Normal CNS, Special Senses, Head and Neck

TOPIC: RETINA and CENTRAL VISUAL PATHWAYS

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LECTURE: Friday, 20 March 2009, 10:00 - 11:30 a.m.

READING: Neuroanatomy, Text and Atlas (J. H. Martin), 3rd Edition
Chapter 7, 'The Visual System,' pp. 270-272,

OBJECTIVES AND GOALS:
From the readings and lecture, the students should know:

1) the anatomy of the retina (names of the layers and their relative positions) and the names of the selected retinal neurons and specialized retinal glia and the generalized function of each cell type.
2) how retinal anatomy and the ratio of the photoreceptors vary by location (e.g. macula, fovea, optic disc), and how visual acuity and sensitivity reflect this anatomical variation.
3) the anatomical and functional relationship between the retina and the Retinal Pigmented Epithelium (RPE).
4) the destinations of the axons in the optic nerve and the basic functions subserved by these target areas (e.g., superior colliculus - eye movements).
5) the concept of the visual field and know the organization of the visuotopic map in the retinogeniculocalcarine tract.
6) the layers of the LGN and primary visual cortex and how the different layers are innervated by optic tract axons and geniculocalcarine axons, respectively.
7) the basic features of "information processing" in the retina and central visual pathways (parallel processing of visual information).

SAMPLE EXAM QUESTION:
Axons from the lateral geniculate nucleus that form Meyer's loop carry information from which portion of the visual field:

A. Central (foveal) visual field **only**
B. Contralateral inferior quadrant
C. Contralateral superior quadrant

Answer: C

D. All of the contralateral field
E. Monocular crescent only

I. Anatomy of the eye

A. The light path

1. Light passing through the cornea is refracted to form an image on the retina
2. The lens is used for fine adjustments of image focus (accommodation).

II. Laminar and cellular anatomy of the retina

A. The retina is a highly ordered, interleaved layers of cell bodies and synaptic neuropil. Ten layers can be identified.

1. Retinal pigmented epithelium
2. Photoreceptor layer
3. Outer limiting membrane
4. Outer nuclear layer
5. Outer synaptic (plexiform) layer
6. Inner nuclear layer
7. Inner synaptic (plexiform) layer
8. Ganglion cell layer
9. Optic fiber layer
10. Inner limiting membrane

B. These layers contain various different types of cells. Some selected types are described below.

1. Retinal pigmented epithelium

   a. a single layer of cuboidal epithelial cells containing the pigment melanin.
   b. these cells have thin processes that interdigitate with the photoreceptors.
   c. functions of the retinal pigmented epithelium

      1. phagocytosis of photoreceptor membranes
      2. transport and storage of vitamin A
      3. breakdown and recycle photoabsorptive pigments
      4. absorb stray light
      5. regulate fluid levels in the sub retinal space

   d. clinical relevance of the retinal pigmented epithelium

      1. retinal detachment
      2. photoreceptor dystrophies

2. Photoreceptors

   a. there are two types of photoreceptors (rods and cones), which are identified both by their shape and function.

1. rods are long, thin cells that subserve scotopic (night) vision. Rods are very sensitive to low levels of light levels and contain the photopigment rhodopsin
2. Cones are short, wide cells that subserve photopic (daylight) vision. Cones subserve high acuity vision; are, inactive at low light levels and subserve color vision. Each cone photoreceptor contains one of three photopigments. Each of these three photopigments has a unique spectral sensitivity curve, and this is the basis of trichromacy in humans. Color blindness is due to defects in one or more of the genes that encode these photopigments.

b. Photoreceptor cells convert photons of light absorbed by their respective photopigments into electrical signals that are used by the brain.

3. Müller (glia) cells

a. Müller cells are a type of radial glia. They extend from the photoreceptor layer to the inner limiting membrane. Tight junctions between Müller cells and photoreceptors form the outer limiting membrane, and the endfeet of Müller cells form the inner limiting membrane.

b. Müller cells help maintain ionic balance in the extracellular space in the retina

4. Bipolar cells provide a direct synaptic link between photoreceptors and ganglion cells.

5. Horizontal cells have processes in the outer synaptic layer

6. Amacrine cells have processes in the inner synaptic layer

a. Together horizontal and amacrine cells process information laterally within the retina

7. Ganglion cells are the output neurons of the retina

a. Together bipolar and ganglion cells process information vertically within the retina.
b. The axons of ganglion cells exit the retina and eye to form the optic nerve

III. Regional specializations of the retina

A. The **macula** is a retinal region specialized for high acuity vision
B. The **fovea** is a site of highest visual acuity, and it lies in the center of the macula
C. The **optic disc** is the site where the axons of the ganglion cells exit the retina and eye

1. The optic disc is the anatomical equivalent of the blind spot

D. **Photoreceptors** are not uniformly distributed across the retina

1. The **fovea** contains only cones, which are packed at a very high density

Rods are absent in the **fovea**, but are at high density in the region around the macula, called the parafovea

IV.CENTRAL VISUAL PATHWAYS: The primary visual pathway can be divided into **six** levels.

1. **Optic nerve**:

a. the optic nerve is the second cranial nerve (SSA), and it contains about 40% of the total afferent fibers found in the 12 cranial nerves
b. From the embryology of the brain, we know that the optic nerve is actually a fiber tract of the CNS. Within the bony orbit, it is covered by the three meningeal layers (dura, arachnoid, pia) as well as cerebral spinal fluid.

