Often asymmetrical
Bladder and rectal sphincter dysfunction	Yes	Yes

Abbreviations: CES, cauda equina syndrome; CMS, conus medullaris syndrome.

- *Brouwers E et al. Spinal Corde 2017*

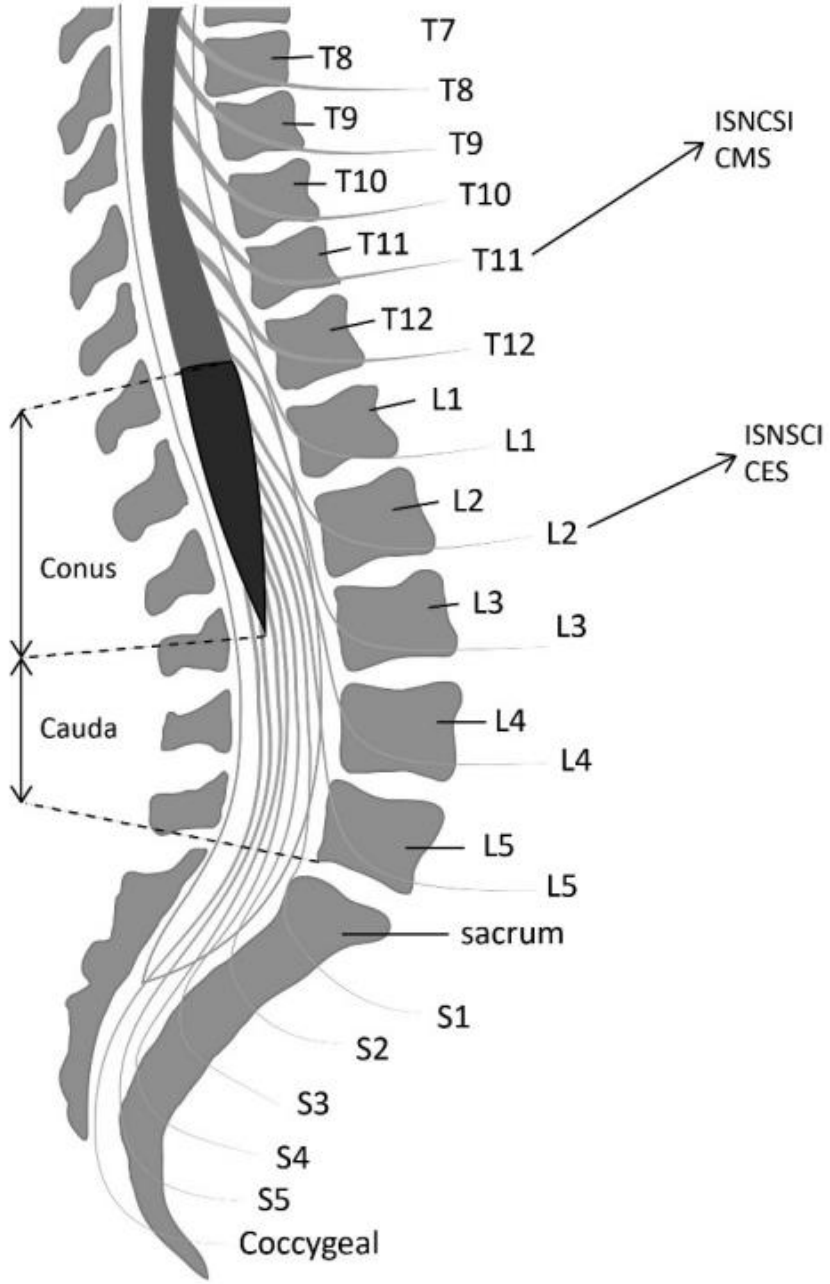
- To add the ISNCSCI gradation to our results from the literature

a clear cutoff point for the border between CMS and CES could be derived

Table 4 Proposal for the definition of the CMS and the CES

	Vertebral level of injury	*Neurological level of injury*	*ISNCSI level of injury*
CMS	T12–L2	T12–S5	T11
CES	L3–L5	L3–S5	L2

Abbreviations: CES, cauda equina syndrome; CMS, conus medullaris syndrome; ISNCSI, International Standard for Neurological and functional Classification of Spinal Cord Injury.



