Pyramidal (Voluntary Motor) System  
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I. INTRODUCTION: Basic Scheme of the Voluntary Motor System

The control over voluntary muscle of the body and head, i.e. skeletal muscle derived from embryonic somites (GSE) and branchiomeric muscle derived from embryonic visceral arches (SVE), consists of a chain of two neurons from the motor cortex to the muscle: upper motor neuron (UMN) and lower motor neuron (LMN).

The upper motor neurons (pyramidal cell bodies in layer V of the motor cortex) project to cranial nerve motor nuclei (corticobulbar) or ventral horn of the spinal cord gray (corticospinal). The lower motor neurons (cell bodies in cranial nerve motor nuclei or spinal gray) send their axons through cranial nerves or spinal nerves to the target muscle.

The lower motor neuron is called the "final common pathway" from the CNS to the muscle, because the combined influences of all premotor systems (whether pyramidal or extrapyramidal or local reflex interneurons) impinge on LMN's, are summated, and conveyed directly to the muscle.

II. ORIGIN OF THE PYRAMidal TRACT (CORTICOBULBAR AND CORTICOSPINAL TRACTS): MOTOR HOMUNUCULUS

The corticobulbar and corticospinal tracts originate primarily from large and giant (Betz) pyramidal cells whose cell bodies are located primarily in layer V (internal pyramidal layer) of the primary motor cortex (precentral gyrus, area 4; head and upper limb and paracentral lobule, lower limb).
Note: While this lecture focuses on the "motor" aspects of the pyramidal tract, there are also corticobulbar and corticospinal fibers that originate in the parietal cortex (postcentral gyrus and superior parietal lobule) that project to cranial nerve sensory nuclei and dorsal horn of the spinal gray that are thought to be concerned with descending cortical modulation of sensory systems. As a general rule, however, the term "pyramidal system" refers to the motor aspects of the system, not the sensory.

The MI primary motor cortex is somatotypically organized (see motor homunculus below) so that the head, upper limb, and trunk are on the precentral gyrus, whereas the lower limb is represented on the medial aspect of the hemisphere in the paracentral lobule. These are referred to as the primary motor cortex, because the largest percentage of corticobulbar and corticospinal "motor" fibers originate there.

### III. THE COURSE OF THE PYRAMIDAL TRACT

The fibers which constitute the pyramidal tract pass through the subcortical white matter and into the internal capsule (corticobulbars in the genu; corticospinals in the posterior limb). The pyramidal tract then courses caudally into the middle three fifths of the crus cerebri of the midbrain, through the basilar pons, and joins the pyramids of the medulla (thus its name "pyramidal"). In the caudal medulla, the majority (80-90%) of the corticospinal fibers cross the midline in the pyramidal decussation and form the lateral corticospinal tract in the contralateral lateral funiculus of the spinal cord. The uncrossed portion forms the anterior corticospinal tract in the ipsilateral anterior funiculus of the spinal cord. In its course through the brainstem, corticobulbar fibers are given off bilaterally to the cranial nerve motor nuclei. Caudal to the midbrain (crus) corticobulbars leave the pyramidal tract and branch off into the pontine tegmentum and medullary reticular formation to terminate bilaterally in relation to or within cranial nerve motor nuclei (i.e., some are direct; some indirect, synapsing first on inter neurons in the adjacent reticular formation).
IV. CORTICOSPINAL TRACT

The corticospinal tract originates from the largest pyramidal cells of layer V of the primary motor cortex - the giant Betz cells in the precentral gyrus and paracentral lobule (lower limb). The majority of these UMN fibers terminate on interneurons in Rexed's lamina VII of the contralateral intermediate zone of the spinal gray. Thus there are interneurons interposed between the upper motor neurons and lower motor neurons. In primates (in contrast to other mammals), 10% or more of the corticospinal fibers terminate directly on alpha motor neurons of Rexed's lamina IX.

The functional integrity of the corticospinal tract is essential for the fractionated (independent) voluntary movements of the digits.
An overview of the entire origin, course, and termination of the pyramidal (corticospinal tract)
From Carpenter and Sutin, Human Neuroanatomy

Hence, corticospinal fibers terminate in the lateral parts of the intermediate and ventral horns on motor neurons that are concerned with the innervation of distal muscles of the extremities.
The corticospinal tract is somatotopically organized from its origin to its termination. In the dorsal lateral funiculus of the spinal cord cervical is most medial. The denticulate ligament is used as a surgical landmark to avoid damage then sectioning spinothalamic tract in anterolateral funiculus.

