

Chapter 2

Anatomy of the Eye and Common Diseases Affecting the Eye

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Abstract The human eye is a unique part of the human body that has been described as the window to the human soul. The eye being a complex organ is broadly divided into two segments—anterior and posterior segments. Each of these broad segments has specific disease conditions associated with them. This chapter will extensively describe these various components of the eye and the common disease conditions associated with it.

Keywords Anatomy · Physiology · Eye diseases

Introduction

The human eye is one of the most complex parts of the body. Among the sense organs in the body, the eye is the most widely used. Most of the information we gather about our surroundings are things we see with our eyes. The eye has been compared to a camera that gathers light and turns it into images.

The eye (Fig. 2.1) is basically divided into two segments: (1) the anterior segment that consists of the cornea, iris, pupil, conjunctiva, ciliary body, anterior

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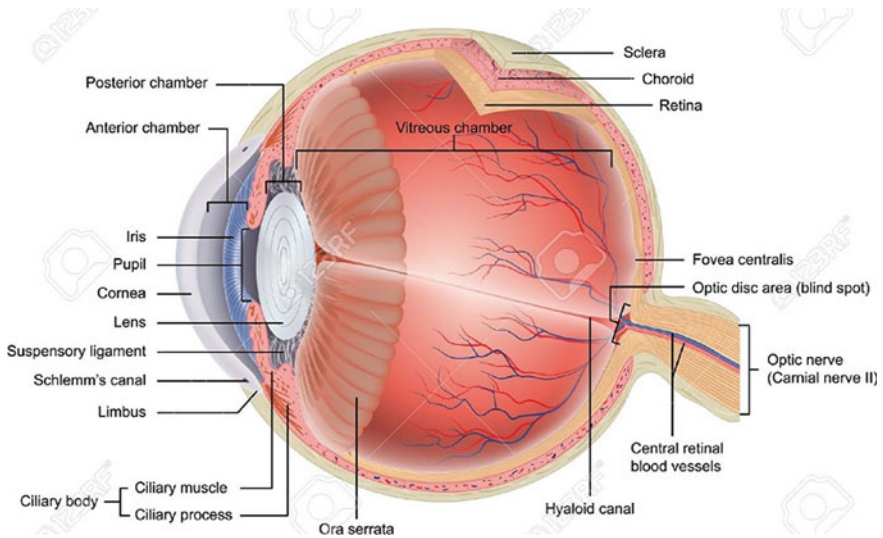


Fig. 2.1 Anatomy of the eye Adapted from Newsplus cited on 24th June 2016 available at <http://www.newsplus.mobi/the-eyes/>

chamber, aqueous humor, trabecular meshwork, and lens. (2) The posterior segment consists of vitreous humor, sclera, choroid, retina, macula and optic nerve.

Anterior Segment

Cornea

It is the outermost part of the eye. It is clear with no blood vessels to nourish it but it obtains its nourishments from the tear and aqueous humor. It is an organized group of cells and proteins arranged in five layers (Vaishya et al. 2014). It provides two-thirds of the total ocular refractory power.

The tear film bathes the corneal surface and helps protect the eye from irritants.

Epithelium

It is the outermost layer of the cornea, about 50 μm thick. It is composed of a layer of basal cells, 4–5 layers of non-keratinized stratified squamous epithelia cells held together by tight junctions to form a barrier against fluid loss and penetration of foreign materials such as dust, bacteria, etc. The epithelium is filled with tiny nerve endings that make the cornea very sensitive to pain. The basement membrane is the part of the epithelium that serves as the foundation on which the epithelial cells anchor and stay organized (National eye Institute).

Bowman's Layer

It lies directly below the basement membrane of the epithelium, a transparent sheet of tissue composed of strong-layered protein fibers called collagen. The collagen is finer than those in the corneal stroma. The compact arrangement of the collagen fibers in this layer makes it resistant to trauma. Once destroyed, it will not regenerate. It helps the cornea to maintain its shape.

Stroma

Comprises about 90 % of cornea's thickness (500 μm), the majority (78 %) of which is made up of water and the remaining is collagen that gives strength, elasticity and form to the cornea. Collagen fibrils are arranged in flat bundles called lamellae and are arranged at right angles to each other. Stroma collagen fibrils compose of type I and V collagen that forms complex surrounded by proteoglycan consisting of keratan sulfate or chondroitin sulfate/dermatan sulfate side chain. They help in the regulation of hydration and structural properties of the cornea (DelMonte and Kim 2011).

