I. ANATOMY OF THE OPTIC NERVE

Introduction

The optic nerve (Cranial Nerve II) contains axons from the approximately 1 million retinal ganglion cells in each eye, which are on their way into the cranial cavity to synapse onto neurons in various visual nuclei in the brain. The axons traveling in the optic nerves represent 40% of the total afferent input to the brain from the 12 pairs of cranial nerves. The optic nerve runs from the eye to the optic chiasm and is divided into four portions or regions: intraocular, intraorbital, intracannicular and intracranial. Here we discuss only the initial portion, which is contained entirely within the eye.

1. Intraocular Optic Nerve.

Optic Disc: The 1mm-long, vertically elliptical (horizontal diameter = ~ 1.5mm, or 5° of visual angle) portion of the intraocular optic nerve that that lies posterior to the vitreous and anterior to the lamina cribrosa is known as the optic disc or optic nerve head. This differs from the optic papilla, which is the term used to describe both the optic disc and the circumferential mound of tissue (consisting of nerve fibers + glia) that immediately surrounds it.

The optic disc is the portion of the intraocular optic nerve that is visible within the eye, and its evaluation is a critical aspect of an eye examination. The overall appearance of the optic disc reveals many things about the heath of the central nervous system, the cardiovascular system and of course the eye itself. Abnormalities in the physical appearance of the optic disc occur in many systemic diseases, and may present as changes in the size and/or shape of the optic disc itself or its physiological cup, asymmetries between the right and left optic discs, the presence of “crescents” (e.g., scleral, pigmentary) adjacent to the rim of the disc and changes in the color of the disc.

It’s important to recognize that the optic disc represents a “bottleneck” in both the retinal vasculature and the information outflow from the retina. All of the blood vessels that feed the inner layers of the retina, and all of the informational outflow from the retina must pass through this relatively confined space. Accordingly, even very small lesions in this location can have widespread and catastrophic effects for vision.
Drawings of optic disc “crescents” as they appear ophthalmoscopically, correlated with the underlying histology:  

- T = Temporal
- N = Nasal
- R = Retina
- PE = Pigment Epithelium
- C = Choroid
- A = Sclera

Left – Scleral crescent. Right – Pigment crescent.

Drawings showing effects of obliquity of the optic nerve on the appearance of the optic cup:

- S = Superior
- I = Inferior
Drawings showing the range of variability in the ophthalmoscopic appearance of the normal optic cup, together with the underlying anatomical features that account for the appearance of each type of cup. N = Nasal; T = Temporal.
Histology of the Intraocular Optic Nerve: The intraocular optic nerve is divided into three regions, with the lamina cribrosa serving as the anatomical landmark for the boundaries between these regions.

The lamina cribrosa is the perforated region of the sclera through which the axons of the ganglion cells must pass as they exit the eye. This arrangement, in which glial-lined bundles of the axons (fascicles) pass through several hundred holes in the sclera represents a good compromise between the need to provide a hole through the dense collagenous tissue for the optic axons, and the need to retain the structural rigidity of the sclera. Nevertheless, the lamina cribrosa is still a relatively weak point in the scleral tunic – a fact that becomes obvious when intraocular pressure is elevated. In such cases, the lamina bows outward, buckling under the pressure, thereby deepening the optic cup and stretching and compressing the optic axons.

The three regions of the intraocular optic nerve are (from internal to external) the prelaminar (which lies internal or anterior to the lamina cribrosa), the laminar (within the lamina cribrosa), and the postlaminar (external or behind the lamina cribrosa). Details of the anatomy of each of these regions are shown in the figures below.
Structure of the Optic Nerve Head

The nerve head is divided by the lamina cribrosa into pre- and postlaminar portions that differ in their detailed structure. The bundles of axons in the prelaminar portion are separated by sheaths of astrocytes; in the postlaminar portion they are sheathed by connective tissue and oligodendrocytes. The astrocytes separate the nerve head from the surrounding retina and choroid and form the inner limiting membrane (of Elschnig) on the vitreal surface. Most of the axons are myelinated in the postlaminar portion.
Blood Supply to the Intraocular Optic Nerve: Blood is supplied to the optic nerve by arteries derived from the ophthalmic artery, and is removed by veins that empty into the ophthalmic vein. The supply of blood to the intraocular portion of the nerve is unusual, in that part of this region (the laminar and prelaminar zones) has only a single source of blood. Elsewhere in the eye and orbit, blood usually can be supplied to tissue by more than one pathway. The increased vulnerability resulting from this lack of redundancy in the blood supply to the laminar and prelaminar regions of the intraocular nerve is revealed in certain vascular diseases in which arterial flow is compromised.

Details of the vascular supply to the intraocular optic nerve are shown in the diagram below.

Blood Supply to the Optic Nerve and Nerve Head
Behind the lamina cribrosa, the optic nerve has two sources of blood supply: (1) branches from the central retinal artery to the central core of the nerve and (2) branches from the plexus in the pia mater; which is derived from the short posterior ciliary arteries. The laminar and prelaminar regions are supplied by branches from the circle of Zinn and from the choroid, with little or no contribution by central retinal artery branches. The central retinal vein (not shown) runs parallel to the artery and drains both the nerve and the nerve head. Behind the lamina cribrosa, the optic nerve is sheathed by pia mater, arachnoid, and dura mater throughout its orbital course.
The Meningeal Sheath of the Optic Nerve: The optic nerve is unique among cranial nerves in that it remains protected by the meningeal lining of the brain throughout its course. Anatomists cite the fact that the optic nerve is sheathed in meninges, and that this meningeal lining merges with the (meninges-like) tough outer collagenous tunic of the eye (sclera), as evidence that the retina is justified in being termed a part of the CNS. The preceding figure illustrates the presence of all three layers of the meninges – the arachnoid, pia and dura mater – just posterior to the intraocular portion of the optic nerve. Note also that the cerebrospinal fluid (CSF) flowing in the subarachnoid space surrounds the optic nerve and actually contacts the sclera.