V. **CORTICOBULBAR TRACT**

All cranial nerve motor nuclei receive bilateral corticobulbar projections. While some corticobulbars end directly in cranial nerve motor nuclei (on alpha motor neurons), most others end on interposed neurons in cell groups in the reticular formation adjacent to their target cranial nerve motor nuclei (see corticobulbars to CN III, IV, and VI).

Area 4 Corticobulbars - from ventrolateral precentral gyrus (head representation) to motor nuclei of V, VII, nucleus ambiguus, and XII
The unique corticobulbar innervation of the facial nucleus is diagnostically important. The upper half of the nucleus (which innervates the upper facial muscles) receives bilateral corticobulbar input, whereas the lower half of the nucleus (which innervates the lower face) only receives crossed corticobulbar input. Therefore, if the corticobulbar tract is lesioned unilaterally, the contralateral lower half of the face is paralyzed.
In most individuals, corticobulbar projections to the hypoglossal nucleus are predominantly crossed, so that a lesion of the corticobulbar tract may also produce a contralateral paralysis of the tongue (tongue deviates to the side opposite the lesion).

Area 8 Corticobulbars - from the frontal eye field in the caudal part of the middle frontal gyrus to extraocular motor nuclei of III, IV, and VI, for voluntary eye movements.
The extraocular motor nuclei (III, oculomotor; IV, trochlear; VI, abducens) do not receive direct corticobulbar fibers. These fibers synapse first in nuclei within the adjacent reticular formation. Thus there are interneurons (premotor) interposed between the upper motor neuron (corticobulbar) and the lower motor neurons of these extraocular motor nuclei.

These premotor centers in the reticular formation are segregated into those affecting vertical versus horizontal eye movements.

Vertical Eye Movement (Saccades) - projections terminate in rostral interstitial nucleus of the medial longitudinal fasciculus (ri MLF) and interstitial nucleus of Cajal (INC) in the rostral mesencephalic reticular formation

Horizontal Eye Movement (Saccades) - projections terminate in paramedian pontine reticular formation (PPRF).

**Brainstem Pre-Oculomotor Centers in the Reticular Formation**

![Brainstem Diagram](image)

From J. Buttner-Ennever

The bilaterality of corticobulbar projections explains why all normal eye movements are conjugate and why it is difficult to contract muscles of pharynx, larynx, masticatory and upper facial muscles unilaterally.

See lecture on "Oculomotor System" for more detail.

Frontal lobe lesions involving the FEF produce a conjugate contralateral gaze paralysis (eyes deviate toward the side of the lesion)
VI. LOWER MOTOR NEURON

Lower motor neuron cell bodies (alpha motoneurons) are located in cranial nerve motor nuclei (C.N. III, IV, V, VI, VII, nucleus ambiguus, and XII), and ventral horn of the spinal cord. Descending influences of pyramidal (corticospinal) and extrapyramidal (reticulospinal, rubrospinal, vestibulospinal) tracts terminate either directly on lower motoneurons or on nearby interposed interneurons and then in turn on the lower motor neurons. The LMN is the final common pathway to voluntary muscles.

The axons of LMN's to extraocular and tongue muscles (GSE), and muscles of mastications, facial muscles, and muscles of the pharynx and larynx (SVE), follow cranial nerves to their target muscles. Those to skeletal muscle of the body (GSE) follow the ventral root and then spinal and peripheral nerves to their targets.

Lesion of the cell bodies or axons of lower motor neurons results in flaccid paralysis, hypotonia, hyporeflexia, with atrophy.

VII. CLINICAL CORRELATIONS/ LESIONS

Upper Motor Neuron Lesion - involving the corticospinal tract; produce spastic paralysis, hypertonia, hyperreflexia, without atrophy; positive Babinski sign; increased deep tendon reflexes

Lower Motor Neuron Lesions - involving a peripheral (cranial or spinal nerve) or nucleus of ventral horn of spinal cord; produce flaccidity, hypotonia, hyporeflexia with atrophy.

A. Primary Motor Cortex Lesion

Occlusion of branches of the middle cerebral artery to lateral aspect of hemisphere involving the precentral gyrus.
Dorsolateral precentral gyrus - represents the upper limb - supplied by the middle cerebral artery - lesion produces contralateral spastic monoplegia of the upper limb.

Ventrolateral precentral gyrus - represents head/face-supplied by the middle cerebral artery - lesion produces contralateral paralysis of the lower face since the contralateral lower facial nucleus only receives crossed corticobulbar innervation (often tongue deviation to contralateral side is present, due to predominantly crossed corticobulbar innervation of the hypoglossal nucleus).

