<table>
<thead>
<tr>
<th>Tract</th>
<th>Origin</th>
<th>Crossing</th>
<th>Synapse</th>
<th>Ends</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor Descending Pathways (Ventral Root)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCST</td>
<td>M1</td>
<td>pyramids (medulla)</td>
<td>lateral intermediate zone</td>
<td>full cord</td>
<td>limb movement</td>
</tr>
<tr>
<td>ACST</td>
<td>M1</td>
<td>bilateral</td>
<td>medial intermediate zone</td>
<td>cervical/thoracic</td>
<td>gait &amp; posture</td>
</tr>
<tr>
<td>Rubrospinal</td>
<td>red nucleus</td>
<td>central tegmental decussation (midbrain)</td>
<td></td>
<td>cervical cord</td>
<td>unknown</td>
</tr>
<tr>
<td>Lateral Vestibulospinal</td>
<td>pons (superior ganglia)</td>
<td>extrapyramidal</td>
<td>full cord</td>
<td>balance</td>
<td></td>
</tr>
<tr>
<td>Medial Vestibulospinal</td>
<td>medulla (inferior ganglia)</td>
<td>bilateral</td>
<td></td>
<td>cervical/thoracic; medial longitudinal fasciculus</td>
<td>head &amp; neck; ocular muscles</td>
</tr>
<tr>
<td>Reticulospinal</td>
<td>reticular formation</td>
<td>extrapyramidal</td>
<td>full cord</td>
<td>gait &amp; posture</td>
<td></td>
</tr>
<tr>
<td>Tectospinal</td>
<td>superior colliculus</td>
<td>extrapyramidal</td>
<td>cervical</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td><strong>Autonomic Pathways (Dorsal Root)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SANS</td>
<td></td>
<td>paravertebral ganglion (symp. chain)</td>
<td>thoracic/lumbar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PANS</td>
<td></td>
<td>peripheral</td>
<td>brainstem/sacral</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Somatosensory Ascending Pathways (Dorsal Root)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsal Column</td>
<td>fasciculus gracilis (lower) &amp; cuneatus (higher)</td>
<td>medial lemniscus (internal arcuate) in medulla</td>
<td>DRG</td>
<td>VPL → S1</td>
<td>vibration &amp; position sense</td>
</tr>
<tr>
<td>Anterolateral/ Spinothalamic</td>
<td>full cord</td>
<td>anterior commissure (2 levels above)</td>
<td>VPL → S1</td>
<td>pain &amp; temperature &amp; crude touch</td>
<td></td>
</tr>
<tr>
<td>Dorsal &amp; Cuneo Spinocerebellar</td>
<td>Golgi tendon organ &amp; spindle fibers</td>
<td>does not cross</td>
<td>Clark’s &amp; cuneate nuclei</td>
<td>cerebellum</td>
<td>proprioreception</td>
</tr>
<tr>
<td>Mesencephalic</td>
<td>face</td>
<td>does not cross</td>
<td></td>
<td></td>
<td>proprioreception</td>
</tr>
<tr>
<td>Chief</td>
<td>face</td>
<td>trigeminal lemniscus in midbrain</td>
<td>trigeminal ganglion</td>
<td>VPM → S1</td>
<td>fine touch &amp; dental pressure</td>
</tr>
<tr>
<td>Spinal</td>
<td>face</td>
<td>trigeminothalamic tract in midbrain</td>
<td>trigeminal ganglion</td>
<td>VPM → S1</td>
<td>pain &amp; temperature &amp; crude touch</td>
</tr>
</tbody>
</table>
tracts
M1 → internal capsule (posterior limb) → cerebral peduncles (midbrain) & basis pontis (pons) → pyramids
VPL/VPM (gets raw & processed copy) → internal capsule (posterior limb) → S1
cauda equina: below L1

reflex arcs
muscle spindle (stretch) & Golgi tendon (force) afferents
muscle stretch → Ia afferent firing rate increases → gamma efferents cause intrafusal fiber contraction & increase gain AND extensor contraction via alpha MN, flexor relaxation via interneurons on alpha MN (+ DC/SCT)
   input to M1 → inhibition of inhibition → more input to gamma MN → intrafusal fibers of extensor contract → raise Ia gain
gamma: tension → Ia → SCT → cerebellum → excitatory → inhibitory → gamma (contract spindle)
withdrawal/crossed-extensor reflex:
thermo/nocio receptors → ALT → VPL
excitation of ipsilateral flexor & contralateral extensor
inhibition of ipsilateral extensor & contralateral flexor
UMN disease:
rest: increased gamma MN activity enhances muscle tone → shortens spindle, increasing Ia gain
stretch: Ia activity elevation is abnormally high → sudden movements leads to spasticity & clonus
Babinski’s sign: extensor (toes fanned) plantar response

