

SPINAL CORD AND EXTREMITY INNERVATION: CLINICAL

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I. SPINAL NERVES - DERMATOMES AND PLEXUSES

A. Nomenclature (naming) of spinal nerves - Spinal nerves are generally named according to the levels of the vertebral column (numbered superior to inferior [top to bottom]) from which they arise.

1. Vertebrae - called Cervical (7 vertebrae in neck), Thoracic (12 vertebrae in chest), Lumbar (5 vertebrae in lower back), Sacral (5 vertebrae in pelvis) and Coccygeal vertebrae (1-3 vertebrae, vestigial tail bones).

2. Spinal nerves - named according to vertebral levels (NOTE: differences); spinal nerves: Cervical (**8**), Thoracic (12), Lumbar (5), Sacral (5) and Coccygeal (typically only one Coccygeal spinal nerve).

Clinically Important Note: There are 8 Cervical Spinal nerves but only 7 Cervical vertebrae; Cervical spinal nerves 1-7 (**C1-C7**) exit above corresponding vertebrae; Spinal nerve **C8** exits below vertebra **C7**; all other spinal nerves exit below corresponding vertebrae. (RULE TO REMEMBER = C1-C7 ABOVE; C8 below C7 vertebra; ALL OTHERS BELOW). This is important in determining damage to specific spinal nerves at different levels (see below).

B. Dermatome - is area of skin innervated by a single spinal nerve; very important clinically.

1. Structure - sensory axons from each spinal nerve innervate strips of skin on the body surface called Dermatomes; regions from different spinal nerves form a continuous series; in thorax dermatome map looks like stripes; more complex in extremities.

2. Overlap - there is some overlap between adjacent dermatomes; overlap is greater on trunk than on extremities

3. Clinical testing - damage to a single spinal nerve or single dorsal root can produce pain or anesthesia in its dermatome; physician can test for damage to a specific spinal nerve by lightly touch (pin prick) area of skin in dermatome.

Note: Because of overlap of dermatomes in region of trunk, damage to a single thoracic spinal nerve will not produce loss of sensation (anesthesia); loss of sensation on skin of trunk will occur if two or more adjacent dorsal roots or spinal nerves are damaged.

4. Specific Dermatomes Important in Extremities - Examples: **Upper Limb - C6 - thumb; C8 - little finger; Lower Limb - L4 - Big Toe; S1 - Little Toe.**

C. Dorsal and Ventral Rami (ramus = branch; pl. rami) of Spinal nerves - this is confusing; Spinal nerves divide into Dorsal and Ventral Rami immediately after they leave the intervertebral foramen; both Dorsal and Ventral Rami contain sensory and motor axons; Dorsal Rami are much smaller than Ventral Rami.

1. **Dorsal Rami** (also called Dorsal Primary Rami) - contain sensory and **motor axons to region of back; sensory axons to skin of back and posterior neck**; motor axons go to Deep muscles of back and neck.

2. **Ventral Rami** (also called Ventral Primary Rami) - much larger than dorsal rami; contain sensory and motor axons to other parts of body; sensory axons to skin of extremities (arm, leg) and

anterior and lateral regions of trunk; motor axons to muscles of extremities and anterior and lateral regions of trunk; ventral primary rami also form plexuses (see below).

D. Plexus - (Latin for a braid) - formed from ventral rami of spinal nerves; ventral rami of spinal nerves interconnect in complex patterns; each plexus contains both sensory and motor axons; there are three major plexuses:

1. Cervical Plexus - innervates neck
2. Brachial Plexus - innervates upper extremity; forms from C5-T1 ventral rami
3. Lumbosacral Plexus - innervates lower extremity; forms from L1-S4 ventral rami.

Note: Each peripheral nerve contains axons derived from a range of spinal levels (ex. Sciatic Nerve from L45, S123); Skeletal muscles also received innervation from defined spinal levels although there is individual variability (ex. Biceps brachii muscle in arm gets innervation from spinal nerves C5, C6).

