SENSORY PATHWAYS

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Somatic sensory pathways

- Primary afferents occupy posterior root ganglia.
- Somas of second order neurons are on the

same side as first order neurons.

- Second order axons cross midline to ascend

to thalamus.

- Third order neurons project to somatic sensory cortex.
- Both pathways are somatotopic.
- Synaptic transmission can be modulated by other neurons.

Sensory pathways

- Receptor fields differ in superficial and deep layers
- Inhibitory network limits excitation spread (stronger field)
- Discriminative touch, proprioception, and vibratory sense in dorsal column.
- Crude touch, pain and temperature sense in ventrolateral column.
- 3 neuron systems.
- Cross either in the brainstem (dorsal columns) or in the spinal cord (ventrolateral system).
- Relay through the thalamus.

Dorsal column (medial lemniscal system)

- Primary neuron is larger spinal ganglion neuron.
- Axon ascends in the dorsal funiculus to synapse in either the nucleus gracilis (lower body) or nucleus cuneatus (upper body).
- Axon of secondary neuron crooses as part of the internal arcuate fibers and ascends in the medial lemniscus to reach the ventro-posterio-lateral nucleus of the thalamus.
- Tertiary neuron in thalamus gives rise to an axon that synapses in the sensory cortex (Area 3,1,2).

Spinothalamic system

- Primary neurons are small spinal ganglion cells.
- Their axons ascend or descend (1-2 segments) in Lissauer's tract before they synapse on secondary neurons in the ipsilateral dorsal horn (lamina I or V).
- Secondary axons cross in the anterior white commisure before ascending in the antero-lateral funiculus.
- Synapse of tertiary neurons in the ventro-posterio-lateral nucleus in the thalamus.
- Tertiary axons synapse in the sensory cortex (Areas 3,1,2).

Slices through the brain stem relating nuclei to cranial nerves and major tracts

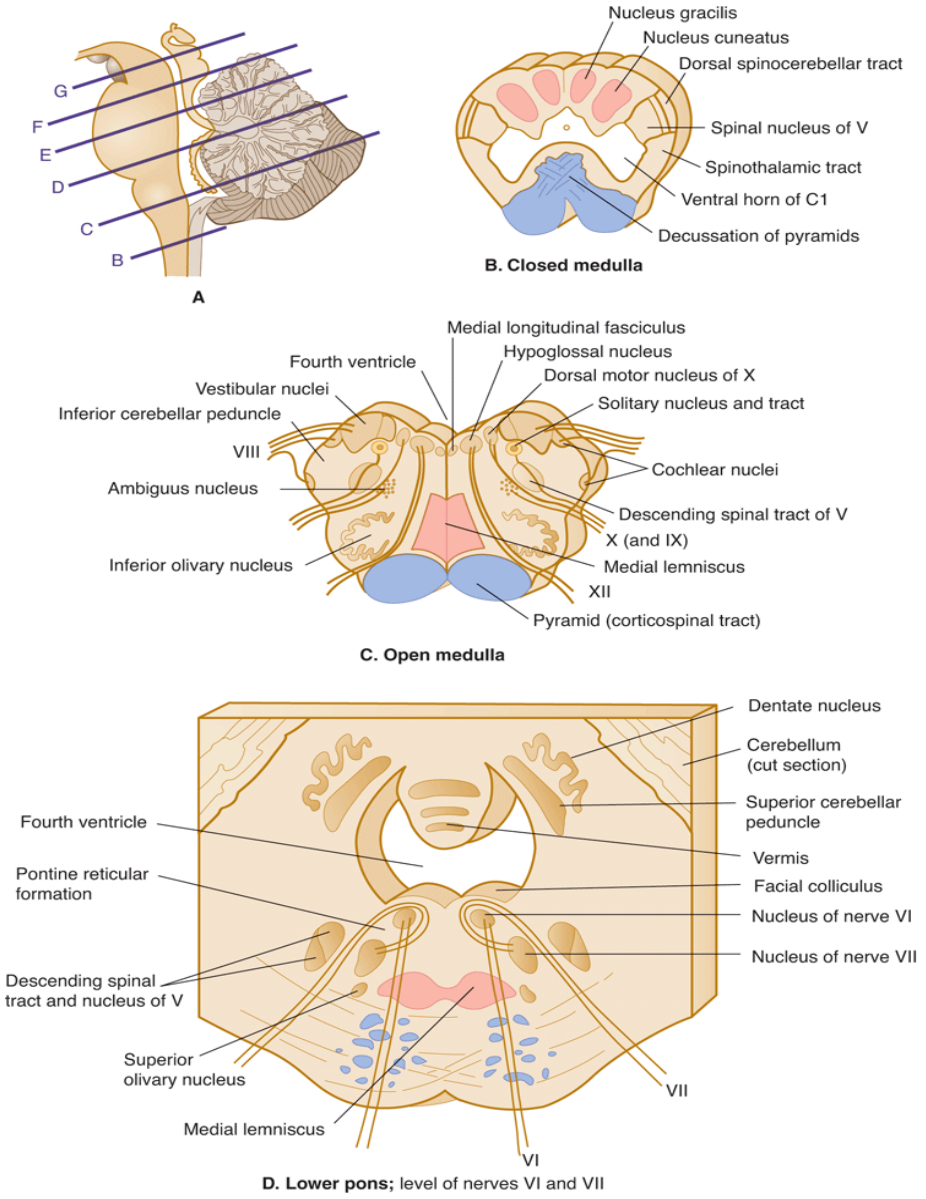
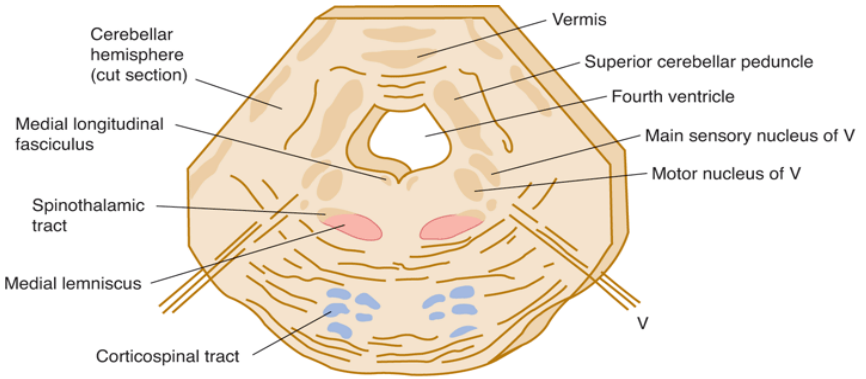
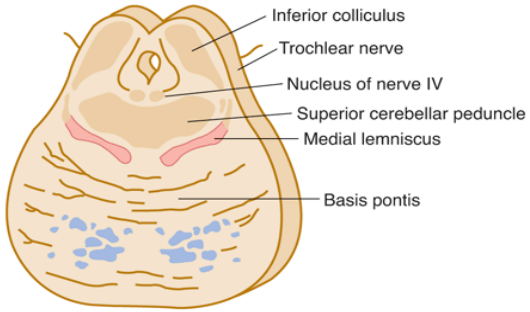


Fig. 7-7 Accessed 02/01/2010

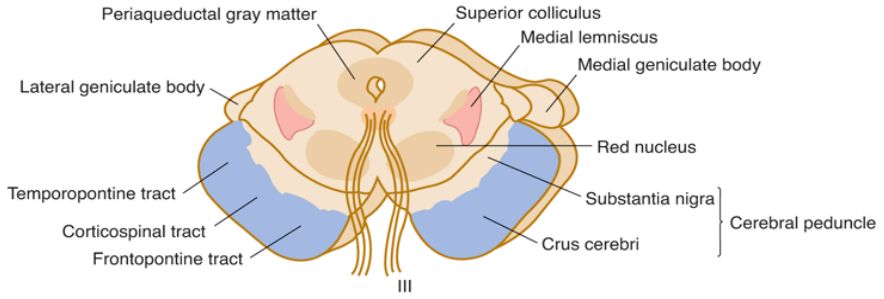
Slices through the brain stem relating nuclei to cranial nerves and major tracts