sensory neurons
touch: mechanoreceptors with different 2-point discrimination
   Merkel (texture) & Meissner (motion) = small, superficial receptive fields
   Pacinain (vibration) & Ruffini (stretch) = large, deep receptive fields
thermo/nocioreceptors: free nerve endings with chemical & heat-sensitive channels
Nerve Plexus
terms to know: transverse & spinous processes, intervertebral disc (usually herniates laterally), foramen (spinal column)
cervical nerves exit below disc → thoracic & lumbar nerves exit above disc → sacral nerves exit not next to discs
plexuses are susceptible to avulsion (tearing) injury → eg whiplash can damage nerves
cervical plexus – C1-C5, including phrenic nerve (C3-C5)

Brachial Plexus
radial (C5-T1):
• motor: arm extension, forearm and thumb movements
• sensory: medial (inner) surfaces of arm
median (C5-T1):
• motor: wrist and thumb movements
• sensory: first three fingers, palm
ulnar (C6,8 and T1):
• motor: wrist and finger movements
• sensory: outer two fingers and palm
axillary (C5,6; axilla = armpit):
• motor: abduction of shoulder
• sensory: sensation on shoulder
musculocutaneous (C5-7):
• motor: arm flexion and supination
• sensory: lower arm

Lumbar Plexus
femoral (L2-L4):
• motor: raise femur (quads), extend shin
• sensory: upper thigh and medial shin
obiturator (L2-L4):
• motor: adduct femur
• sensory: inner thigh
sciatic (L4-S2):
• motor: flex knee (hamstrings)
• sensory: calf and top of foot
• gives rise to: tibial (plantar flexion, sensation on soles of feet) and peroneal (foot eversion, dorsiflexion, sensation on lateral shin and toes) nerves
Motor/Sensory Deficits

- ALS: primary (cortical UMNs), bulbar (brainstem LMNs), typical (spinal cord LMNs)
- MS: demyelinating neuropathy (disease of axon tracts)
- musculoskeletal (e.g., disc disease, trauma; myasthenia gravis (autoimmune NMJ) & muscular dystrophy)
- peripheral neuropathies (e.g., diabetes- and chemotherapy-induced; stocking and glove syndrome)
- diseases affecting LMNs (e.g., polio) and DRG neurons (e.g., syphilis)
- cortical lesions (bilateral loss in internal capsule & pyramids (below face); graphesthesia & stereognosis)
- UMN vs LMN: atrophy & fasciculations vs clonus; tone; power

ALS

- amyotrophic lateral sclerosis
- motor neurons die from oxidative stress: unique expression of transporters, glutamate receptors, and Ca2+ buffers
- treatment: Na channel inhibition to tamper exitotoxicity
- mitochondria failing → oxidative stress → not enough ATP → defective axonal transport → not interacting with postsynaptic partners → loss of trophic factors → presynaptic die back → stress → don’t buffer calcium well → activate secondary messengers they shouldn’t → more mitochondrial damage → reactive gliosis → AHHHHHHHHHH
- Wallerian degeneration - damaged nerve retracts from target towards root
- familial ALS: mutated superoxide dismutase interferes with ETC, triggering apoptosis
- BCL2 family regulates apoptosis by modulating cytochrome c release
- excitotoxicity hypothesis: NMDA receptors letting in too much calcium, binding too often, too much extracellular glutamate, glial cells aren’t reuptaking glutamate

Multiple Sclerosis

- autoimmune attack of myelin sheaths (interleukin receptor mutation; shown in oligoclonal CSF bands) → reactive gliosis (diffuse glial white matter lesions) → diffuse symptoms (mood, optic neuritis, dysarthria, etc)
- treatment: reduce permeability of BBB to immune cells; inhibit IL genes in T cells and IL receptor in B cells
**KEY**
- Lesion
- Sensory/Motor Loss: Vibration and position sense loss
- Pain and temperature sense loss
- Motor loss

