

# SPINAL CORD AND EXTREMITY INNERVATION: CLINICAL TESTS

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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

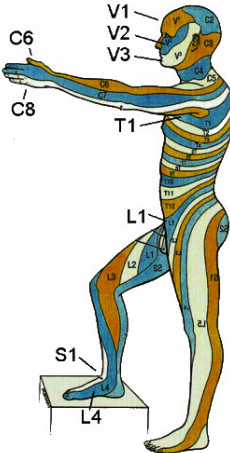
**Spinal cord ends inferiorly - L1 in adult, L3 in children**

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

**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)) <b>Hyporeflexia</b> - decrease in stretch reflexes occurs in Spinal Nerve compression, Lower Motor neuron Diseases, Muscle atrophy etc. <b>Hyperreflexia</b> - (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]