E. Middle pons; level of nerve V



F. Pons/midbrain; level of nucleus VI



G. Upper midbrain; level of nerve III

Fig. 7-7 Accessed 02/01/2010

Slices through the brain stem relating nuclei to cranial nerves and major tracts

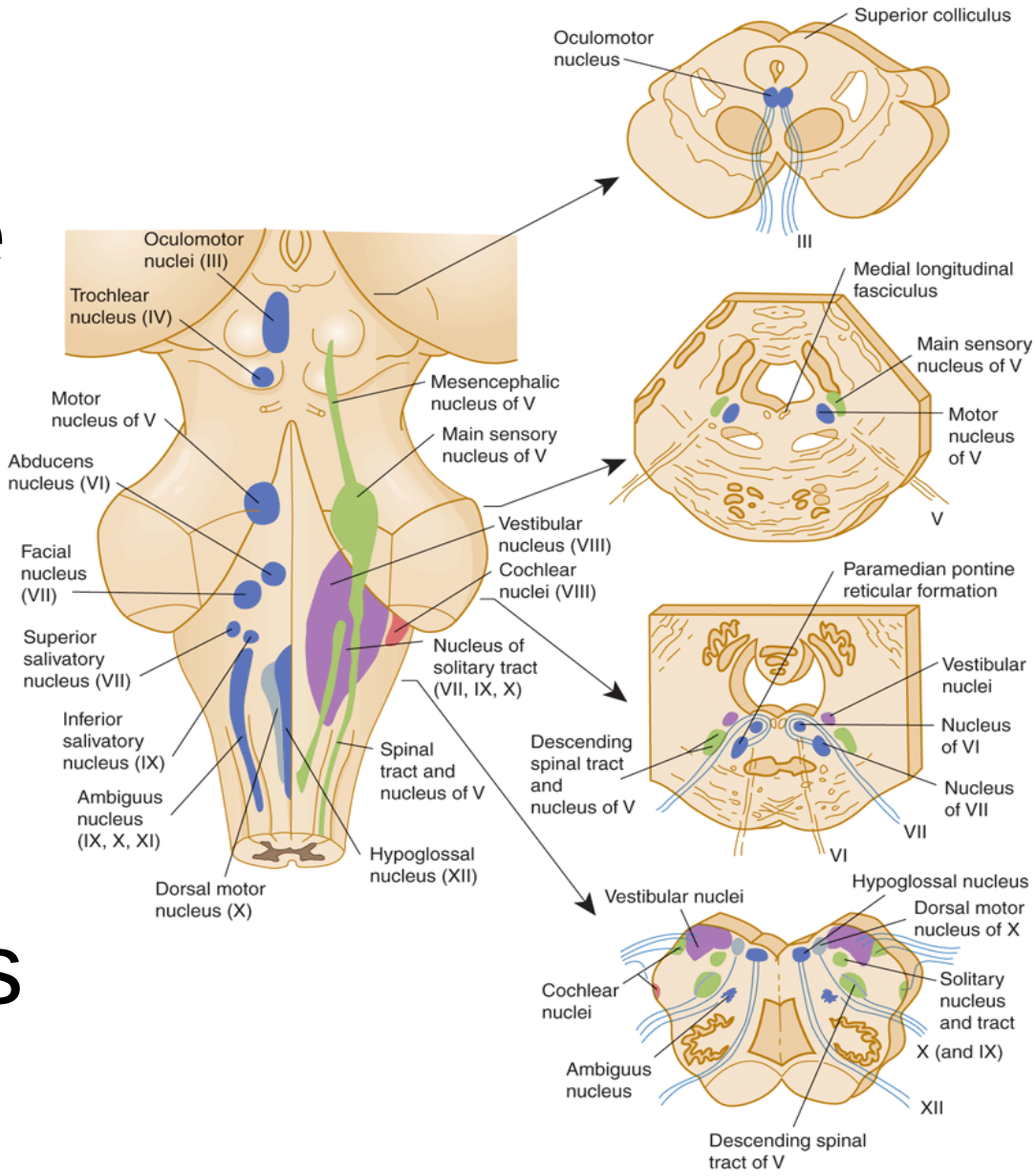
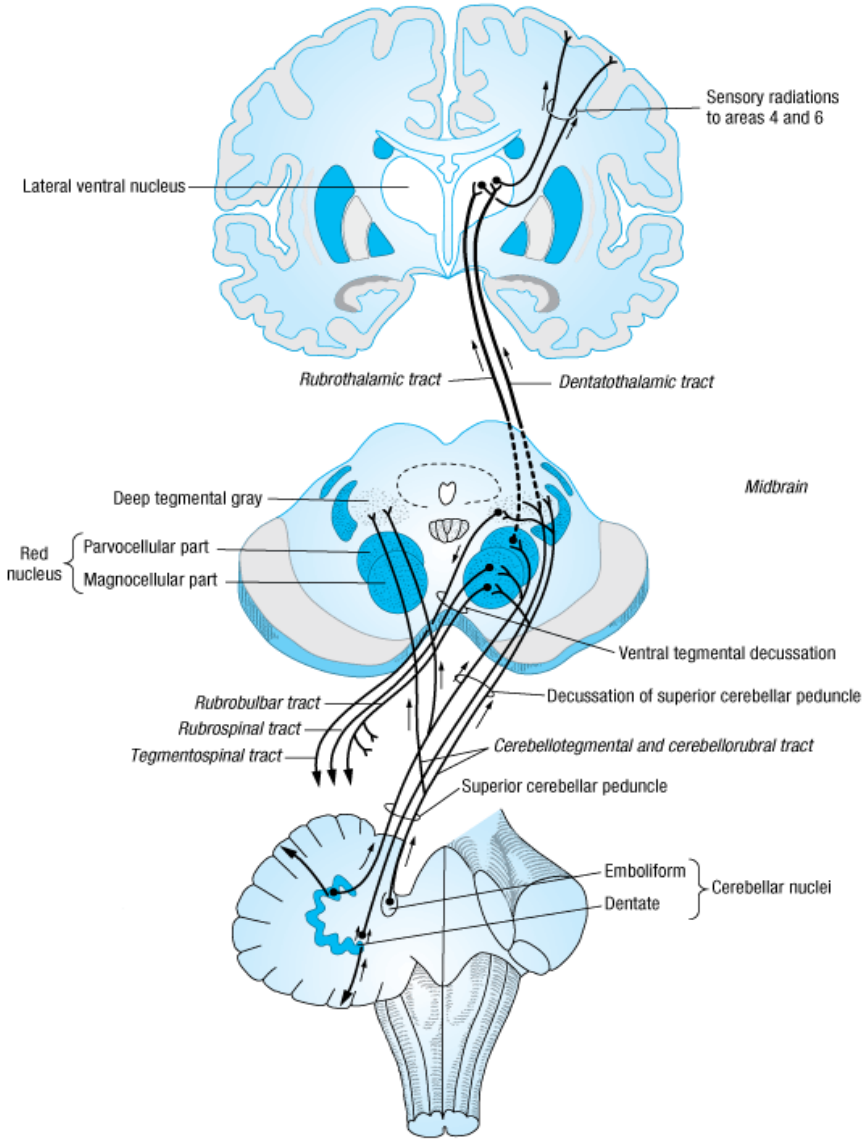


Fig. 7-6 Accessed 02/01/2010

Cerebellar projections



Source: Ropper AH, Samuels MA: *Adams & Victor's Principles of Neurology 9th Edition*: http://www.accessmedicine.com

(Adapted by permission from House EL et al: *A Systematic Approach to Neuroscience*, 3rd ed. New York, McGraw-Hill, 1979.)