Inferior frontal gyrus (Broca's speech area) - difficulties with speech production.

Occlusion of branches of the **anterior cerebral artery** to the medial aspect of the frontal lobe involving the **paracentral lobule**.

Paracentral lobule - rostral half is contiguous with motor cortex of the precentral gyrus; represents the lower limb - supplied by the anterior cerebral artery - lesion produces contralateral spastic monoplegia of the lower limb. (not illustrated).

**B. Lesion of the Internal Capsule** (pyramidal tract) - branches of the middle cerebral artery to genu and posterior limb.

Occlusion of branches of **middle cerebral artery** to the **internal capsule**.

Genu - corticobulbar tract - produces contralateral paralysis of the lower face (and sometimes tongue deviation to contralateral side).

Posterior Limb - corticospinal tract - produces contralateral spastic hemiplegia (upper and lower limb).
Retro lentricular portion of posterior limb - involves optic radiations, and results in contralateral homonymous hemianopsia.

![Image of brainstem lesions and hemiplegias](image)

**Figure 13.** From House, Pansky, and Siegel, A Systematic Approach to Neuroscience

C. **Brainstem Lesions/Alternating Hemiplegias** - brainstem vascular insult produces upper motor neuron lesion of corticospinal tract (expressed contralaterally), combined with lower motor neuron lesion of a cranial nerve (expressed ipsilaterally).

1. **Alternating Oculomotor Hemiplegia (Weber's Syndrome)** - basal midbrain lesion involves the corticospinal tract in the crus cerebri, combined with lesion of oculomotor nerve (C.N. III) - supplied by **branches of the posterior cerebral artery** - produces contralateral spastic hemiplegia with ipsilateral oculomotor palsy (ptosis, exotropia, dilated pupil).

   **Ptosis** - eyelid droop due to interruption of oculomotor fibers to levator palpebrae superioris.

   Dilated pupil (**mydriasis**) - due to interruption of parasympathetic fibers in oculomotor nerve (III) from EW nucleus to ciliary ganglion to sphincter pupillae muscle.

   **Exotropia** (external strabismus) - lateral deviation of eye due to unopposed action of lateral rectus (medial rectus paralyzed).

   Lesion of corticobulbar tract in crus cerebri results in contralateral paralysis of lower half of face (and possibly contralateral paralysis of tongue).
2. **Alternating Abducent Hemiplegia** - lesion of the pyramidal (corticospinal) tract in the basilar pons, combined with lesion of the abduces nerve (C.N. VI)- supplied by branches of the basilar pontine artery- produces contralateral spastic hemiplegia with ipsilateral abducent palsy (internal strabismus).

Internal strabismus (estropia) - medial deviation of eye due to unopposed action of medial rectus (lateral rectus paralyzed)

3. **Alternating Hypoglossal Hemiplegia (Medial Medullary Syndrome)** - lesion of the pyramidal (corticospinal) tract in the medullary pyramid, combined with lesion of the hypoglossal nerve (C.N. XII) - supplied by branches of the anterior spinal artery-produces contralateral spastic hemiplegia with ipsilateral hypoglossal palsy (tongue paralyzed ipsilaterally, tongue deviates toward the side of the lesion).
D. Other Cranial Nerve Lesions (Lower Motor Neuron)

**Bell's Palsy** - facial nerve (C.N. VII) - whole ipsilateral side of face paralyzed

Cranial Nerve Lesions - in severing a cranial nerve the motor deficits always ipsilateral to the lesion

E. Spinal Cord Lesions

1. **Brown-Sequard Syndrome** - spinal cord hemisection - involving lateral corticospinal tract in the lateral funiculus; produces ipsilateral spastic monoplegia of lower limb (if lesion is at thoracic level or below) or spastic hemiplegia (if lesion is cervical above enlargement)

Sensory Deficits - ipsilateral loss of conscious proprioception in extremity (ies) - from lesion of dorsal column; contralateral loss of pain and temperature - from lesion of anterolateral quadrant (spinthalamic tract).

2. **Amyotrophic Lateral Sclerosis** (ALS, Lou Gehrig's disease) - Affects both upper and lower motor neurons. Demyelination (sclerosis) of the corticospinal tract to twitches (fasciculations) and atrophy in muscle groups.
3. Lower Motor Neuron Lesions/Spinal Cord

Poliomyelitis - cell death of ventral horn alpha motoneurons produces ipsilateral flaccid paralysis in extremities with atrophy

Peripheral Nerve Lesions - severing peripheral nerves carrying motor fibers produces ipsilateral flaccid paralysis, with hypotonia, hyporeflexia, and atrophy.