Neuroanatomy Guide

Neuroanatomy is bewildering when first encountered. In the mass of structures and connections, it is hard to differentiate between critical and trivial facts. In this course, we attempt to identify and emphasize those structures that you must know for practical neurologic diagnosis. Many of these are visible in magnetic resonance images and CT scans, which are vital in the diagnosis and management of neurologic disease. Interruption of certain pathways leads to clinical signs of great value in pinpointing the site of the lesion and in narrowing the possible causes.

In the first part of this course, we will introduce you to a selected set of terms, most referring to some structure in the brain that will figure in our subsequent functional discussions. Their functions will be identified in this part of the course and treated in detail later. We have selected certain figures from the Watson atlas for special study. Also, we have provided some other images with which you need to be familiar in order to read MRI scans.

The following lists, arranged by lecture session, identify structures you should be able to point out or name on external views or sections of the brain. Be aware that certain structures go by more than one name. We will alert you to the more important instances of this. Most of these names will recur again and again in our discussions. The object here is for you to get used to hearing them and to begin to associate them with specific structures in the brain. As time goes by, they will become very familiar, as will the functions with which they are associated.

We urge you to use both the Watson atlas and the computer-based *NeuroSyllabus* in studying the neuroanatomy. The latter includes movies which are helpful in developing a three dimensional concept of the anatomy. The program also includes interactive quizzes.

The syllabus references recommended images in the form 'NeuroSyllabus: 1/4', meaning chapter 1, image 4. It is recommended that you explore the other resources of this program on your own. Some images may be helpful, others not. Relevant pages in Martin are given for those using this text.

There are also many web sites that contain teaching material for neuroscience, particularly neuroanatomy. Extensive links may be found at **http://www.neuropat.dote.hu/index.html**. Good figures are found at **Virtual Hospital**.

External Anatomy of the Brain.

From this lecture and the assigned reading you should be able to locate the following structures on <u>external</u> and <u>midsagittal</u> views of the brain.

Cerebrum or cerebral hemisphere
Cerebellum
Brainstem
Spinal cord
Lobes: frontal, parietal, temporal, occipital
Insula
Uncus
Cerebral cortex
Central sulcus or Rolandic sulcus
Precentral and postcentral gyri
Lateral Sulcus or Sylvian fissure
Longitudinal Fissure or Sagittal fissure
Corpus callosum (including splenium, body and genu)
Medulla
Pons
Midbrain or mesencephalon
Diencephalon (Thalamus, Hypothalamus)
IIIrd ventricle
Septum pellucidum
Cingulate gyrus
Olfactory tract
Optic nerve, optic chiasm and optic tract
Pyramidal decussation
Olive
Pontine protuberance
Cerebral peduncle
Interpeduncular fossa (lying between the cerebral peduncles)
Mammillary bodies
Inferior cerebellar peduncle
Middle cerebellar peduncle
Superior cerebellar peduncle
Floor of IVth ventricle
Cerebral aqueduct or Aqueduct of Sylvius
Superior colliculus
Inferior colliculus
Pineal gland or body
Pituitary gland (hypophysis)
Cranial nerves III-XII

Text References:

Watson: 109-123
DigAnat: 1/8, 1/9, 1/11, 1/13, 1/14, 1/17, 1/19, 1/20, 1/24, 3/3, 3/8.
Martin: Chapter 1 and Atlas figures A1-1 through A1-7 (pages 482-495)

Blood supply and meninges.

From this lecture and the assigned reading you should be able to locate and identify the structures listed below. You should also be able to trace the path of cerebrospinal fluid from its formation to its entry into the venous system.

Text References:

Watson: 71-93, 99, 101
DigAnat: 2/3, 2/4, 2/12, 2/22, 2/23

Circle of Willis
Major arteries (internal carotid; middle cerebral; anterior cerebral; posterior cerebral; anterior and posterior communicating; vertebral; basilar; anterior spinal; posterior inferior cerebellar; anterior inferior cerebellar; superior cerebellar; posterior spinal)
Superior sagittal sinus
Choroid plexus
Interventricular Foramen or Foramen of Monro
Cisterna magna
Lumbar cistern
Falx cerebri
Tentorium cerebelli
Arachnoid granulations

BLOOD SUPPLY OF THE BRAIN AND SPINAL CORD

You have studied in BI 181 the basic anatomy of the blood supply of the brain and spinal cord and their meningeal coverings. Here we will outline the pertinent details. It is useful to think about the blood supply of the brain as comprising two distinct systems, the anterior and posterior circulations. Compromised perfusion of the major arteries of these systems leads to patterns of deficit that can be useful in identifying the site of disease.