Fig. 5-2 Accessed 02/01/2010

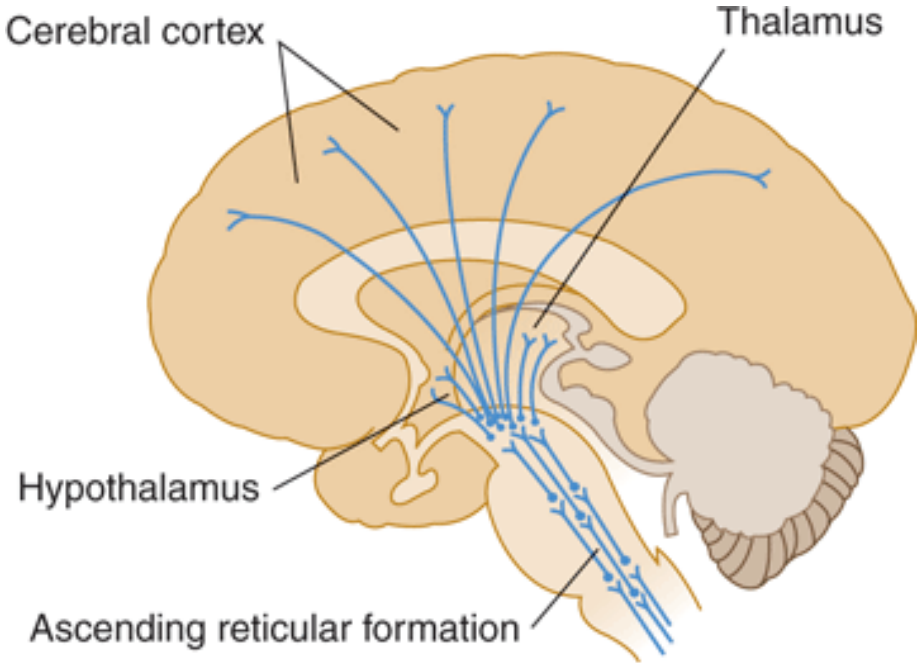
Ascending tracts

System	Function	Origin	Ending	Location in Cord
Dorsal column system	Fine touch, proprioception, two-point discrimination	Skin, joints, tendons	Dorsal column nuclei. Second-order neurons project to contralateral thalamus (cross in medulla at lemniscal decussation)	Dorsal column
Spinothalamic tracts	Sharp pain, temperature, crude touch	Skin	Dorsal horn. Second-order neurons project to contralateral thalamus (cross in spinal cord close to level of entry)	Ventro-lateral column

Ascending tracts

System	Function	Origin	Ending	Location in Cord
Dorsal spinocerebellar tract	Movement and position mechanisms	Muscle spindles, Golgi tendon organs, touch and pressure receptors via nucleus dorsalis (Clarke's column)	Cerebellar paleocortex (via ipsilateral inferior cerebellar peduncle)	Lateral column
Ventral spinocerebellar	Movement and position mechanisms	Muscle spindles, Golgi tendon organs, touch and pressure receptors	Cerebellar paleocortex (via contralateral and ipsilateral superior cerebellar peduncle)	Lateral column

Reticular formation



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

The spino-reticular tract ascends in the ventro-lateral column of the spinal cord. It has its origin in deep somatic structures. The pathway is polysynaptic. Deep and chronic pain is modulated through this path. Diffuse.

Fig. 18-1 Accessed 07/01/2010

Spinocerebellar tract

- The posterior spinocerebellar is principally concerned with non-conscious proprioception in the lower limb and trunk. Originates in posterior thoracic nucleus (Clarke's) in lamina VII. The nucleus runs from T1-L1.
- Receives afferents (joints, muscles, muscle spindle primaries) via the gracile fasciculus. Collaterals are received from cutaneous sensory neurons.
- Enters inferior cerebellar peduncle.

Spinocerebellar tract

- The cuneocerebellar tract is principally concerned with non- conscious propriocetion in the upper limb and trunk. Arises from the accessory cuneate nucleus. Afferents reach the tract via the cuneate fasciculus. As with the posterior spinocerebellar tract, this also enters the inferior cerebellar peduncle.
- Large, fast conducting (first-order) neurons
- Anterior and rostral spinocerebellar tracts report continuously the relation among the internuncial neurons of the spinal cord (spinal reflex arcs).

Spinocerebellar tract

- From the lower half of the cord, the component fibers of the anterior tract cross initially, enter the superior cerebellar peduncle, and re-cross within the cerebral white matter.
- From the upper half of the cord, the tract ascends without crossing and enters the inferior cerebellar peduncle.

Other ascending pathways

- The spinotectal tract runs alongside the spino-thalamic pathway which it resembles in origin and functional composition. It terminates in the superior colliculus where it joins crossed visual inputs involved in turning the eyes, head, trunk toward sources of sensory stimulation.
- The spino-olivary tract sends tactile information to the inferior olivary nucleus in the medulla oblongota. It may have a role in modifying olivary discharge when a moving part encounters an obstacle.

Reticular system

- Spinoreticular fibers originate in laminae V-VII and accompany the spinothalamic pathway as far as the brainstem.
- Half the fibers may be uncrossed.
- Terminate at all levels of the brainstem.
- Not somatotopically arranged.
- Impulse traffic is continued rostrally to the thalamus.
- Arouse the cerebral cortex.
- Inform limbic cortex of anterior cingulate gyrus about the nature of the stimulus.
- Can influence motor neurons as well as visceral functions via connections to autonomic centers

Reticular system

- The reticular formation can be divided into a number of distinct groups:
- Pre-cerebellar
- Central group is located mainly in the midbrain and includes the paramedian pontine reticular formation. This group contributes to the reticulospinal tract (motor) and the central tegmental tract (to thalamus).
- Cholinergic
- Catecholaminergic. Locus ceruleus.
- Lateral Parvocellular
- Parabrachial
- Medullary

Reticular system

- The parvocellular area is co-extensive with the “expiratory center” and the parabrachial area with the “pneumotaxic center”.
- Damage to the pontine (or higher) reticular formation results in coma.
- Damage to the medullary reticular formation results in insomnia.
- Projects to the thalamus as part of an ascending pathway for poorly localized pain.
- Descending 5HT neurons target sensory centers to prevent the relay of pain information.

Raphe nuclei

- Situated adjacent to the midline.
- Most raphe nuclei use 5HT and distribute to sensory centers, cerebral cortex, brainstem, cerebellum, and autonomic centers.
- Inputs to raphe nuclei arise in the cerebral cortex, hypothalamus, peri-acqueductal gray, and sensory centers.

Pain

- C fiber is not myelinated (autonomic, pain)
- Aα fiber thickly myelinated (motor)
- Aβ fiber (nociceptor)
- Aδ fiber thinly myelinated
- Aβ, Aδ, C found in layers I, V
- Large Aβ fibers inhibit level V
- Aδ, C inhibitory, principally found in level II (gating)
- In the dorsal horn, NMDA receptor activated by glycine; glutamate activates AMPA receptor. Voltage gated Na^+ channels altered. Hyperexcitability.

Pain

- ATF3 upregulated in small neurons in dorsal root ganglion. ATF3 is a cAMP dependent transcription factor (part of CREB complex).
- c-FOS upregulated in cells of lamina 1 and 2. FOS dimerizes with JUN to activate transcription factor AP1.
- Allodynia due to loss of central inhibition (GABA). Increased activity in descending inhibitory pathways.

Pain

- Burning pain as a result of ectopic C fiber discharge. (TRPV1 upregulated, particularly at 41C).
- If nociceptors damaged (Aβ fibers), TRPV1 production increases. TRPV1 is a non-selective Ca^{2+} permeant cation channel that leads to increased H^{+} influx and intracellular acidosis. Related to capsaicin function.
- Neuropathic pain characterized by sensory loss and hyperesthesia as well as allodynia.