- *Brouwers E et al. Spinal Corde 2017*

- A clear cutoff point for the border between CMS and CES
- It is important to recognize the syndrome at an early stage to predict neurological recovery
- From the standpoint of decision-making and informing the patient and family, it is important to minimize ambiguity about these syndromes

- *Brouwers E et al. Spinal Corde 2017*

Differentiation of the clinical features between cauda equina lesion and conus medullaris lesion

Symptoms, sign	Cauda equina lesion	Conus medullaris lesion
Symmetry	Often asymmetrical	More often symmetrical
Stretch reflexes	Depressed reflexes according to involved roots	Usually preserved
Sensory loss	According to involved roots	Saddle pattern
BCR, anal reflex	Usually absent	Preserved in high conus injury or epiconus lesion
Pain	Common	Less common
Bladder activity	Usually absent	Preserved in high conus injury or epiconus lesion
Recovery	More likely	Less likely

Ko HY. Management and Rehabilitation of SCI. 2nd ED, 2022

Electrodiagnostic Studies

- NCS and needle EMG may play a critical role in localization of a disease process to the cauda equina.
- These studies cannot always readily differentiate the cauda equina from conus medullaris.
- The isometric strengths of the KE, ADF, and APF and the CMAP amplitude of the electrophysiologic parameters were correlated in CES patients and a significant correlation with MMT grade was also identified
  - *Han JH, et al. Medicine 2022*

Imaging Studies

- MRI is the gold standard neuroimaging procedure of choice
  - Taumatic, HNP, Spinal stenosis
  - Can identify aortic dissection, and may identify spinal cord infarcts.
  - Critical to assess for hematoma, infection, tumor, other structural causes, or various autoimmune causes.
  - With gadolinium administration
    - distinguishing neoplastic from other inflammatory and infectious disorders

Recovery of Motor/Sensory and Function in CES

- Earlier rehabilitation onset was a significant predictor for recovery in the ability to walk and improvement in FIM bowel/baldder score
- The change in LEMS was similar between AIS AB vs CD
- Recovery of the ability to walk
  - At admission to rehabilitation, 10% reported to be able to walk
  - At discharge, 52% of patients were able to walk
    - (64% AIS C/D vs. 36% AIS A/B, : 89% L3–S3 vs. 35% L1)
      - *Attabib N et al. J of Neurotrauma 2021*
- The pattern of recovery was quite varied with the most common pattern being motor followed by bowel/ bladder followed by sensory recovery.
  - *Dhatt et al. Eur Spine J 2011*