The internal carotid arteries supply the anterior circulation which is formed by the middle and anterior cerebral arteries and their branches. The anterior cerebral artery supplies the medial surface of the hemisphere anteriorly and the middle cerebral artery supplies most of the lateral surface of the hemisphere as well as deeper structures of the forebrain. The posterior circulation is supplied by the vertebral arteries which fuse at the caudal end of the pons to form the basilar artery. This system is sometimes called the vertebro-basilar system. The basilar artery divides at the rostral end of the pons to form the paired posterior cerebral arteries which supply blood to the occipital lobe, medial aspects of the temporal lobe and parts of the midbrain. Branches of the vertebrobasilar system also supply the brainstem. There are four important named branches with which you should be familiar. The <u>anterior spinal artery</u> forms from the fusion of two branches of the vertebral arteries. It supplies parts of the medulla as well as the anterior part of the spinal cord, extending the length of the cord and receiving additional blood from branches of the aorta. The <u>posterior inferior cerebellar arteries</u> branch from the vertebrals to supply the dorsolateral aspect of the medulla as well as the posterior inferior part of the cerebellum. The <u>anterior inferior cerebellar arteries</u> supply the inferior aspects of the cerebellum anteriorly and the <u>superior cerebellar arteries</u> supply the superior aspect of the cerebellum, as their name implies. In addition to these named branches of the vertebro-basilar system, a series of <u>paramedian</u> and <u>circumferential pontine arteries</u> leave the basilar to penetrate and feed the pons.

The anterior and posterior circulations are united through the <u>Circle of Willis.</u> You should be able to diagram this system of major and communicating arteries. Normally little mixing occurs via this system and the anatomy is highly variable. A relatively common deviation from the textbook pattern is that a posterior cerebral artery on one side will arise from the internal carotid. This reflects the embryologic development of the brain's arterial system. The posterior cerebrals begin as branches of the internal carotids, but as the occipital and temporal lobes expand, the basilar begins to supply most of the blood to these regions through the posterior cerebral arteries, which eventually become branches of the basilar. The segments between the internal carotid and the basilar become the posterior communicating arteries.

Blood is supplied to the spinal cord through branches of the midline anterior spinal artery and the paired posterior spinal arteries. These extend the length of the cord but usually do not form continuous vessels but rather a network of channels supplied by both intracranial vessels as well as radicular branches of the cervical, thoracic and lumbar segmental vessels. The latter are subject to disease processes affecting the aorta, such as atherosclerosis and dissecting aneurysm, which can result in neurologic signs traceable to the spinal cord. As might be expected the anterior half of the cord depends mostly on the anterior spinal artery and the posterior half on the posterior spinal arteries. Blockage of these arteries can lead to regional syndromes of the spinal cord. The middle of the cord is hemodynamically farthest from the heart so, if blood pressure drops drastically, it is the center of the cord that tends to suffer more than the periphery. This also leads to a specific syndrome, the central cord syndrome.

MENINGEAL COVERINGS OF THE BRAIN

Three meningeal layers surround the brain and spinal cord. The outermost dura mater lies next to the skull or vertebrae and is very tough. The arachnoid lies adjacent to the dura and extends filamentous pillars to the pia mater, which is in intimate contact with the tissue of the CNS, extending down into the sulci of the brain. In contrast, the arachnoid bridges the sulci. Between the bone and the dura lies the epidural space. A dangerous situation occurs when a fracture of the temporal bone ruptures the middle meningeal artery that lies in this space, causing an epidural hemorrhage. This can cause death quickly if it is not stopped. Between the dura and the arachnoid lies the subdural space. Bleeding here is usually venous and is often associated with relatively mild head trauma in elderly people. Because the venous pressure is low, bleeding occurs slowly and a subdural hematoma forms. Between the arachnoid proper and the pia lies the subarachnoid space, bridged by the filamentous arachnoid pillars. Arteries supplying the surface of the brain travel in the subarachnoid space. Subarachnoid hemorrhage, often caused by trauma or leaking aneurysms, is life threatening.