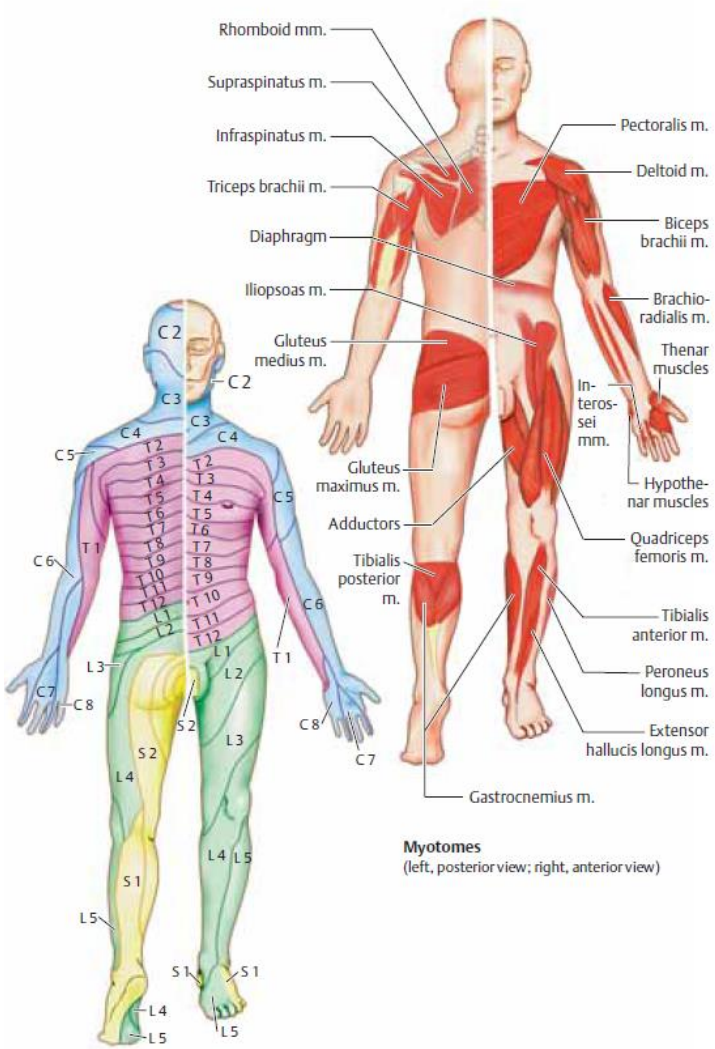
Pain

- Pulsed radiofrequency (ultrasound) induces temperature change (loss) of C and Aδ fibers. EPSP diminished.
- Glutamate opens post synaptic NDMA channels, may lead to central hypersensitization. Following central sensitization, nociceptive neurons lower firing threshold.
- μ receptors found in PAG, ventral medulla, dorsal horn

Chronic pain

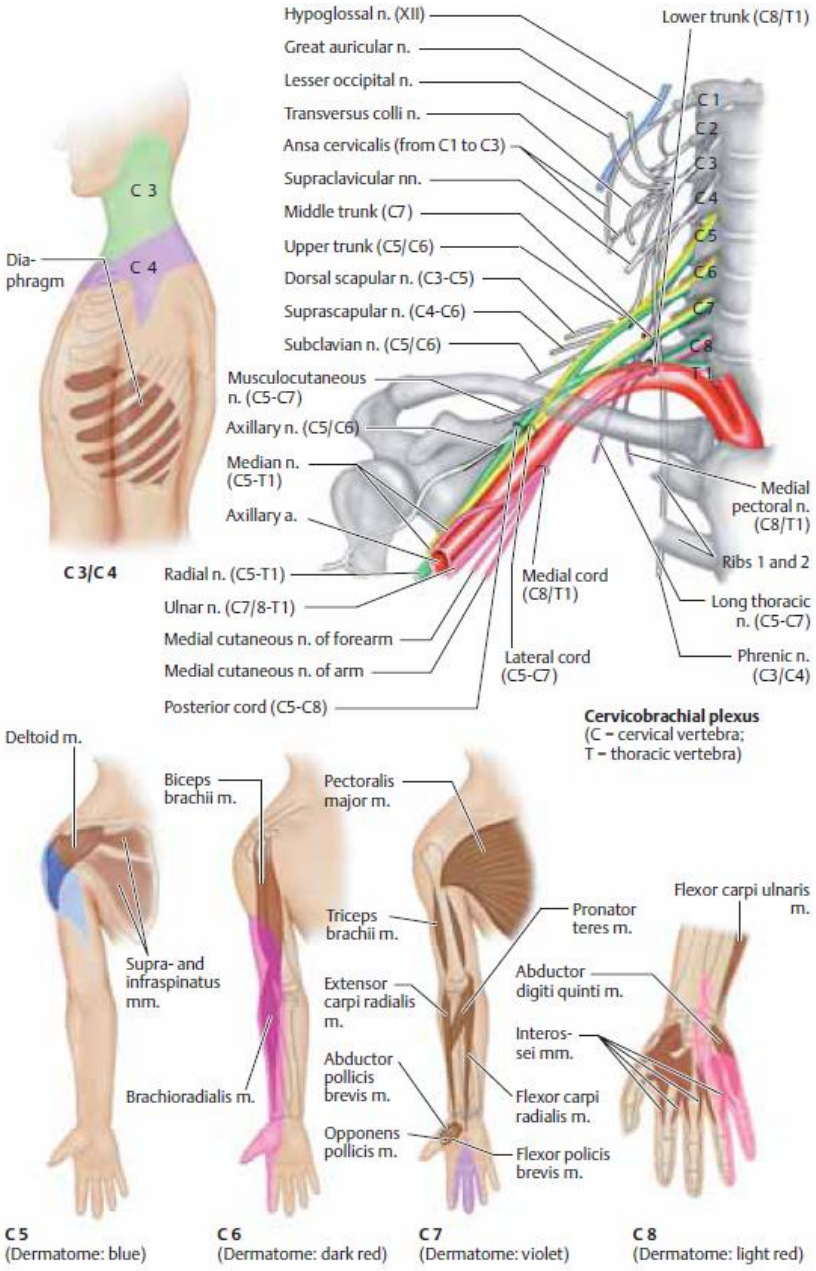
- Ventral posterolateral and ventral posteriormedial nuclei hyperactive in chronic pain; stimulation produces parasthesia.
- Cortical stimulation increases interval firing in thalamus; effective in reducing pain if central lesion of spinal cord.
- Periventricular gray stimulation leads to endorphin release.
- Amygdala activated in helplessness.
- Increased limbic area activity in pain anticipation.