II. REFLEXES CAN BE USED TO IDENTIFY SPINAL LEVELS OF NERVE DAMAGE

A. Review: **Definition of a reflex = stereotyped motor response to a specific sensory stimulus.**

B. **Stretch reflex** (also termed: Monosynaptic Stretch Reflex, Myotatic Reflex, Deep Tendon Reflex)

1. **Stimulus** - fast stretch of muscle; clinically, produced by a brief sharp tap to a muscle tendon. This produces a sudden small lengthening of muscle (not stimulation of tendon receptors).

2. **Sense organ excited - Muscle spindle sensory neurons (afferents) detect muscle stretch.**

3. **Primary response - MONOSYNAPTIC** activation of alpha motor neurons in **muscle that is stretched; Reflex causes muscle to contract rapidly.** Monosynaptic reflex is the fastest reflex known, with a central delay of about 1 msec at the synapse.

4. **Effects on synergist and antagonist muscles** - a. **Excite synergist muscles** - Activate muscles with similar action (ex. in arm - biceps spindle sensory neurons excite motor neurons to brachialis muscle). b. **Inhibit antagonist muscles (RECIPROCAL INHIBITION)** - Decrease activity in muscles with opposing action (ex. biceps spindle neurons produce inhibition of triceps motor neurons); these connections are polysynaptic.

Note: Changes in stretch reflexes are symptomatic: **In general, Decrease stretch reflexes can indicate Lower Motor Neuron (Alpha motor neuron to muscle) Disorders, Increase Stretch reflexes can indicate Upper Motor Neuron Syndromes (ex. cortical stroke); some clinical conditions affect both Lower and Upper Motor Neurons.**

C. Tendon Tap reflexes - can be used to test for specific level of spinal nerve damage. Tapping on a tendon elicits contraction of the muscle; if muscle contraction is reduced or absent, it is possible to locate lesion by knowing the segmental levels of the spinal nerves that innervate of that muscle.

EXAMPLE: 'Knee Jerk' Reflex (formally called Quadriceps Tendon Reflex) - Anatomy - Quadriceps femoris muscle (commonly called 'Quads' at the YMCA) inserts onto patella in front of knee; patella is linked to tibia by patellar tendon (Patellar ligament); Method - tapping on Patellar tendon stretches Quadriceps muscle and elicits reflex contraction of muscle causing rapid knee extension; this tests function of innervation of Quadriceps muscle from Lumbosacral Plexus (Femoral nerve, L234).

III. LOCATION OF SPINAL CORD IN VERTEBRAL CANAL - spinal column (vertebra) increases greatly in length in development; spinal cord only has small increase in size; in adult, vertebral canal is longer than spinal cord.

A. **Conus medullaris** - is **inferior (caudal) end** of spinal cord

1. In **newborn**, conus medullaris is located at vertebral level **L3**
2. In **adult**, conus medullaris is located at vertebral level **L1**.

B. **Cauda equina** (Latin for Horse's tail) - as vertebral column grows longer, lower dorsal and ventral rootlets also grow longer so they pass through correct intervertebral foramina; these rootlets extend inferior to conus medullaris at lower lumbar, sacral and coccygeal levels and are collectively called the Cauda Equina (located in vertebral canal, inferior to spinal cord).

IV. MENINGES OF SPINAL CORD - meninges are layers of connective tissue that surround and protect nervous system; described as three layers.

A. **Dura mater** (Latin for tough mother) - tough outer layer that forms sac that completely surrounds spinal cord in vertebral canal; Dural sac surrounds also cauda equina below level L1 in adult (L3 in newborn); dural sac ends inferiorly at level S2.

1. **Epidural space** - dural sac is separated from inner side of vertebral canal by space (Epidural space) containing fat and loose connective tissue; also contains Internal Vertebral Venous plexus; Epidural space contains no major neuronal structures.