In addition to covering the outside of the CNS, the dura forms the falx cerebri which lies between the two cerebral hemispheres just dorsal to the corpus callosum, and the tentorium cerebelli, which separates the superior surface of the cerebellum from the inferior surface of the occipital lobe. In several locations the dura splits to form venous sinuses that return blood to the heart via the jugular veins and vena cava. The falx cerebri contains the superior and inferior sagittal sinuses, and the tentorium contains the straight and tranverse sinuses.

PRODUCTION AND CIRCULATION OF THE CEREBROSPINAL FLUID

The cerebrospinal fluid (CSF) is produced by the choroid plexus that lies in the cerebral ventricles. CSF formed in a lateral ventricle flows through the interventricular foramen of Monro into the third ventricle. From there it moves caudally though the cerebral acqueduct into the fourth ventricle. Apertures in the walls of the fourth ventricle allow the CSF to enter the subarachnoid space. It exits this space through the arachnoid granulations that lie near the venous sinuses, particularly the superior sagittal sinus. These form a channel from the subarachnoid space into the venous system. CSF is produced constantly and any interference with its circulation causes increased intracranial pressure due to hydrocephalus. Blockage at the cerebral aqueduct causes internal hydrocephalus, whereas extensive damage to the arachnoid granulations, for instance by meningitis, can cause an external hydrocephalus.

Internal anatomy of the brainstem.

From this lecture and the assigned reading you should be able to locate and identify the following structures on external views and cross sections of the brainstem.

Midbrain
Superior colliculus
Inferior colliculus
Periaqueductal or Central gray
Cerebral Aqueduct or Aqueduct of Sylvius
Substantia Nigra
Red Nucleus
Basis pedunculi or cerebral peduncle
Medial longitudinal fasciculus

Text References:

Watson: 209, 213, 225
DigAnat: 4/2, 4/3, 4/8, 4/12, 4/14, 4/19, 4/26
Martin, Chapter 3, pp. 61-73; atlas figures AII-7 through AII-14 (pp. 510-525).

Medial lemniscus
Decussation of the superior cerebellar peduncle

Pons
Fourth Ventricle
Superior, middle and inferior cerebellar peduncles
Pontine nuclei
Corticospinal/corticobulbar tract
Medial lemniscus
Medial longitudinal fasciculus
Cerebellum

Medulla
Dorsal column nuclei
Nucleus gracilis
Nucleus cuneatus
Fourth Ventricle
Inferior cerebellar peduncle
Pyramid (corticospinal tract)
Inferior olivary nucleus
Reticular formation
Medial lemniscus
Medial longitudinal fasciculus

CRANIAL NERVES.

From this lecture and the assigned reading you should know the function of each cranial nerve and the brainstem nuclei with which they are associated. You should also be able to locate on cross sections of the brainstem the cranial nerve nuclei listed below. Remember that, like the spinal nerves, the cranial nerves have sensory, motor and

Text References:

Watson: 109, 115, 117
DigAnat: 4/3, 4/8/ 4/33-4/38
Martin, pages 353-362; 383-402, and atlas figures A1-5 through A1-7 (pages 491-495).

autonomic components. When speaking of peripheral nerves, including cranial nerves, the word **afferent** refers to axons carrying information to the brain or spinal cord, while the word **efferent** refers to axons carrying information away from the brain or spinal cord.

Midbrain
Oculomotor
Trochlear

Pons
Main sensory nucleus of the trigeminal
Spinal tract and nucleus of the trigeminal
Abducens
Facial nucleus and nerve

Medulla
Spinal tract and nucleus of the trigeminal
Auditory/Vestibular complex
Nucleus ambiguus
Dorsal motor nucleus of the vagus
Nucleus and tractus solitarius
Hypoglossal nucleus and nerve

The following material outlines the salient facts that you should know at this point about each cranial nerve. These nerves will be discussed in much greater detail as we proceed through the course.

I. The Olfactory Nerve

What is usually referred to as the Olfactory Nerve is really the Olfactory Tract. The true Olfactory Nerve passes from the olfactory mucosa through the cribriform plate and terminates in the olfactory bulb. Damage to the olfactory nerve, for instance in head trauma that shears off the axons, causes anosmia.