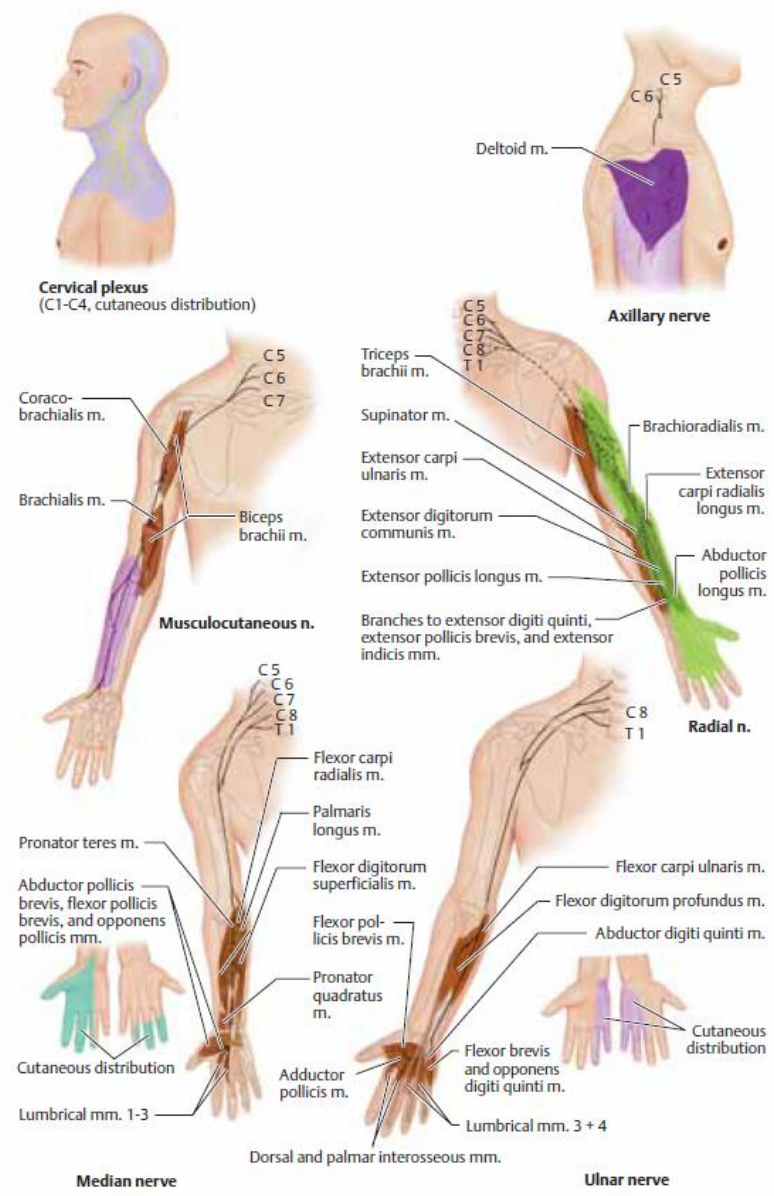
Dermatomes and myotomes

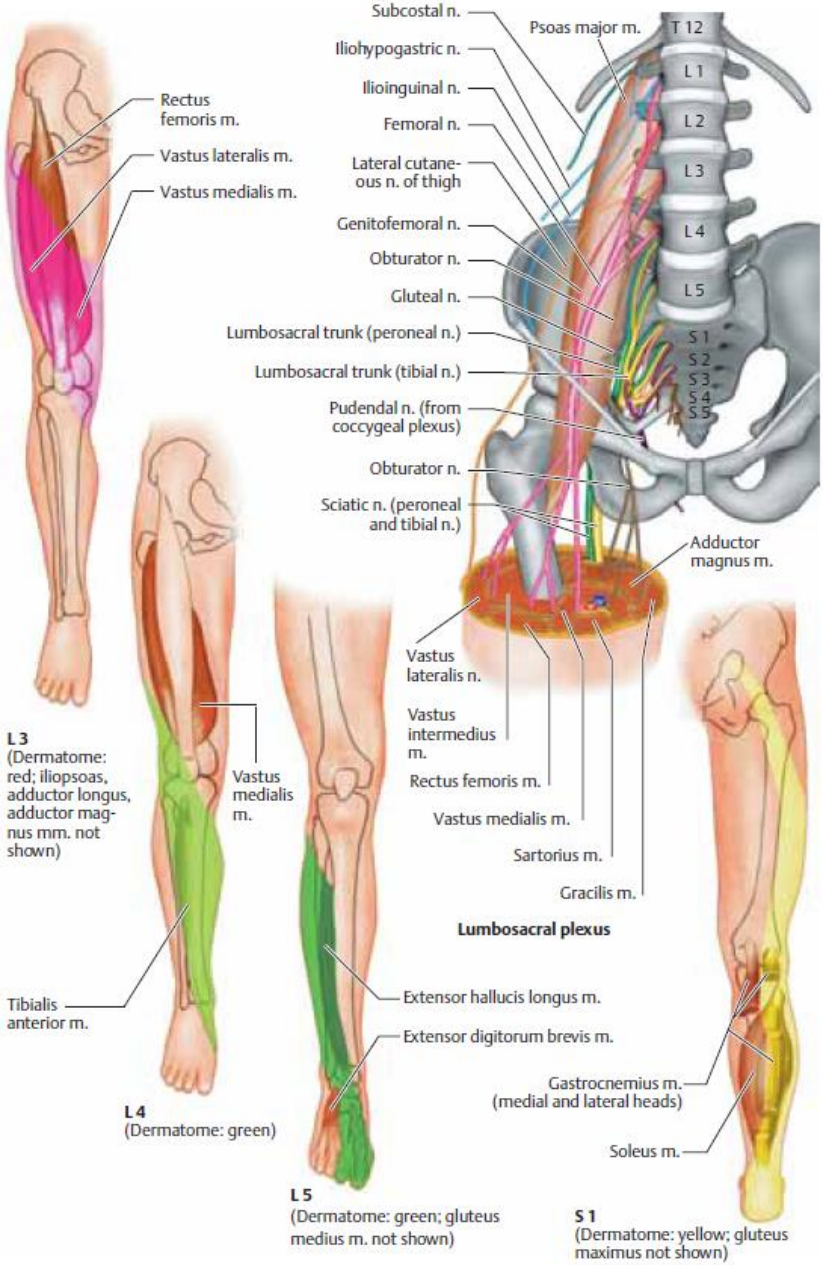


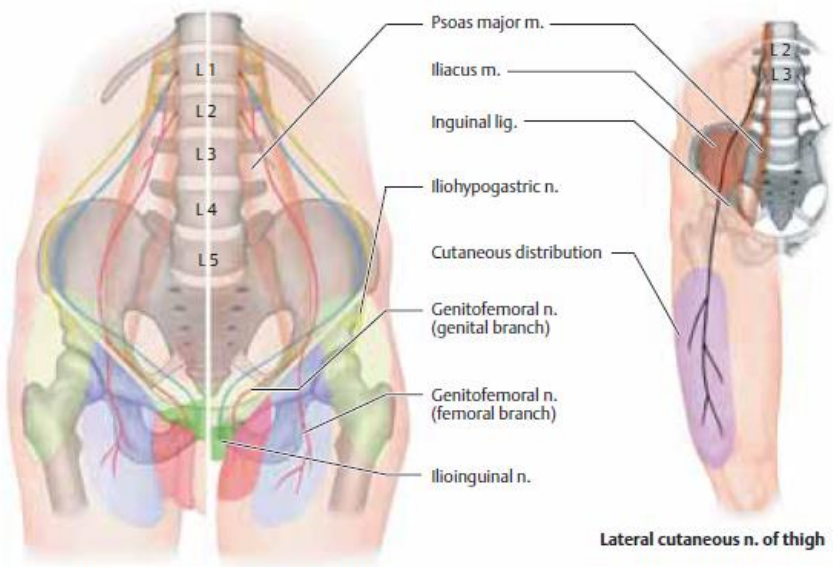
Myotomes
(left, posterior view; right, anterior view)

Dermatomes (left, posterior view; right, anterior view)