The Pattern of Retinal Nerve Fibers: The axons of the ganglion cells follow a very specific pattern as they make their way across the retina into the optic nerve head. Features of this pattern include the nasotemporal dividing line or division, which passes vertically through the fovea. Fibers nasal to this line pass directly to the optic disc, cross the optic chiasm and synapse in the contralateral hemisphere of the brain. Fibers temporal to this line arch above or below the fovea and end in the ipsilateral side of the brain. Foveal fibers, of which of course there are a great number, run nasally to the disc in a large mass called the papillomacular bundle. The horizontal raphe is a line running temporally from the fovea across the retina. Axons from cells located above this line arch upward to enter the superior quadrant of the optic disc, while those from below the line arch downward to enter the inferior quadrant of the disc. This pattern is illustrated in the following diagram.
Within the narrow confines of the intraocular optic nerve, the axons of the retinal ganglion cells are arranged in a very orderly pattern. Each site within the optic nerve head contains axons derived from cells at a specific retinal locus. This results in a fairly precise map of the retina across the face of the optic disc, the details of which are given in the following diagram.

2. Clinical Considerations of the Intraocular Optic Nerve

**Papilledema:** The cylindrical column or sleeve of CSF that surrounds the optic nerve terminates at the sclera in a circumferential ring just posterior to the optic nerve head. This column is of course continuous with the CSF that bathes the rest of the central nervous system. Because this is a closed system, elevations in the pressure of the CSF, caused for example by a space consuming lesion (e.g., a tumor or hemorrhage) in the cranial cavity are distributed evenly throughout the CSF. This pressure exerted around the optic nerve squeezes its contents and can lead to a pathological condition known as papilledema, or "choked disc." Since venous blood pressure is lower than arterial, and veins have softer walls than arteries, the effect of this "pressure cuff" is to collapse the central retinal veins, causing blood to back-up inside the eye. This produces characteristic changes in the appearance of the disc (swollen and hyperemic) and the retinal vasculature (tortuous veins and retinal hemorrhages around the optic disc). The following fundus image shows an example of papilledema.
Lesions of the Optic Nerve Head: As a result of the precise, highly compact map of the retina that is present in the optic axons at the level of the optic disc, even very tiny lesions in this area can lead to a marked loss of function across a wide region of the retina. The result is usually a segmental defect in the visual field, typically detected during visual field testing (i.e., perimetry), whose shape and location indicate the site of the underlying lesion at the optic disc. Examples of these kinds of visual field defects are shown in the following diagram.
Glaucoma: Glaucoma refers to a group of eye disorders characterized by progressive optic nerve damage, at least partly due to increased intraocular pressure (IOP). The disease produces characteristic changes in the appearance of the optic cup and the visual field, each of which is understandable on the basis of the underlying anatomy.

In glaucomatous patients, the optic cup slowly deepens and widens as the lamina cribrosa bulges outward in response to increasing IOP. These progressive changes in the depth and width of the optic cup are a hallmark of this disease. A consequence of the deformation of the lamina cribrosa is that retinal axons passing through it are subject to compression, stretching and bending, all of which negatively impact their function, disrupting both axoplasmic flow and impulse conduction.

Here again, the appearance of the slowly growing visual field defect caused by this progressive loss of optic axon function is stereotypical of the disease. Evidence indicates that the superior and inferior quadrants of the lamina cribrosa are the first to be deformed by the rising IOP. Thus, the resulting field defect usually begins with a vertical enlargement of the blind spot. This initial loss gradually grows into arcuate (or arching) defects in the upper and lower field that eventually meet (with an offset) at the nasal raphe, eliminating peripheral visual field and leaving the patient with “tunnel vision. End-stage glaucoma involves all the retinal axons and produces blindness.

The following figures illustrate these anatomically-based features of glaucoma.
Changes in the appearance of the optic cup in glaucoma. Left – Normal optic cup for comparison. Right – Optic cup in a patient with moderate glaucoma. Note thinning of the “rim” of the optic disc, so that the enlarged cup now occupies a much greater proportion of the disc’s surface. This deeper, wider cup is also elongated vertically. The wedge-shaped darker area radiating out from the disc at the 7-o’clock position reflects damage to the NFL in an arc-shaped region of the retina.
The retina and optic nerve in glaucoma. A. Left panel, normal retina; right panel, the retina in long-standing glaucoma (same magnification). The full thickness of the glaucomatous retina is captured (right), a reflection of the thinning of the retina in glaucoma. In the glaucomatous retina, the areas corresponding to the nerve fiber layer (NFL) and ganglion cell layer (GC) are atrophic; the inner plexiform layer (IPL) is labeled for reference. Note also that the outer nuclear layer of the glaucomatous retina is aligned with the inner nuclear layer of the normal retina due to the thinning of the retina in glaucoma.

B. Glaucomatous optic nerve cupping results in part from loss of retinal ganglion cells, the axons of which populate the optic nerve. C. The arrows point to the dura of the optic nerve. Notice the wide subdural space, a result of atrophy of the optic nerve. There is a striking degree of cupping on the surface of the nerve as a consequence of long-standing glaucoma.

Visual Field Defects in Glaucoma
The dark regions in the visual field are absolute scotomas. The arcuate scotomas radiate from the blind spot above and below the horizon into the nasal visual field. The arcuate scotomas are offset where they meet along the raphe, creating a characteristic "nasal step."