II. The Optic Nerve

This is not a cranial nerve at all, but a tract of the brain. Its axons are at least 3rd order in the visual pathway. Axons from the two optic nerves partially decussate at the optic chiasm and continue to the brain as the optic tracts. The names applied to the pathway change because the optic nerve contains fibers from only one eye but the optic chiasm and optic tracts contain fibers from both eyes,. Transection of the optic nerve results in blindness of the ipsilateral eye. More complex patterns result when the axons are damaged in the chiasm and tract.

III. THE OCULOMOTOR NERVE.*

This is a purely motor nerve and contains both motor and preganglionic parasympathetic axons. Its nuclei are in the midbrain at the base of the central gray matter at the level of the superior colliculus and it exits the brainstem in the interpeduncular fossa. Just as it exits it lies between the superior cerebellar artery and the posterior cerebral artery. Aneurysms here may first present as IIIrd nerve palsies.

The motor component of CN III supplies the superior, inferior and medial rectus muscles and the inferior oblique, as well as the levator palpebrae superioris. The preganglionic autonomic component travels to the ciliary ganglion and from there postganglionic fibers innervate intrinsic muscles of the eye: the ciliary muscle and the constrictor pupillae.

Damage to CN III leads to ipsilateral pupillary dilation (mydriasis), drooping (ptosis) of the eyelid, loss of accommodation to near objects and inability to move the eye in certain directions, particularly up (elevation) and medially (adduction). Because the eyes are not aligned properly, the patient may experience double vision or diplopia.

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*Be aware that the term 'oculomotor' is sometimes applied to the collection of nerves supplying the extraocular muscles. This rarely causes confusion.

IV. THE TROCHLEAR NERVE.

This purely motor nerve innervates only one extraocular muscle, the superior oblique. Its nucleus lies in the midbrain at the base of the central gray and it exits dorsally after crossing above the cerebral aqueduct. The nerve has a very long intracranial course, which makes it particularly vulnerable to various insults.

Damage to CN IV reduces the ability of the eye to turn downward (depression) and outward (abduction). There is also a tendency for the eye to rotate around the line of sight (cyclotorsion), so patients will sometimes tilt their heads to produce an equal cyclotorsion in the normal eye and counteract the resulting diplopia. A congenital origin of IVth nerve palsy can often be established by observing this head tilt in successive photographs of a child as it grows.

V. THE TRIGEMINAL NERVE.

This mixed nerve has what is perhaps the most complex architecture inside the brainstem. Although it exits on the ventrolateral aspect of the pons, it has nuclei at every level of the brainstem and even in upper levels of the spinal cord. We will examine this anatomy in detail later.

Motor axons from the motor nucleus of CN V supply the muscles of mastication and a small middle ear muscle, the tensor tympani. Sensory axons travelling in the nerve have their cell bodies in the trigeminal or semilunar ganglion and provide sensory innervation to the skin and mucous membranes of most of the head and to the meninges and vasculature of the cranial cavity.

Lesions of CN V paralyze the muscles of mastication and produce loss of somatic sensation ipsilaterally. Headache, mediated by the trigeminal nerve, is a common symptom associated with vascular and other disorders of the head, both inside and outside the skull.

VI. THE ABDUCENS NERVE.

This purely motor nerve innervates the lateral rectus muscle of the eye. Its nucleus lies in the pons near the midline and the nerve also exits near the midline. Damage to this nerve interferes with abduction of the eye.

VII. THE FACIAL NERVE

This is a mixed nerve containing motor, autonomic and sensory axons. Its motor nucleus lies in the pons and its axons exit laterally near the pontomedullary junction to innervate the muscles of facial expression as well as the stapedius muscle of the middle ear. Its preganglionic parasympathetic neurons arise in the superior salivatory nucleus and innervate ganglia that supply the sublingual and submaxillary salivary glands and the lachrimal gland. Its sensory axons have their cell bodies in the geniculate ganglion, which is located in the temporal bone. These axons supply the taste buds on the anterior 2/3 of the tongue.

Damage to the facial nerve causes "Bell's palsy", i.e. paralysis of the facial muscles that may be accompanied by loss of taste on the ipsilateral anterior 2/3 of the tongue.