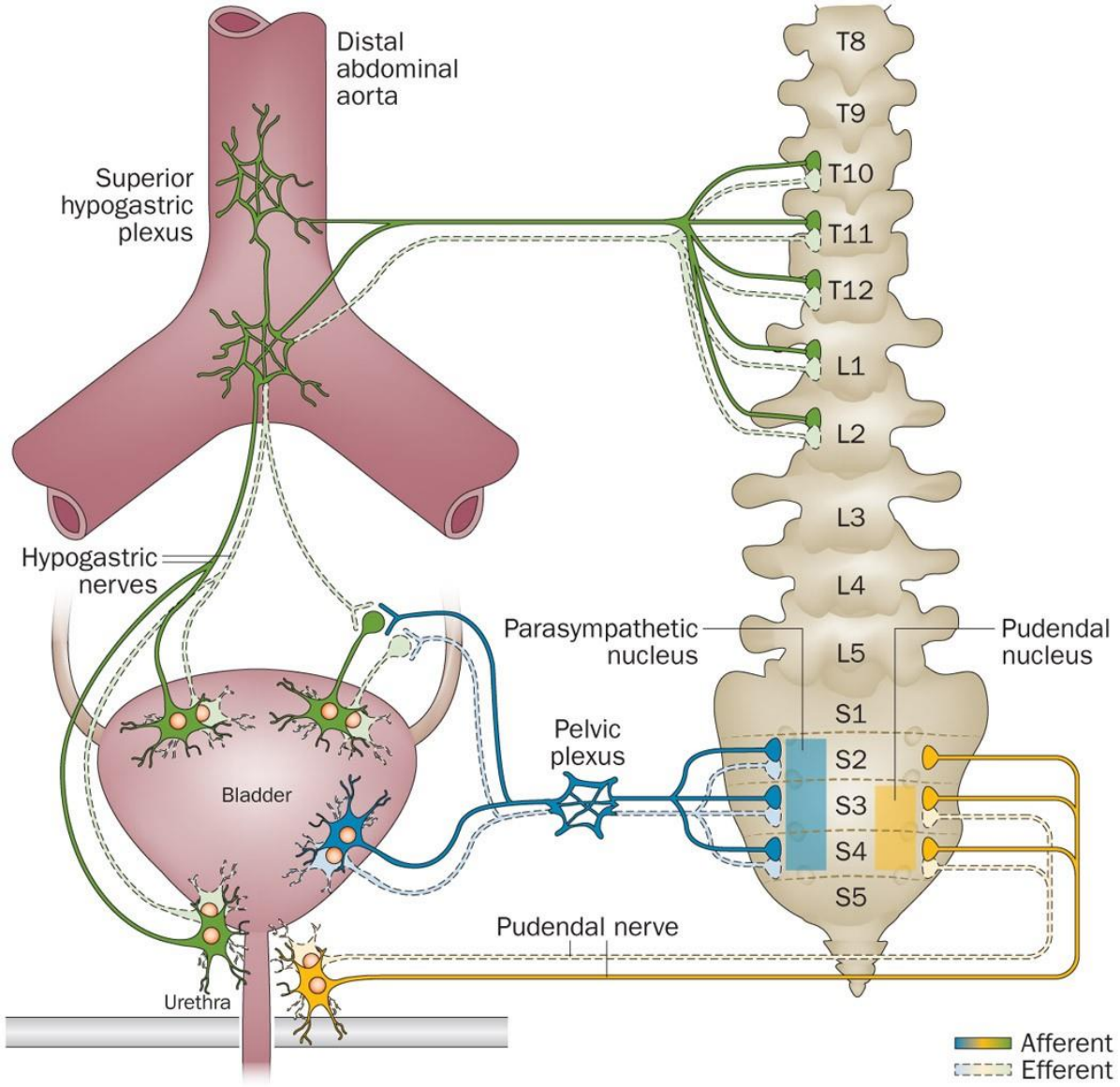
Recovery of bowel and bladder function in CES

- In addition to motor and sensory improvement, recovery of bowel and bladder function is top priority for those living with SCI
- Associated with a person's independence and quality of life

- Anal wink as a predictor of bladder and bowel recovery
  - *Dhatt et al. Eur Spine J 2011*

- Perineal sensory deficit strongly correlated with LUT dysfunction
  - *Podnar S et al. Neurol. Urodynamics 2006*

Bladder



- *Wit EMK & Horenblas S, Nat. Rev. Urol. (2014)*

Conal/Infraconal Neurogenic Bladder

- Urinary retention with overflow incontinence
- Neurologic status do not always predict the bladder types.
  - They can evolve over months before stabilized.
- Poor correlation between patients' symptoms and filling cystometry findings
- Monitored by regular urodynamic examinations
  - *Podnar S et al. Neurol. Urodynamics 2006*