2. **The optic chiasm**:

a. The optic chiasm lies beneath the anterior-ventral floor of the third ventricle, above the pituitary.
b. The optic chiasm is the region of a **partial decussation** of the two optic nerves

1. The axons that originate from ganglion cells in nasal retina cross the midline and enter the contralateral optic tract.
2. The axons of ganglion cells that originate in temporal retina do not cross the midline and enter the ipsilateral optic tract.

3. **The optic tract**:

a. Posterior to the optic chiasm, the axons of the retinal ganglion cells form the optic tract, which curves around the posterior aspect of the basis peduncle to innervate the lateral geniculate nucleus of the thalamus and nuclei within the midbrain (see below).
b. Because of the partial decussation at the chiasm, the contralateral visual field is represented in each optic tract.

4. **The lateral geniculate nucleus (LGN)**

a. Most of the axons in the optic tract synapse onto cells in the LGN, a laminated nucleus that is located in ventrolateral thalamus.
b. Axons originating from the two eyes are anatomically segregated in the LGN. The LGN has six cellular layers. Half are innervated by axons from the contralateral retina; half are innervated by axons from the ipsilateral retina. This anatomical segregation persists in the geniculocortical projection (see below).
c. There is a precise visuotopic map within the LGN.

5. Geniculocortical axons (Optic radiations)

a. The axons of LGN cells course within the internal capsule and subcortical white matter, sometimes collectively referred to as the optic radiations.
b. A subset of these axons (representing the contralateral superior visual field; lateral LGN) loop into the temporal lobe. These axons are collectively called Meyer's loop.
c. The geniculocortical axons innervate (synapse onto neurons) in layer IV of primary visual cortex.

6. Primary visual cortex (or Brodman's area 17 or striate cortex)

a. Primary visual cortex is the obligatory entry point for all conscious visual information. It lies dorsal and ventral to the calcarine sulcus in the occipital lobe.
b. There is also a precise visuotopic map in visual cortex.

1. The superior visual field is represented in the inferior bank of the calcarine sulcus, (also known as the lingual gyrus)
2. The inferior visual field is represented in the superior bank of the calcarine sulcus (also known as the cuneate gyrus).
3. The central regions of the contralateral visual field are represented caudally; the fovea is represented at the caudal pole of the occipital lobe.
4. The peripheral regions of the contralateral visual field are represented anterior portions of area 17.

c. a useful mnemonic for reconstructing the topographic organization of the central visual pathways is the three Ls.

Lower retina, **L**oop (Meyer's), **L**ower bank of calcarine sulcus.

Axons that originate in **L**ower retina (superior visual field) synapse onto cells in the LGN, whose axons travel in Meyer's **L**oop and terminate in the **L**ower bank of calcarine sulcus.

d. Like all primary cortical areas, primary visual cortex has a columnar organization. In this case, the columns reflect the segregation of inputs originating from the two eyes.

1. The axons from each LGN that receive inputs from the contralateral and ipsilateral eye are segregated into columns in primary visual cortex. These columns are known as **ocular dominance columns**.

V. Visual association cortex.

In addition to primary visual cortex, there numerous are other visual cortical areas, all of which are heavily interconnected with each other and with primary visual cortex. These higher order visual areas are thought to be responsible for our perceptions of our visual world.

VI. sub-cortical projections of ganglion cell axons:

A. retina to midbrain: Some axons from the optic nerve and tract bypass the lateral geniculate nucleus, or give rise to collaterals that form the brachium of the superior colliculus. These axons innervate the **superior colliculus** (involved in eye movements) and cells in the **pre-tectum** that, in turn, synapse onto pre-ganglionic parasympathetic nuclei in the midbrain (**Edinger-Westphal nucleus**) (involved in the pupillary light reflex.

B. retina to hypothalamus: There is a small hypothalamic nucleus located just dorsal to the optic chiasm that is called the **suprachiasmatic nucleus**. This nucleus receives a sparse input from the retina and is thought to be involved in neuroendocrine functions that are modulated by photic stimuli, e.g. circadian rhythms that are entrained by the day/night cycle. It has recently been shown that a small group of retinal ganglion cells are the photoreceptors of this pathway.

VII. VISUAL INFORMATION PROCESSING

Parallel pathways for visual information processing (retina - thalamus-cortex) flow from the retina to cortex. Our visual system extracts information from the image cast on the retina and parcels this information into at least 2 different parallel streams of information that leave the retina toward higher visual centers.

1. The **ventral stream** encodes information about the color and form of a visual stimulus and is important for the perceptual identification of objects. The ultimate cortical target of this information is the **inferior temporal lobe** (a cortical region important for object recognition).
2. The **dorsal stream** encodes information about movement and location in depth of visual stimulus and is important for sensory-motor transformations for visually guided behaviors. The ultimate cortical target of this information is the **parietal lobe** (a cortical region important in recognizing spatial relations between objects).

VII. Blood Supply to the Visual System

The retina and eye is supplied by the ophthalmic arteries, which branch from the internal carotid artery. The LGN and occipital lobes are primarily supplied by branches from the posterior cerebral arteries.