VIII. AUDITORY-VESTIBULAR, VESTIBULO-COCHLEAR OR STATO-ACOUSTIC NERVE.

This nerve contains sensory axons from the inner ear that originate in ganglia associated with the vestibular apparatus and the cochlea. It enters the brainstem laterally at the pontomedullary junction. The nerve also contains efferent fibers from certain brainstem nuclei that are part of a feedback system to the auditory and vestibular sensory organs. These are not motor axons in the strict sense.

Damage to the VIIIth nerve can cause impaired hearing, tinnitus and vestibular signs and symptoms such as vertigo, falling and jerky movements of the eyes (nystagmus).

IX. The Glossopharyngeal Nerve

This is a mixed nerve containing motor, preganglionic autonomic and sensory axons. Its motor nuclei lie in the medulla and it exits laterally near the pontomedullary junction. The motor axons supply certain striated muscle of the oropharynx. The preganglionic autonomic axons arise in the inferior salivatory nucleus and innervate ganglia supplying parasympathetic input to the parotid glands. The sensory nerves have their cell bodies in a ganglion located on the nerve just after it exits the skull, and mediate general sensation from the oropharynx as well as taste from the posterior 1/3 of the tongue. Axons from the baroreceptors in the carotid arteries reach the brainstem via the glossopharyngeal nerve.

The most common clinical sign of interruption of the glossopharyngeal nerve is loss of the gag reflex. Damage to CN IX can lead to localized loss of taste, disturbance in salivary secretion and, if bilateral, to hypertension.

X. The Vagus Nerve

This complex nerve, like CN IX, contains motor, preganglionic autonomic and sensory axons. Its motor and parasympathetic nuclei lie in the medulla and it exits laterally. Its motor axons supply striated muscles of the oropharynx and larynx. Its autonomic fibers provide preganglionic input to the ganglia that eventually innervate the smooth muscle of the larynx, thorax, abdomen and pelvis. Sensory axons have their cell bodies in a ganglion located on the nerve just as it exits the skull and mediate sensation and the sensory limb of autonomic reflexes from the oropharynx, thorax, abdomen and pelvis.

The most useful signs of vagus nerve involvement are hoarseness due to paralysis of the vocal cords, absence of the gag reflex and difficulty swallowing. Disturbances in cardiac and visceral function may also occur.

XI. THE SPINAL-ACCESSORY NERVE.

This is a mixed nerve containing motor and some sensory fibers. Its motor neurons lie in the ventrolateral part of the anterior horn of segments C1 through C4 as well as in a nucleus of the medulla. The medullary component supplies some muscles of the larynx and pharynx, along with CN X. The spinal component exits the cord in the cervical region, rises through the foramen magnum and joins its medullary component inside the skull. Axons of the spinal component supply the sternocleidomastoid and trapezius muscles. Little is known about its sensory function.

Damage to CN XI causes winging of the scapula (trapezius paralysis) and weakness in turning the head away from the damaged side (sternocleidomastoid paralysis).

A classic mnemonic

ON	Olfactory
OLD	Optic
OLYMPUS'	Oculomotor
TOWERING	Trochlear
TOP	Trigeminal
A	Abducens
FINN	Facial
AND	Auditory-Vest.
GERMAN	Glossopharyng.
VIEWED	Vagus
SOME	Spinal-Access.

XII. THE HYPOGLOSSAL NERVE

This is a purely motor nerve. Its cell bodies lie in the medulla near the dorsal midline and its axons exit near the ventral midline, passing between the olive and the pyramid. It supplies the muscles of the tongue.

Damage to CN XII causes ipsilateral weakness of the tongue, so that it points to the side of the lesion when protruded.

SOME ORGANIZING PRINCIPLES OF THE CRANIAL NERVE NUCLEI.

There are certain rules that are helpful in understanding the layout of the cranial nerve nuclei of the brainstem. They derive principally from the embryologic history of the brainstem.

The motor neurons of the cranial nerves can usefully be divided into those supplying muscles derived from embryonic somites and those supplying muscles derived from embryonic branchial arches. These are sometimes called <u>somatic motor</u> and <u>branchiomotor</u> nerves or axons respectively. The only muscles of somite origin innervated by cranial nerves are the extraocular muscles and the muscles of the tongue. Thus, cranial nerves III, IV, VI and XII compose this group. The utility of this distinction is that the motor nuclei of these cranial nerves are all located in the same paramedian position in the brainstem, just at the inferior margin of the central gray matter. Furthermore, their axons all exit near the midline, III, VI and XII ventrally and IV dorsally.