**Spinal Cord Structures**
- Posterior columns (vibration and position sense)
- Lateral corticospinal tract (UMN)
- Anterior horn cells (LMN)
- Anterolateral pathway (pain and temperature sense)
- Ventral commissure

### Radial
- Extension at all arm, wrist, and proximal finger joints below the shoulder; forearm supination; thumb abduction in plane of palm
- Posterior cutaneous nerve of arm
- Posterior cutaneous nerve of forearm
- Dorsal digital nerves (radial)

### Median
- Thumb flexion and opposition, flexion of digits 2 and 3, wrist flexion and abduction, forearm pronation

### Ulnar
- Finger adduction and abduction other than thumb; thumb adduction; flexion of digits 4 and 5; wrist flexion and adduction

### Axillary
- Abduction of arm at shoulder beyond first 15°

### Musculo-cutaneous
- Flexion of arm at elbow, supination of forearm

### Femoral
- Leg flexion at the hip, leg extension at the knee
- Femoral nerve

### Obturator
- Adduction of the thigh
- Obturator nerve

### Sciatic
- Leg flexion at the knee (see also tibial and peroneal nerves, in column at left)
- Common peroneal nerve
- Sural nerve
- Common peroneal nerve
- Tibial nerve
- Sural nerve

### Tibial
- Foot plantar flexion and inversion, toe flexion
- Tibial nerve

### Superficial peroneal
- Foot eversion
- Superficial peroneal nerve

### Deep peroneal
- Foot dorsiflexion, toe extension
- Deep peroneal nerve

### C5
- Deltoid, infraspinatus, biceps
- Biceps, pectoralis
- Shoulder, upper lateral arm

### C6
- Wrist extensors, biceps
- Biceps, brachioradialis
- First and second fingers, lateral forearm

### C7
- Triceps
- Triceps
- Third finger

### L4
- Iliopsoas, quadriceps
- Patellar tendon (knee jerk)
- Knee, medial lower leg

### L5
- Foot dorsiflexion, big toe extension, foot eversion, inversion
- None
- Dorsum of foot, big toe

### S1
- Foot plantar flexion
- Achilles tendon (ankle jerk)
- Lateral foot, small toe, sole
**Cranial Nerves**

midbrain = 2-4; pons = 5-7; medulla = 8-11

CN2: retinal ganglion cells → *dorsal lateral geniculate nucleus of thalamus* (image-forming)  
*superior colliculus* (eye movement → vestibular output)  
*superchiasmatic nucleus* (light intensity → pupillary reflex & circadian regulation)

CN8: hearing: cochlea → cochlear nerve (soma in spiral ganglion) → cross extensively in trapezoid body fibers → lateral lemniscus carries output to contralateral inferior colliculus  
vestibular sense: semicircular canals = angular acceleration; utricle & saccule = linear acceleration

**Eyes:**
muscles: 3 (medial & upward), 4 (superior oblique – head tilt), 6 (lateral rectus)  
PANS: 3 (pupils & lens), 7 (lacrimal glands), 9 (lacrimal glands)

**Mouth:**
motor: 12 (tongue), 5 (mastication)  
salivary glands: 7  
taste: 7 (front), 9 (back), 10 (epiglottis & pharynx)  
sensory: 5 (front tongue & teeth), 9 (back tongue)

**Ear:**
motor: 5 (tensor tympani) & 7 (stapedius)  
somatic sensory: 7 & 10 (outer), 9 (inner & outer)  
hearing & vestibular senses: 8

**Face:**
motor: 7  
sensory: 5

**Throat:**
motor: 9 & 10 (swallowing), 10 (voice box)  
sensory: 9 & 10 (pharynx)

**Parasympathetic:**
carotid body chemo & carotid sinus baro-receptor: 9  
aortic arch chemo & baro-receptor: 10  
all organs of chest and abdomen (heart, lungs, & digestive tract via splenic flexure): 10