Clinical Note: Epidural Anesthesia - injection of anesthetic into epidural space can block conduction in spinal nerves; effect is by diffusion; this technique permits complete anesthesia (block pain and sensation) in limited areas of the body.

B. **Arachnoid** (Latin for spider like) - middle layer of meninges; attached to inner side of dura but has fine strands that extend to pia mater (like spider's web).

2. **Subarachnoid space** - found between arachnoid and pia; contains Cerebrospinal fluid.

C. **Pia mater** (Latin for tender mother) - thin layer that is adherent to surface of spinal cord; contains blood vessels supplying cord.

1. **Denticulate Ligaments** (denticulate, Latin for tooth like) - projections of pia on each side of cord that extend to inner side of Dura; there are 21 pairs of denticulate ligaments; denticulate ligaments stabilize spinal cord

Note: **Denticulate ligaments are used as landmarks** in neurosurgery; dorsal rootlets travel dorsal to denticulate ligaments; ventral rootlets are ventral to denticulate ligaments; can cut dorsal rootlets (dorsal rhizotomy) to relieve chronic pain using denticulate ligaments as guide.

2. **Filum Terminale** - pia extends as a thin strand below conus medullaris; strand traverses dural sac, pierces dural sac at S2 and continues inferiorly to attach at first coccygeal vertebra (Co1); the part of the filum terminale between S2 and Co1 is called the coccygeal ligament

V. CEREBROSPINAL FLUID (CSF) AND SPINAL TAP - CSF is clear, acellular fluid contained in subarachnoid space; surrounds and protects spinal cord; produced within choroid plexuses (mostly in brain).

1. Changes in CSF can indicate disease processes - excessive CSF production (or decreased reabsorption) produces increased pressure (hydrocephalus); also blood cells in CSF can indicate infection or hemorrhage.

2. Lumbar Puncture (Spinal Tap) - CSF is sampled by inserting needle into Subarachnoid space; is performed with vertebral column flexed and patient sitting or lying on side (lateral decubitus position).

a. Level of Lumbar Puncture

i. **Adult** - between **L3-L4** or **L4-L5** (spinal cord extends to L1)

ii. **Children** - done at **L4-L5** (spinal cord at birth extends to L3)

CLINICALLY IMPORTANT: REVIEW CLINICAL PROCEDURES

1- **EPIDURAL ANESTHESIA** - space surrounding **SPINAL CORD, INSIDE VERTEBRAL CANAL; contains NO MAJOR NEURONAL STRUCTURES; ONLY FAT, INTERNAL VERTEBRAL VENOUS PLEXUS** (net work of veins); **ALL MAJOR STRUCTURES ARE INSIDE DURA (DURAL SAC);**

2- **LUMBAR PUNCTURE** - sampling of Cerebrospinal fluid (CSF) - needle inserted into Subarachnoid space (deep to **DURA** and **ARACHNOID**, which adheres to inner side of **DURA**) inferior to **SPINAL CORD**; (**SPINAL CORD** ends at **L1** in **ADULT**, **L3** in children (newborns)); **INSERT NEEDLE** at **L3-L4** or **L4-L5** in **ADULT**; must be **L4-L5** in children.

REVIEW FACTS, LEVELS

Levels of spinal nerves = C1-C7 above vertebra, C8 and all other below vertebra)

Dermatome = area of skin innervated by single spinal nerve or cranial nerve

Dermatomes of upper extremity - landmarks - C6 thumb, C8 little finger; lower extremity - L4 big toe, S1 little toe

Dorsal root ganglion - contains cell bodies of sensory neurons (no synapses)

Dorsal root of spinal nerve - contains afferent (sensory) axons

Ventral root of spinal nerve - contains efferent axons

Dorsal ramus of spinal nerve - sensory and motor axons going to skin and muscles of the back

Ventral ramus of spinal nerve - sensory and motor axons going to skin and muscles of rest of body

Plexus - interconnections of spinal nerves that give rise to peripheral nerves (ex. Ulnar Nerve).