Descemet's Membrane

The Descemet's membrane is a thin but strong sheet of tissue that serves as a protective barrier against infection and injuries. It is composed of collagen fibers made by the endothelial cells that lie below it. It is regenerated readily after injury. It thickens throughout life because it is constantly being produced, hence making it resistant to enzymatic degradation and toxins. They are about 3 μm at birth and gets up to 10 μm with age.

Endothelium

The innermost layer of the cornea that keeps it clear. It is on the posterior surface of the cornea facing the anterior chamber. It serves two functions to maintain the health and clarity of the stroma. It pumps excess fluid that leaks into the stroma out and allows nutrients and molecules from the aqueous humor. In addition to these, they are responsible for the synthesis of the Descemet's membrane (Yu et al. 2011).

Iris

It is a circular, thin structure in the eye responsible for controlling the pupil. It consists of two layers: pigmented fibrovascular layer known as stroma and the

second layer is pigmented epithelia cells. The iris separates the space between the lens and the cornea into two chambers: the anterior chamber (between cornea and iris) and the posterior chamber (between iris and lens). The color of the iris is established genetically and it depends on the amount of pigment in the iris.

Pupil

It is an opening in the iris through which light passes before reaching the lens to be focused on the retina. The size of the pupil depends on the amount of light it is exposed to and the muscles of the iris control the size (Albert and Gamm 2016).

Conjunctiva

It is a thin membrane that lines the inside of the eyelid and covers the sclera. It is composed of non-keratinized stratified epithelium and goblet cells. It helps to protect the eyes by producing mucus that helps in lubricating the eyes and prevents entry of microorganisms. The conjunctiva firmly adheres to the edge of the cornea and there are loose folds in the cul-de-sac that allow for easy movement of the eye. The conjunctiva is highly vascularized; this explains why the eye is always red in response to injury or disease (Agarwal et al. 2016). The conjunctiva consists of three parts: the palpebral, which lines the under surface or posterior surface of the eyelid, bulbar and fornix (Vision RX 2005). The palpebral is subdivided into three: the marginal conjunctivae, tarsal conjunctivae and orbit conjunctivae. The bulbar is the thinnest part of the conjunctiva. It is so transparent that the underlying white sclera and vessels are seen clearly. The fornix is the fold lining the cul-de-sac formed by conjunctiva covering the posterior surface of the lids to the conjunctiva covering the anterior surface of the globe. The goblet cells are unicellular glands which secrete mucin. They are round and oval and may produce up to 2.2 ml of mucous daily to lubricate and protect epithelial cells. It also reduces the surface tension of tear film thus ensuring its stability (Majumder 2008).

Ciliary Body

It is a ring-shaped thickened tissue inside the eye, consisting of ciliary muscle that helps the lens in focusing properly and ciliary epithelium that helps in the secretion of aqueous humor. It is joined to the lens by connective tissues known as zonular fibers. The ciliary body forms part of the uvea. The anterior portion is known as pars plicata characterized by the ciliary process while posterior part is pars plana,

which has a relatively flat and pigmented inner surface (Borges-Giampani and Junior 2013). The ciliary muscles consists of three muscle fibers:

Longitudinal or Meridional Fibers

These are the external part that attaches the ciliary body at the anterior part to the scleral spur and trabecular meshwork at the limbus, and at the posterior to the supra-choroidal lamina fibers that connect choroid and sclera (Bruce 1997). Contraction of these fibers leads to the opening of the trabecular meshwork and Schlemm's canal.

Oblique or Radial Fibers

These are in the middle connecting longitudinal and circular fibers. They originate in the sclera spur and are attached to collagenous substance near the ciliary process. The contraction of these fibers may widen the uveal trabecular spaces.

Circular or Sphincter Fibers

These run parallel to the limbus. Contraction of these fibers makes the zonules relax, increasing the lens axial diameter and its convexity.

Anterior Chamber

It is the part of the eye that contains the aqueous humor (~0.25 mL), about 3 mm deep.

Aqueous Humor

Aqueous humor is a clear fluid that fills and helps form the anterior and posterior chambers of the eye. It has been stated earlier that the aqueous humor provides nutrition for the cornea which is avascular structure that must remain clear to allow light transmission, and therefore cannot be invested within a vasculature. The aqueous humor is analogous to a blood surrogate for these avascular structures. It removes excretory products from metabolism, transports neurotransmitters, stabilizes the ocular structure and contributes to the regulation of the homeostasis of these ocular tissues. Aqueous humor also permits inflammatory cells and mediators to circulate in the eye in pathological conditions, as well as drugs to be distributed

to different ocular structures (Sires 1997). Aqueous humor is an important component of the eye's optical system secreted by the ciliary epithelium. The major components of the aqueous humor are organic and inorganic ions, carbohydrates, glutathione, urea, amino acids, proteins, oxygen, carbon dioxide and water. It is slightly hypertonic to plasma in a number of mammalian species (Goel et al. 2010).