**cranial nerve pathology**

- CN III,IV,VI palsies
- Migraine (CN V): cerebrovascular (CAv2.1 channel antagonists, triptans to block transmission from spinal noocioreceptors, tricyclics to lower cortical excitability, steroids treat CBF & CSD)
- Wallenberg syndrome (CN V): medullary stroke above ALT crossing & below trigeminal crossing; pain/temperature loss contralateral, trigeminal loss ipsilateral
- UMN (CN VII): spares forehead; can also cause arm/hand weakness
- Bell’s palsy (CN VII): entire face; simultaneous PANS & motor output; treat with steroids
- Hearing/vestibular deficits (CN VIII)
Brainstem
label: 5 structures, 4 junctions, inferior olive, pyramid, pyramidal decussation, superior & inferior colliculus, cerebral peduncle, cerebellar peduncles, nuclei cuneatus & gracilis cranial nuclei - sensory & motor pathways carry information from multiple nuclei, but are spatially segregated (motor is medial & sensory is lateral)
inferior olive – inputs: contralateral SCT & CST + ipsilateral M1 & red nucleus 
output: contralateral cerebellum
midbrain: tectum: superior colliculus (visual nuclei) & inferior colliculus (auditory nuclei) → tecto & vestibulo spinal tracts
tegmentum: substantia nigra, red nucleus, periaqueductal grey, & reticular formation +
medial lemniscus
pain: ALT & limbic system → periaqueductal grey → modulates dorsal columns
basis: long tracts of corticospinal & corticobulbar fibers
pons: pontomesencephalic reticular formation (PRF) receives inputs from somatosensory (cord),
limbic/cingulate cortex, frontoparietal association cortex, & thalamic reticular nucleus
thalamic reticular nucleus: cortical input → modulate other thalamic structures → project
to PRF
locked-in syndrome: bilateral damage to corticospinal & corticobulbar tracts in ventral pons

neurotransmitters
up = cortex, thalamus, & basal ganglia
down = cerebellum, medulla, & spinal cord
NE: increase MN excitability, sleep, deficits in attention & mood disorders
down from lateral tegmental area & up from locus ceruleus
5-HT: increases MN excitability, psychiatric disorders (transporter mutations)
down from caudal raphe nuclei (caudal pons & medulla) & up from rostral raphe nuclei
(rostral pons & midbrain)
Histamine: tuberomammillary nucleus → alertness
Ach: pontine nuclei → motor function via thalamus, cerebellum, basal ganglia, tectum,
medulla/cord
basal forebrain → attention & memory via Alzheimer’s, theta rhythm (arousal, memory formation)

internal capsule
anterior limb: frontopontine (corticofugal) & thalamocortical fibers (between lenticular nucleus & head caudate)
genu ("knee"): corticobulbar (cortex to brainstem) fibers
posterior limb: corticospinal & sensory fibers (medial lemniscus and the anterolateral system)
(between lenticular nucleus & thalamus)
other: retrolenticular fibers from LGN, branch to optic radiation
sublenticular fibers including auditory radiations and temporopontine fibers
The Cerebellum

gross anatomy

cerebellar peduncles: fiber tracts that run through brainstem (trace these)
  superior: primary output of the cerebellum to red nucleus & thalamus
  middle: input from the contralateral cerebral cortex via the pons
  inferior: fibers from ipsilateral spinocerebellar tract (proprioceptive), inferior olives, vestibular nuclei

somatotopic input: repeats & layering provide multiple modes of coordination & interactions
  inner → outer: head → legs in posterior & anterior lobes
  audio/visual input in medial vermis

motor planning: direction, force, speed, & amplitude of movements

circuitry

all ascending fibers are excitatory & descending fibers are inhibitory

output: Purkinje (spontaneously active/tonic) → deep cerebellar & vestibular nuclei
input: climbing fibers (inferior olive)
  mossy fibers (pontine nuclei & vestibular ganglia) → granule cells → parallel fibers

structures providing input to Purkinje also provide input to structure that receives inhibitory output of Purkinje cells (raw & processed nuclei)
big proprioreceptive-motor loop modulated by input from locus coeuruleus (NE), raphe nuclei (5-HT)

output circuitry

all output paths are double-crossed: once in decussation of superior cerebellar peduncle & once in spinal cord (or bilateral)
all deep cerebellary nuclei project to VLN → motor & associate cortices → down LCST
ventral SCT: cross in ventral commissure → synapse in intermediate zone → affect ACST/LCST
lateral: dentate nucleus → parvo red nucleus → inferior olivary nucleus → down rubrospinal tract
  extremity ataxia: finger tapping test