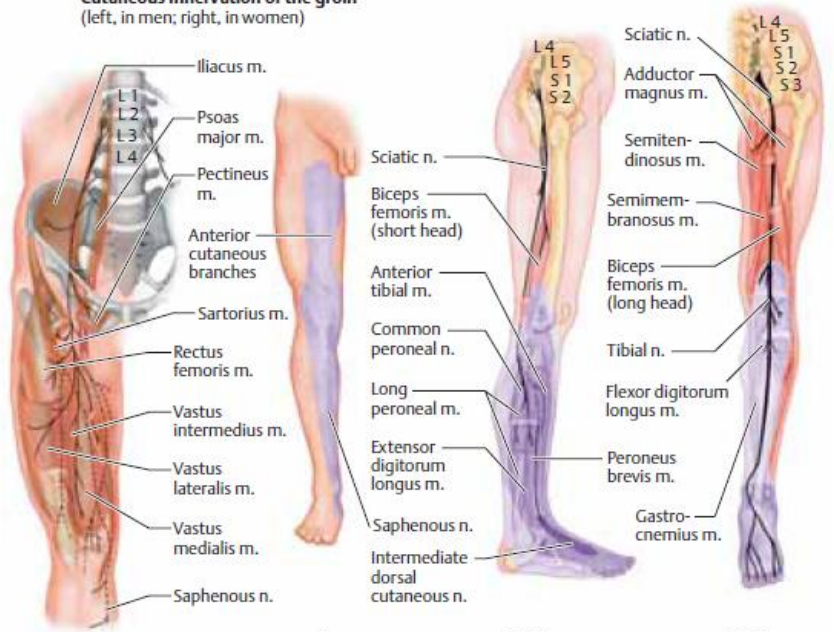

Hypoglossal n. (XII)
Great auricular n.
Lesser occipital n.
Transversus colli n.
Ansa cervicalis (from C1 to C3)
Supraclavicular nn.
Middle trunk (C7)
Upper trunk (C5/C6)
Dorsal scapular n. (C3-C5)
Suprascapular n. (C4-C6)
Subclavian n. (C5/C6)
Musculocutaneous n. (C5-C7)
Axillary n. (C5/C6)
Median n. (C5-T1)
Axillary a.
Radial n. (C5-T1)
Ulnar n. (C7/8-T1)
Medial cutaneous n. of forearm
Medial cutaneous n. of arm
Posterior cord (C5-C8)
Lateral cord (C5-C7)
Medial cord (C8/T1)
Lower trunk (C8/T1)
C 1
C 2
C 3
C 4
C 5
C 6
C 7
C 8
T 1
Medial pectoral n. (C8/T1)
Ribs 1 and 2
Long thoracic n. (C5-C7)
Phrenic n. (C3/C4)
C 3
C 4
Dia-phragm
C 3/C 4
Cervicobrachial plexus
(C = cervical vertebra;
T = thoracic vertebra)
Deltoid m.
Biceps brachii m.
Supra- and infraspinatus mm.
Brachioradialis m.
Pectoralis major m.
Triceps brachii m.
Extensor carpi radialis m.
Abductor pollicis brevis m.
Opponens pollicis m.
Pronator teres m.
Flexor carpi radialis m.
Flexor policis brevis m.
Flexor carpi ulnaris m.
Abductor digiti quinti m.
Interos-sei mm.
C 5
(Dermatome: blue)
C 6
(Dermatome: dark red)
C 7
(Dermatome: violet)
C 8
(Dermatome: light red)


Cervical plexus
(C1-C4, cutaneous distribution)
C 5
C 6
Deltoid m.
Axillary nerve
C 5
C 6
C 7
C 8
T 1
Triceps brachii m.
Supinator m.
Extensor carpi ulnaris m.
Extensor digitorum communis m.
Extensor pollicis longus m.
Branches to extensor digiti quinti, extensor pollicis brevis, and extensor indicis mm.
Brachioradialis m.
Extensor carpi radialis longus m.
Abductor pollicis longus m.
Radial n.
C 5
C 6
C 7
Coraco-brachialis m.
Brachialis m.
Biceps brachii m.
Musculocutaneous n.
C 5
C 6
C 7
C 8
T 1
Flexor carpi radialis m.
Palmaris longus m.
Pronator teres m.
Flexor digitorum superficialis m.
Abductor pollicis brevis, flexor pollicis brevis, and opponens pollicis mm.
Flexor pol-licis brevis m.
Pronator quadratus m.
Cutaneous distribution
Lumbrical mm. 1-3
Median nerve
C 8
T 1
Flexor carpi ulnaris m.
Flexor digitorum profundus m.
Abductor digiti quinti m.
Cutaneous distribution
Adductor pollicis m.
Flexor brevis and opponens digiti quinti m.
Lumbrical mm. 3 + 4
Dorsal and palmar interosseous mm.
Ulnar nerve


Subcostal n.
Iliohypogastric n.
Ilioinguinal n.
Femoral n.
Lateral cutaneous n. of thigh
Genitofemoral n.
Obturator n.
Gluteal n.
Lumbosacral trunk (peroneal n.)
Lumbosacral trunk (tibial n.)
Pudendal n. (from coccygeal plexus)
Obturator n.
Sciatic n. (peroneal and tibial n.)
Psoas major m.
T 12
L 1
L 2
L 3
L 4
L 5
S 1
S 2
S 3
S 4
S 5
Adductor magnus m.
Vastus lateralis n.
Vastus intermedius m.
Rectus femoris m.
Vastus medialis m.
Sartorius m.
Gracilis m.
Lumbosacral plexus
Rectus femoris m.
Vastus lateralis m.
Vastus medialis m.
L 3
(Dermatome: red; iliopsoas, adductor longus, adductor magnus mm. not shown)
Vastus medialis m.
Tibialis anterior m.
L 4
(Dermatome: green)
Extensor hallucis longus m.
Extensor digitorum brevis m.
L 5
(Dermatome: green; gluteus medius m. not shown)
Gastrocnemius m. (medial and lateral heads)
Soleus m.
S 1
(Dermatome: yellow; gluteus maximus not shown)



Cutaneous innervation of the groin
(left, in men; right, in women)



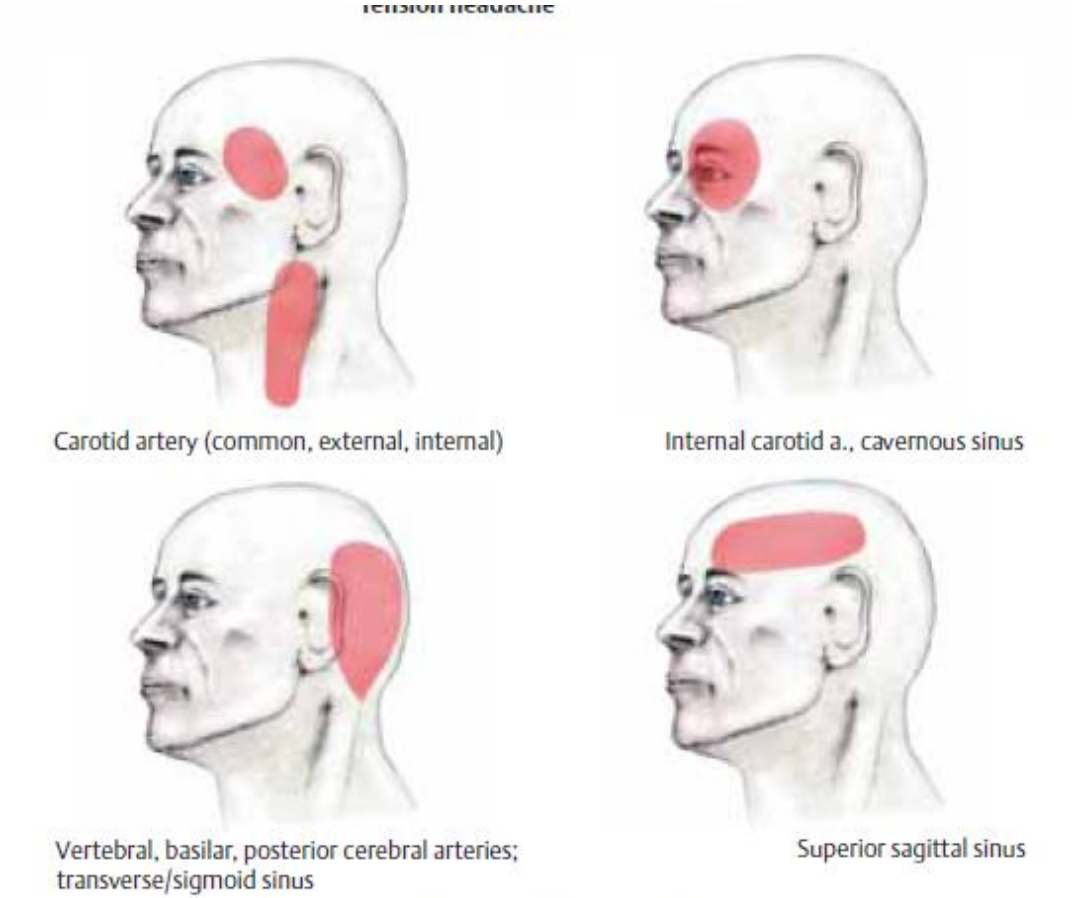
Femoral nerve

Femoral nerve
(cutaneous distribution)