Lower motor neuron lesion bladder

- Management goals include avoidance of bladder overdistension and retrograde urine flow.
- If there is incontinence due to insufficient sphincter tone
  - condom catheters in male/ indwelling cath. for female.
- If the sphincter tone is sufficient to maintain continence
  - CIC
  - Valsalva or Crede' maneuver
- Medication
  - Cholinergic agonist : not effective
  - Alpha adrenergics : insufficient effect & side effect

Ko HY. Management and Rehabilitation of SCI. 2nd ED, 2022

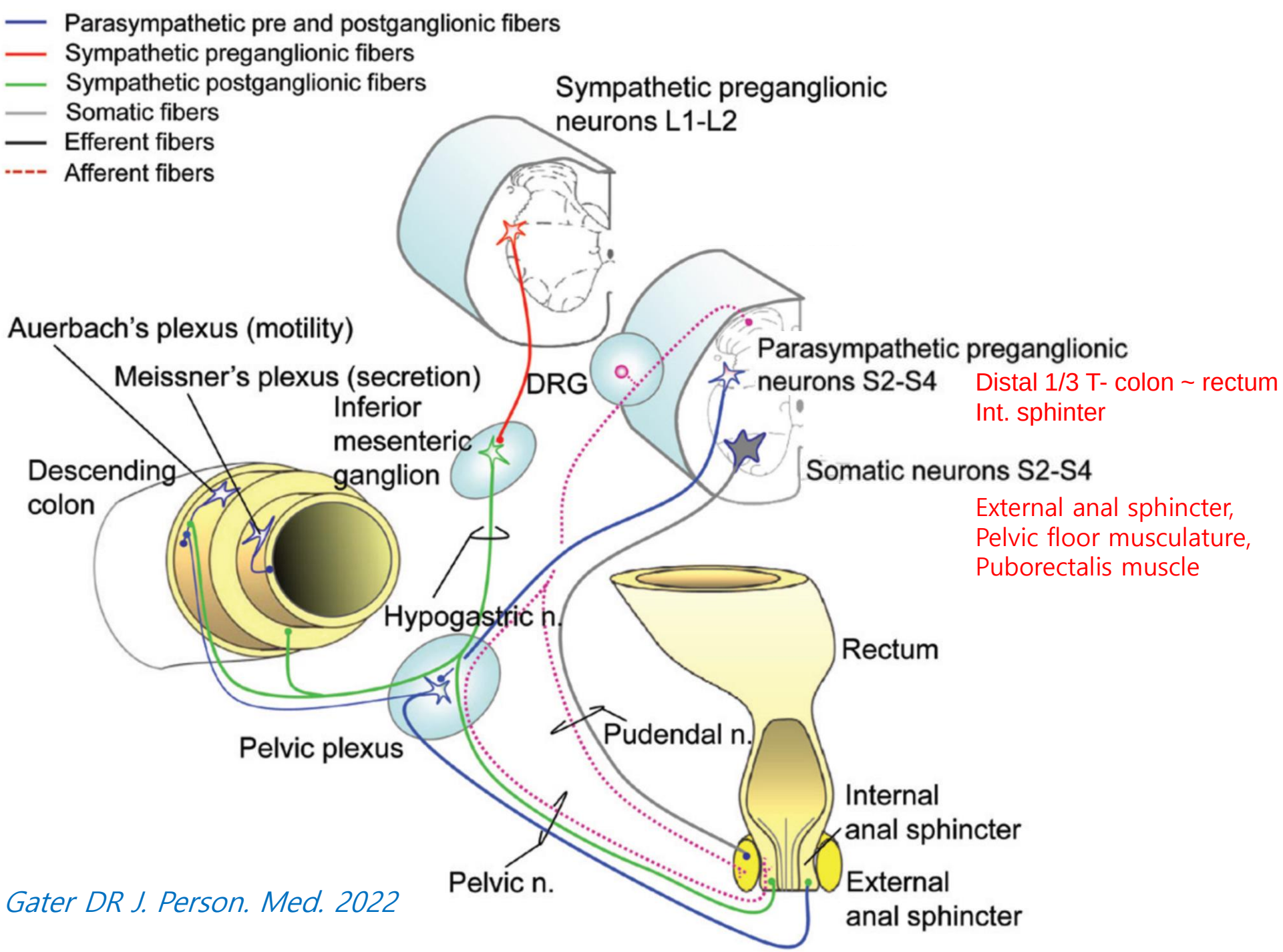
Bethanechol in cats with chronic cauda equina lesions