Dura mater - completely surrounds spinal cord; separated from inner side of vertebral canal by Epidural space (site of Epidural anesthesia)

Denticulate ligaments - extension of pia mater, attach to dura; surgical landmarks

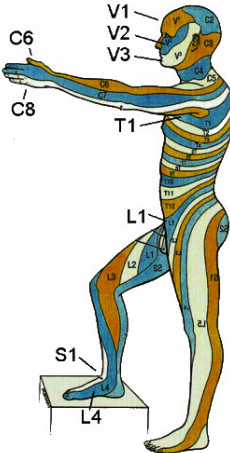
Spinal cord ends inferiorly - L1 in adult, L3 in children

Lumbar puncture - do at L3-4, L4-5 in adults; L4-5 in children

Dural sac ends - S2 (adult)

Filum terminale (extension of pia) attaches inferiorly - Co1 (first Coccygeal vertebra)

SUMMARY CHART: CLINICAL ANATOMY OF SPINAL NERVES

Syndrome/ Procedure	Anatomy	Structures	Clinical, ID Features on CT
Nerve Compression	Convention: Cervical spinal nerves C1-C7 exit Above corresponding vertebrae; C8 exits below C7 and All other spinal nerves exit Below corresponding vertebrae	Dermatomes - area of distribution of single nerve root to skin; Reference list: learn when discussed in lecture Head - Cranial nerve V [V1 - Face (above eyes *) V2 - Face (below eyes*) V3- Face (below mouth)*] C5 - Shoulder C6 - Thumb C8 - Little finger L4 - Big toe S1 - Little toe	Symptoms of compression of nerves - Paresthesia, pain, sensory loss, hyporeflexia, muscle weakness  Note: overlap of dermatomes in region of trunk: sensory loss in trunk only with Two Thoracic spinal nerves
Lumbar Puncture	Inferior end of Spinal Cord = Conus medullaris	Conus medullaris at 1. In Newborn , vertebral level L3 2. In Adult , conus at vertebral level L1	Lumbar Puncture done below Conus Medullaris (region of Cauda Equina); Level: 1. Children - L4-L5 2. Adult - L3-L4 or L4-L5
Epidural Anesthesia	Epidural Space (outside Dura) Dura is separated from inner side of vertebral canal; Note: in Skull, there is no epidural space	Contains: No major neuronal structures: only Fat and Internal Vertebral Venous plexus - inside vertebral canal in Epidural Space;	Anesthetic injected into Epidural space can safely produce local block of spinal nerves (spread by diffusion).

REVIEW STRETCH REFLEX AND CLINICAL DIAGNOSIS OF LESIONS TO SPINAL NERVES

REFLEX	STIMULUS/SENSE ORGANS	RESPONSE	CLINICAL/ABNORMAL RESPONSES
Stretch (Myotatic, Deep Tendon) Reflex	Rapid Stretch of muscle (test: tap on muscle tendon) Excites Muscle Spindle sensory neurons (NOT Golgi Tendon Organ)	Stretched muscle contracts rapidly (monosynaptic connection); also excite synergist and Inhibit antagonist	<u>Clinical Diagnosis</u> - tap to single muscle tendon can be used to test innervation of muscle (Ex. Tap to Quadriceps Tendon (knee jerk reflex tests Femoral Nerve (L2/3/4)) Hyporeflexia - decrease in stretch reflexes occurs in Spinal Nerve compression, Lower Motor neuron Diseases, Muscle atrophy etc. <u>[Hyperreflexia</u> - (increase) - <u>Note: characteristic of CNS NOT peripheral nerve damage</u> - Upper Motor Neuron lesions (ex. damage Corticospinal tract); note: <u>Clonus</u> = hyperreflexia - repetitive contractions to single stimulus]