Sciatic nerve, peroneal nerve
(purple: cutaneous distribution)

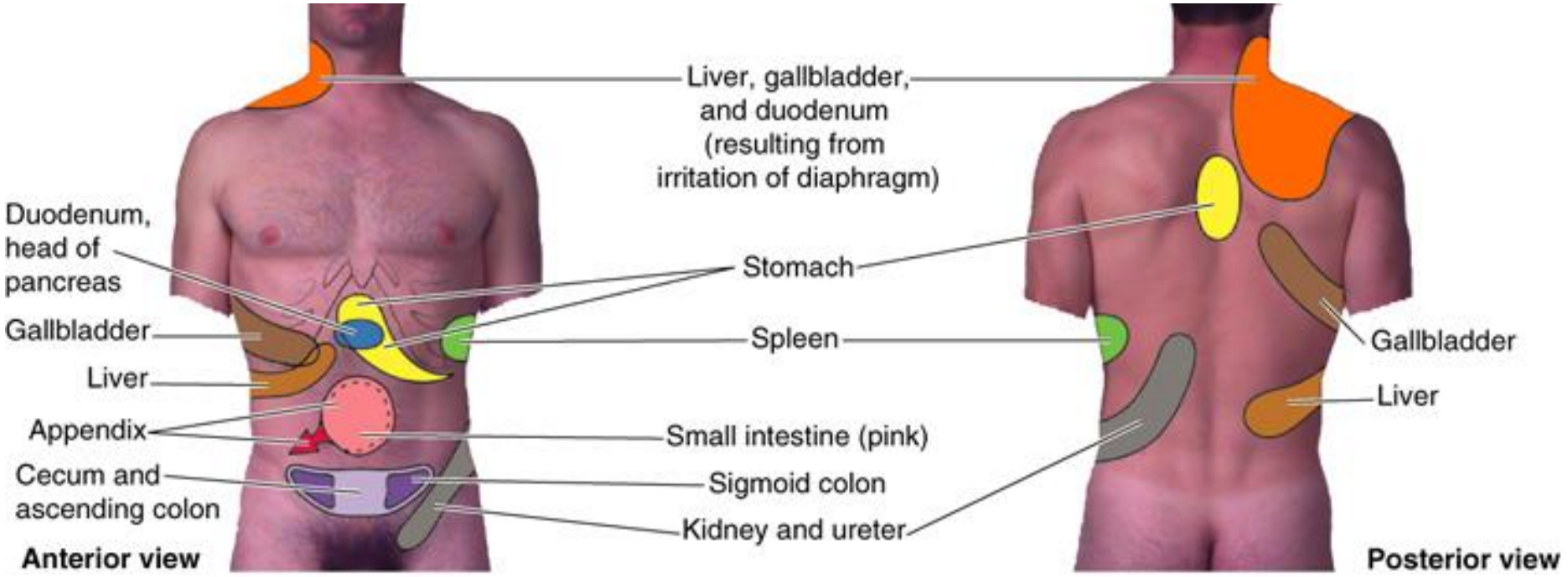
Sciatic nerve, tibial nerve
(purple: cutaneous distribution)