- *El-Salmy S et al. J of Urol. 1985*

- Bladder and urethral supersensitivity to bethanechol chloride in with complete lesions
- The urethra also showed exaggerated constriction responses
  - Adrenergically mediated and exerted through the vesicourethral short neuron system
  - The rest of the response was due to stimulation of urethral muscarinic receptors.

- Bethanechol may not assist in improving bladder emptying
  - 1) the contraction produced is not the powerful, abrupt and sustained contraction seen in the bladder normally
  - 2) the urethra also responds in a supersensitive manner to bethanechol.

Bowel

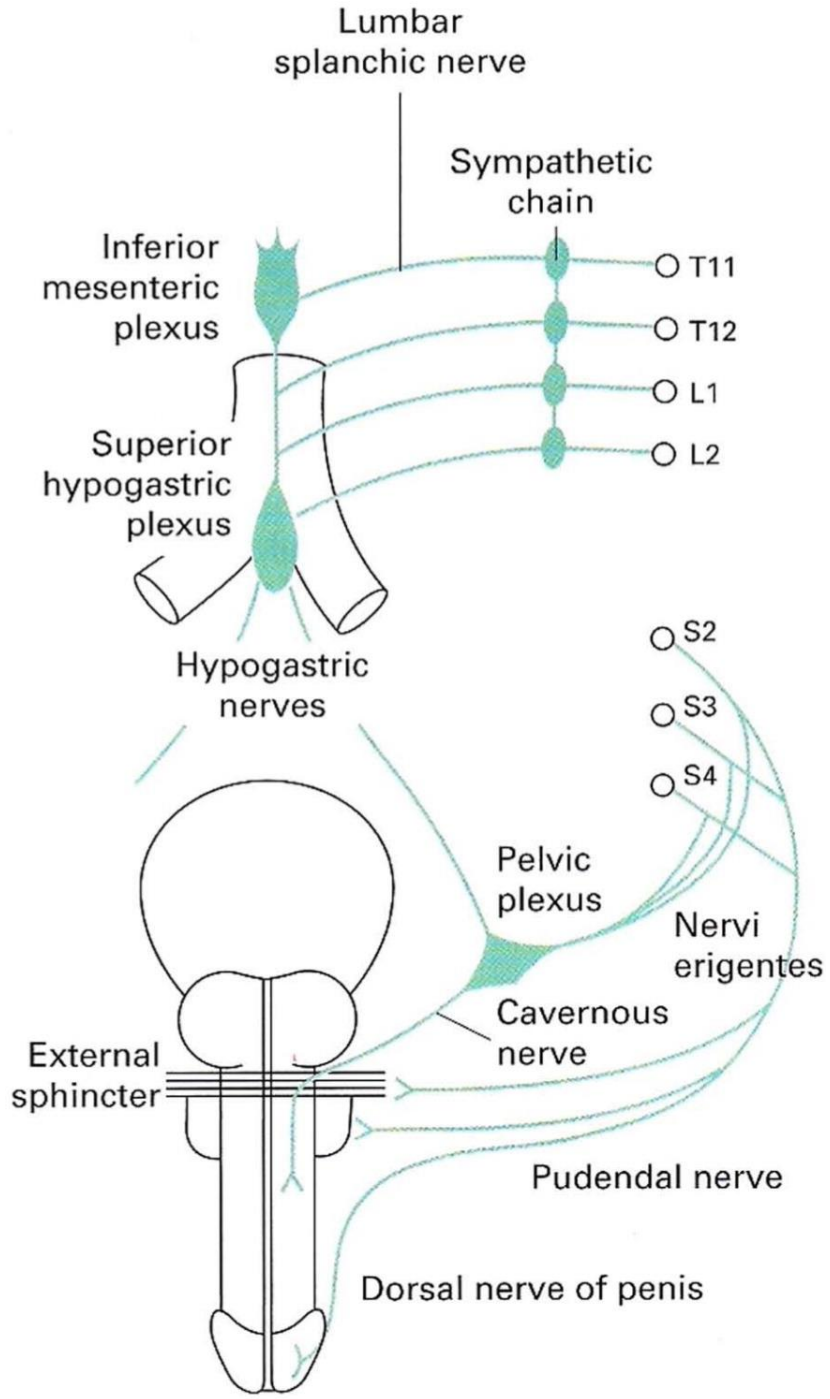


- *Rodriguez GM & Gater DR J. Person. Med. 2022*

Conal/Infraconal Neurogenic Bowel

- Reduced parasympathetic and somatic tone
- Diminished or absent anocutaneous, bulbocavernosus, and other lumbosacral reflexes
- Only enteric mediated reflexes remained
- Delayed transit time
- Overflow incontinence, Paradoxical liquid incontinence around stool impaction

- Manual removal of stool, Valsalva maneuver or flushing enemas
- Oral bowel stimulants and/or osmotic medications
  - be used with caution since watery stools can increase episodes of fecal incontinence



Psychogenic erection

: Usually poor quality and short duration

Reflex erection

Kalsi J & Muneer A, J. Clin. Urol. 2013

TABLE 1: Summary of complete epiconus injuries, CMIs, and CEIs*

Neurological Syndrome	Neurological Level of Injury	Clinical Examination	Electrophysiological Testing	Bowel, Bladder, & Sexual Function