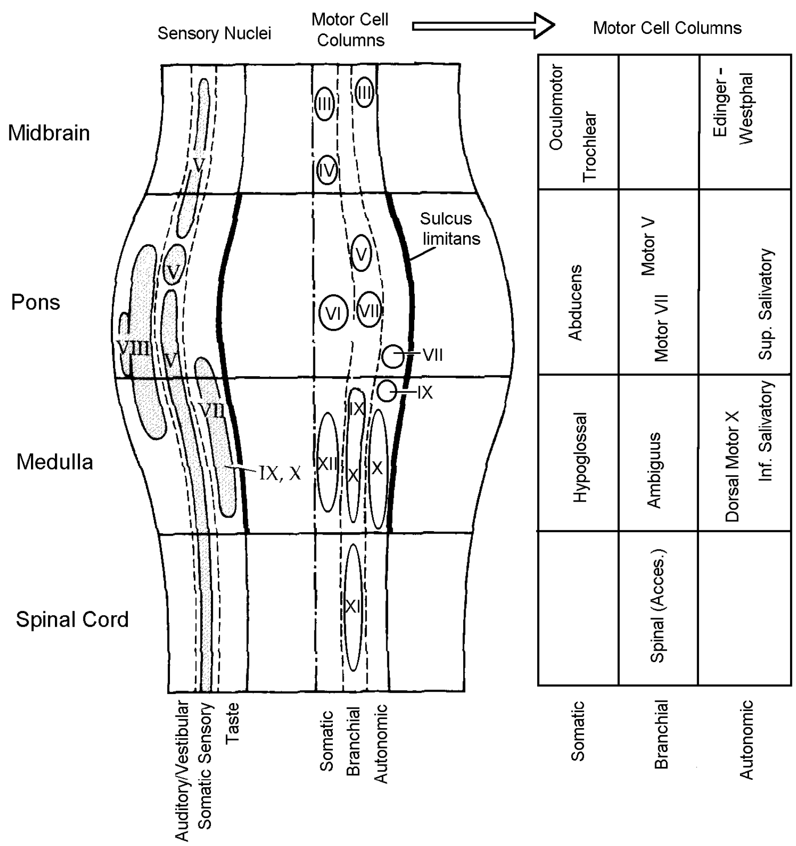

Figure 1.

Left: alignment of the ‘puddles’ of cranial nerve nuclei, sensory on the left, motor on the right. This is a dorsal view of a horizontal section along the long axis of the brainstem.

Right: names of the motor nuclei and their relative positions in the brainstem.

Cell bodies of branchiomotor nerves are located in three nuclei, the motor nuclei of V and VII in the pons and the nucleus ambiguus in the medulla. These nuclei lie ventral and lateral to the somatic motor column and the nerves (V, VII, IX, X and XI) all exit laterally.

All preganglionic parasympathetic axons arise from one of four nuclei in the brainstem. Those travelling in CN III have their cell bodies in the Edinger-Westphal nucleus of the midbrain that lies just dorsal to the somatic motor cells of this cranial nerve. Those travelling in cranial nerves VII and IX arise respectively from the superior and inferior salivatory nuclei near the ponto-medullary junction. Those in cranial nerve X arise in from the dorsal motor nucleus of the vagus. These nuclei form an interrupted column through the brainstem.

Primary sensory nuclei of the brainstem associated with the cranial nerves are easily recalled by simply remembering what sense organs are located in the head. Here it is important to exclude the nose and eyes which, as noted above, are special cases.

Taste: all fibers, regardless of which nerve they travel in (VII, IX, X), terminate in the medullary nucleus of the solitary tract.

Somatic sensation from the face and head: all fibers, regardless of which nerve they travel in (V, IX, X) end either in the main sensory nucleus or spinal (descending) nucleus of V.

Hearing: VIIIth nerve fibers from the cochlea terminate in the cochlear nuclei of the medulla.

Vestibular: VIIIth nerve fibers from the vestibular labyrinth terminate in the vestibular nuclei of the medulla.