Referred pain

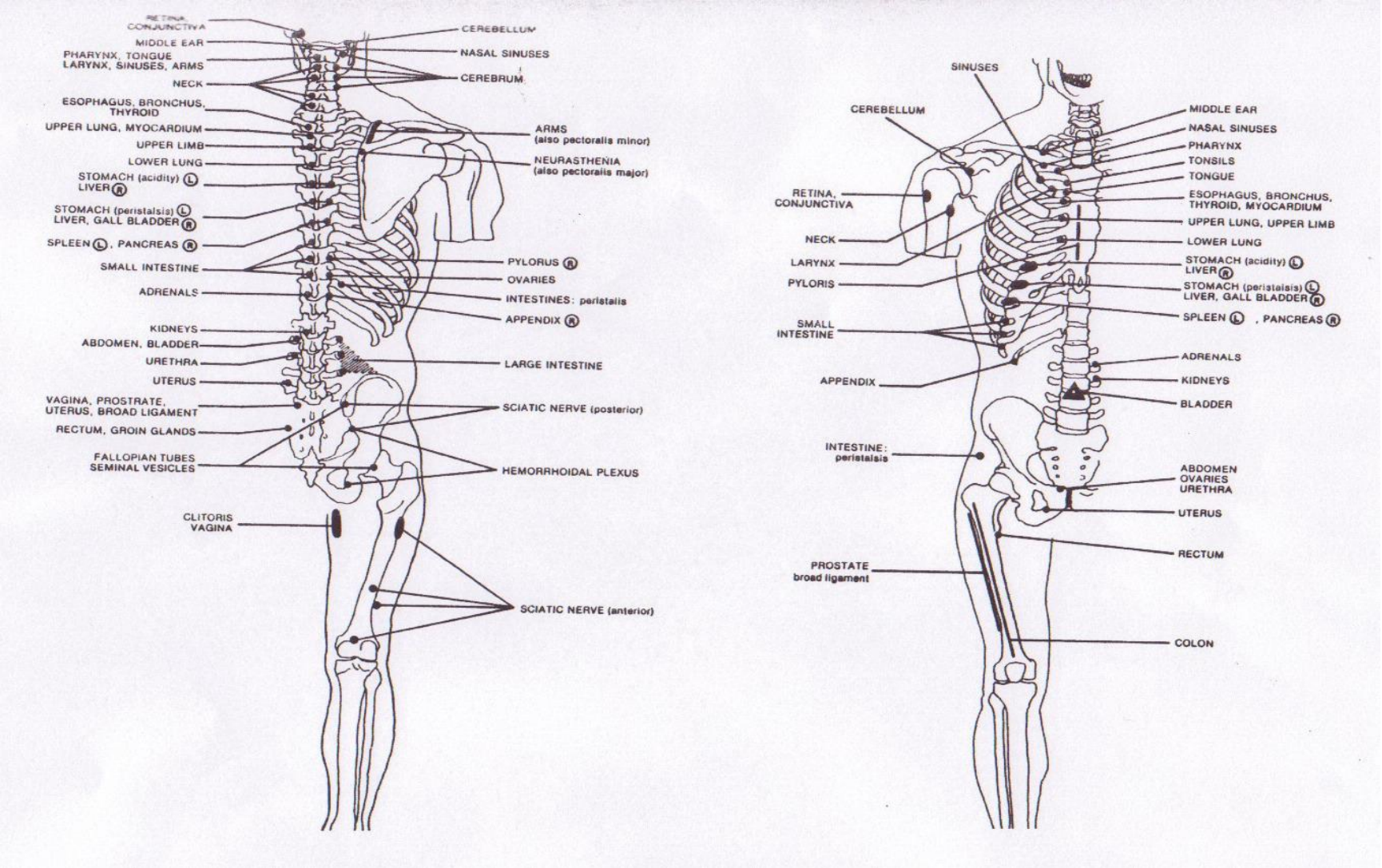


Referred pain due to cerebrovascular lesions

Referred abdominal pain

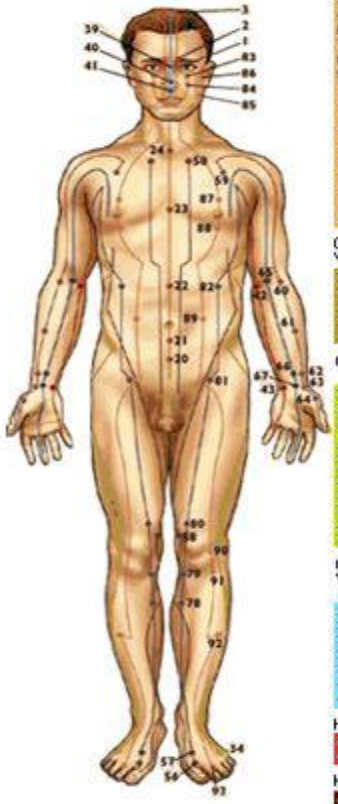


Chapman reflex points



Acupuncture points and meridians

Figure 1a



Bladder (BL)
1 BL1
2 BL2
3 BL7
4 BL10
5 BL13
6 BL23
7 BL25
8 BL27
9 BL28
10 BL29
11 BL30
12 BL31
13 BL32
14 BL33
15 BL34
16 BL40
17 BL57
18 BL58
19 BL60

Conception Vessel (CV)
20 CV4
21 CV6
22 CV12
23 CV17
24 CV22

Gall Bladder (GB)
25 GB 2
26 GB 8
27 GB 14
28 GB 20
29 GB 21
30 GB 30
31 GB 34
32 GB 39
33 GB 40
34 GB 41

Governing Vessel (GV)
35 GV4
36 GV14
37 GV16
38 GV20
39 GV24.5
40 GV25
41 GV26

Heart (HE)
42 HE3
43 HE7

Kidney (KI)
44 KI1
45 KI2
46 KI3
47 KI5
48 KI6
49 KI7
50 KI27

Large Intestine (LI)
51 LI4
52 LI10
53 LI11
54 LI15
55 LI20

Liver (LV)
56 LV2
57 LV3
58 LV8

Lung (LU)
59 LU1
60 LU5
61 LU6
62 LU7
63 LU9
64 LU10

Pericardium (PE)
65 PE3
66 PE6
67 PE7

Small Intestine (SI)
68 SI3
69 SI4
70 SI5
71 SI8
72 SI10
73 SI11
74 SI17

Spleen (SP)
75 SP 3
76 SP 4
77 SP 6
78 SP 8
79 SP 9
80 SP 10
81 SP 12
82 SP 16

Stomach (ST)
83 ST 2
84 ST 3
85 ST 6
86 ST 7
87 ST 16
88 ST 18
89 ST 25
90 ST 35
91 ST 36
92 ST 40
93 ST 44

Triple Warmer (TW)
94 TW 3
95 TW 4
96 TW 5
97 TW 15
98 TW 17
99 TW 21

Acupuncture points and meridians

Figure 1b

Bladder (BL)
1 BL1
2 BL2
3 BL7
4 BL10
5 BL13
6 BL23
7 BL25
8 BL27
9 BL28
10 BL29
11 BL30
12 BL31
13 BL32
14 BL33
15 BL34
16 BL40
17 BL57
18 BL58
19 BL60

Conception Vessel (CV)
20 CV4
21 CV6
22 CV12
23 CV17
24 CV22

Gall Bladder (GB)
25 GB 2
26 GB 8
27 GB 14
28 GB 20
29 GB 21
30 GB 30
31 GB 34
32 GB 39
33 GB 40
34 GB 41

Governing Vessel (GV)
35 GV4
36 GV14
37 GV16
38 GV20
39 GV24.5
40 GV25
41 GV26

Heart (HE)
42 HE3
43 HE7

Kidney (KI)
44 KI1
45 KI2
46 KI3
47 KI5
48 KI6
49 KI7
50 KI27

Large Intestine (LI)
51 LI4
52 LI10
53 LI11
54 LI15
55 LI20

Liver (LV)
56 LV2
57 LV3
58 LV8

Lung (LU)
59 LU1
60 LU5
61 LU6
62 LU7
63 LU9
64 LU10

Pericardium (PE)
65 PE3
66 PE6
67 PE7

Small Intestine (SI)
68 SI3
69 SI4
70 SI5
71 SI8
72 SI10
73 SI11
74 SI17

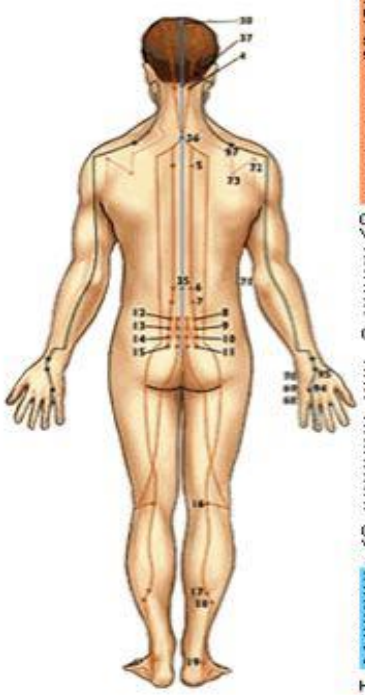
Spleen (SP)
75 SP 3
76 SP 4
77 SP 6
78 SP 8
79 SP 9
80 SP 10
81 SP 12
82 SP 16

Stomach (ST)
83 ST 2
84 ST 3
85 ST 6
86 ST 7
87 ST 16
88 ST 18
89 ST 25
90 ST 35
91 ST 36
92 ST 40
93 ST 44

Triple Warmer (TW)
94 TW 3
95 TW 4
96 TW 5
97 TW 15
98 TW 17
99 TW 21

Acupuncture points and meridians

Figure 1c



Bladder (BL)
1 BL1
2 BL2
3 BL7
4 BL10
5 BL13
6 BL23
7 BL25
8 BL27
9 BL28
10 BL29
11 BL30
12 BL31
13 BL32
14 BL33
15 BL34
16 BL40
17 BL57
18 BL58
19 BL60

Conception Vessel (CV)
20 CV4
21 CV6
22 CV12
23 CV17
24 CV22

Gall Bladder (GB)
25 GB 2
26 GB 8
27 GB 14
28 GB 20
29 GB 21
30 GB 30
31 GB 34
32 GB 39
33 GB 40
34 GB 41

Governing Vessel (GV)
35 GV4
36 GV14
37 GV16
38 GV20
39 GV24.5
40 GV25
41 GV26

Heart (HE)
42 HE3
43 HE7

Kidney(KI)
44 KI1
45 KI2
46 KI3
47 KI5
48 KI6
49 KI7
50 KI27

Large Intestine(LI)
51 LI4
52 LI10
53 LI11
54 LI15
55 LI20

Liver (LV)
56 LV2
57 LV3
58 LV8

Lung (LU)
59 LU1
60 LU5
61 LU6
62 LU7
63 LU9
64 LU10

Pericardium (PE)
65 PE3
66 PE6
67 PE7

Small Intestine(SI)
68 SI3
69 SI4
70 SI5
71 SI8
72 SI10
73 SI11
74 SI17

Spleen(SP)
75 SP 3
76 SP 4
77 SP 6
78 SP 8
79 SP 9
80 SP 10
81 SP 12
82 SP 16

Stomach(ST)
83 ST 2
84 ST 3
85 ST 6
86 ST 7
87 ST 16
88 ST 18
89 ST 25
90 ST 35
91 ST 36
92 ST 40
93 ST 44

Triple Warmer(TW)
94 TW 3
95 TW 4
96 TW 5
97 TW 15
98 TW 17
99 TW 21

Solar reflex points