epiconus	above T-12	conus segments intact, UMN syndrome, BCR & AR preserved; muscle tone increased	segmental recordings intact (EMG, NCS, F-wave, H-reflex); SSEP: tibial & pudendal abolished	bladder–bowel dysfunction, UMN type (bladder-detrusor-sphincter dyssynergia); sexual dysfunction (in men preserved reflexogenic erections, loss of psychogenic erection)
conus medullaris	T12–L1 to S4–5	complete damage of conus medullaris; LMN syndrome; all reflexes (sacral & limbs abolished); muscle tone flaccid w/ atrophic changes	NCS: tibial & peroneal nerves show axonal damage (<10 days); EMG: limb & sacral myotomes show severe denervation; SSEP: tibial & pudendal abolished	bladder–bowel dysfunction, LMN type (atonic bladder & flaccid anal sphincter); sexual dysfunction (in men loss of reflexogenic erection, psychogenic erection preserved)
cauda equina	below L-2	LMN syndrome; motor: variable L/E weakness, diminished tone (asymmetry favors CEI over CMI); sensory: variable sensory deficit; reflexes: dependent on level of injury	NCS: tibial (L5–S1) & peroneal (L4–5 dependent on level of injury); EMG: normal proximal limb, denervation distal limb & sacral; SSEP: pudendal affected, tibial may be preserved	bladder–bowel dysfunction, LMN type (atonic bladder & flaccid anal sphincter); sexual dysfunction (in men loss of reflexogenic erection, psychogenic erection preserved)

* Reflects a summary of complete lesions; more variation will be observed for incomplete lesions. Abbreviations: AR = adductor reflex; L/E = lower extremity; LMN = lower motor neuron; NCS = nerve conduction study; UMN = upper motor neuron; SSEP = somatosensory evoked potential.

- *Kingwell SP et al. Neurosurg Focus 2008*