intermediate/paravermis: interposed nuclei (emboliform & globose) → same as above, except through magno red nucleus
  appendicular ataxia: dysrhythmia (abnormal timing) or dysmetria (abnormal trajectories in space) (excessive check/finger to nose test)
medial: vermis: fastigial nucleus → contralateral tectospinal; bilaterally to VLN → cortex → ACST
  flocculonodular lobe: reticular formation & vestibular nuclei
  truncal ataxia, disequilibrium, eye movement abnormalities (Romberg’s test)


cerebral pathology

infarcts & hemorrhages:
  • small in SCA: unilateral ataxia
  • PICA and SCA: vertigo, nausea, horizontal nystagmus, limb ataxia, unsteady gait, headache (from swelling, hydrocephalus, usually occipital)
  • SCA has brainstem involvement while PICA does not

ataxia:
  • peduncle/pontine lesions; hydrocephalus; prefrontal cortex; spinal cord disorder; contralateral ataxia-hemiparesis
• sensory ataxia: loss of joint-position sense; overshooting movements
• vestibular ataxia is gravity dependent: goes away when patient lies down
• cerebellar ataxia: irregularities in rate, rhythm, amplitude, & force of movements
• inherited ataxia: polyglutamine expansion (CAG) which affects channels or other proteins (like PKC) → these are in all neurons/cells → kills Purkinje cells

disorders of equilibrium
parapontine reticular formation: input from VN + superior colliculus & output to motor nuclei
where vestibulo & tecto tracts interact
front eye fields: activated prior to planned eye movements; also integrate these inputs
control the excitability of medial motor neurons based on head position
**Basal Ganglia**
striatum (caudate + putamen), globus pallidus (lenticular nucleus when combined with putamen), subthalamic nucleus, substantia nigra, nucleus accumbens, ventral pallidum
basal ganglia evaluate voluntary motor program based on cortical & thalamic inputs → signal to thalamus to initiate or terminate
inhibition of thalamus → reduction of drive back to motor system

circuitry
input: from striatum (98% GABAergic, 2% cholinergic)
cortical & thalamic + domainergic modulation from SNC
output: GABAergic via GP and SNr (pars reticulata)
GPi inhibits thalamus, which projects to frontal lobe
SNr inhibits superior colliculus (visual & vestibular inputs influence locomotion in Parkinson’s)
both output to reticular formation → influence over lateral & medial motor systems
distinct pathways for: motor control, eye movements, cognitive & emotional functions
direct pathway: excite thalamus via disinhibition
cortex → striatum → inhibits GPi/SNr → reduces inhibition of thalamus
indirect pathway: inhibit thalamus via STN
cortex → striatum → inhibits GPe → reduces inhibition of STN → excites GPi/SNr → inhibit thalamus
dopamine enhances striatum output depending on DA receptor expression in medium spiny neurons: D1Rs excite direct & D2Rs inhibit indirect → disinhibition of thalamus
input modulates spontaneous firing activity: low activity: striatum (putamen) & SNC; moderate activity: STN; high activity: GPi & SNr; irregular (low & high): GPe

**pathology**
movement disorders distinct from cerebellar ataxia: all have cognitive/emotional components
hypokinetic (e.g., Parkinson’s): rigidity, difficulty initiating movement, direct pathways
- motor symptoms: tremor, bradykinesia, cog-wheel rigidity, postural and gait instability (antero- or retro-pulsion)
- DA in SNC die → direct pathway loses strength → more inhibition of thalamus
- treatment: levodopa (BBB-permeant DA precursor) increases DA “tone” in striatum; deep brain stimulation stimulate thalamus via depolarizing block of GPI & STN; isradipine
- continuous Ca2+ influx in these pacemaking cells may lead to mitochondrial dysfunction by disrupting ATP production (same genes tied to PD, patients have reduced mitochondrial complexin 1, blocking influx causes reversion of juvenile pacemakers)
hyperkinetic (e.g., Huntington’s): uncontrolled involuntary movements, indirect pathways
- degeneration of projections from striatum to GPe → STN more inhibited → SNr less inhibited → less inhibition of thalamus
- increased polyglutamine repeats in Huntington gene (autosomal dominant and fully penetrant)
- initial symptom is chorea (jerky, random movements); cognitive/emotional component arises later