Trabecular Meshwork

It consists of connective tissues surrounded by endothelium, divided into three parts (Van Buskirk 1986; Llobet et al. 2003):

Uveal Meshwork

This is formed by prolongations of connective tissue arising from the iris and ciliary body stroma totally covered by endothelial cells. Uveal meshwork forms the lateral border of the anterior chamber, extending from the iris root and ciliary body to the peripheral cornea, consists of bands of connective tissue, with irregular openings that measure between 25 and 75 μm (Goel et al. 2010).

Corneoscleral Meshwork

This is characterized by the presence of lamellae covered by endothelium-like cells standing on a basal membrane. The lamellae formed by glycoproteins, collagen, hyaluronic acid and elastic fibers. It extends from the scleral spur to the anterior wall of the scleral sulcus and is the most extensive portion of the trabecular meshwork. It is composed of perforated sheets that become progressively smaller nearing Schlemm's canal (Goel et al. 2010). The corneoscleral meshwork has four layers: connective tissue with collagen fiber layer, elastic fiber layer, "glass membrane" layer (delicate filaments embedded in ground substance) and endothelia layer (Gong et al. 1989; Goel et al. 2010).

Juxtacanalicular Meshwork

This is formed by cells embedded in a dense extracellular matrix, is in direct contact with the inner wall of endothelial cells from Schlemm's canal, comprised of endothelial cells surrounded by connective tissue like a vein. Schlemm's canal possesses internal collector channels and is connected to episcleral and conjunctival veins through the external collector channels, the intrascleral venous plexus, the deep scleral plexus and the aqueous veins (Gong et al. 1996; Goel et al. 2010).

Lens

It is the clear and elastic part behind the pupil. It can easily change its shape due to its elasticity. The lens loses its elasticity and ability to focus light sharply with age (mostly 40–50 years). At times, the lens can become hardened, clouded and difficult to focus a condition known as cataract.

Posterior Segment

Vitreous

A transparent, colorless gel liquid that fills the space between the lens and the retina. Vitreous contains about 98 % water, hyaluronic acid and collagen fibrils that form a scaffolding and there is absence of blood vessels. The fluid is stagnant if substances enter the humor it has to be removed surgically because it can affect a person's field of vision.

Sclera

It is the white part of the eye, opaque and elastic, consisting of collagen fibers. The opacity is due to the irregular arrangement of the collagen fibers. Its function is to protect and maintain the globe shape of the eye. It is thicker in males than females, thickens gradually towards the cornea. The sclera is divided into three parts:

Episclera

This is the outermost part of the sclera, composed of fibers of collagen, loose fibrous and elastic tissues that attach to the Tenon capsule. There are three types of blood vessels in the episclera:

- Bulbar conjunctival plexus: a superficial plexus of fine vessels (arteries) overlying and freely moveable over the episclera.
- Episcleral plexus: straight radially arranged vessels (veins) in the superficial episclera. They are also moveable over the deep layers (although less easily than the bulbar conjunctival vessels).
- Deep episcleral plexus (also called scleral plexus): a crisscross of vessels closely applied to the sclera.

Sclera Stroma

This contains irregularly arranged collagen bundles, proteoglycans, glycoproteins, and fibroblasts, which play an important role in the synthesis of proteoglycans and glycoproteins.

Lamina Fusca

This is the innermost layer of the sclera containing pigmented cells or melanocytes that migrate from the choroid. The suprachoroidal space separates it from the choroid.

Choroid

It is a vascular layer of the eye containing connective tissues, fibroblasts, melanocytes and resident immunocompetent cells that lie between the sclera and the retina (Nickla and Wallman 2010). The choroid is the posterior portion of the uveal tract (ciliary body, iris, and choroid) which supplies oxygen and nourishment to the retina. The smooth inner surface is attached to the retinal-pigmented epithelium (RPE), while the outer surface is attached to the sclera at the optic nerves and exit at vortex veins. The choroid helps in light absorption thus reducing the amount of light that enters the retina (in species with pigmented choroids), thermoregulation via heat dissipation, and modulation of intraocular pressure (IOP) via vasomotor control of blood flow. The choroid also plays an important role in the drainage of the aqueous humor from the anterior chamber, via the uveoscleral pathway (Nickla and Wallman 2010). Its thickness decreases from 200 μm at birth to about 80 μm by age 90 (Ramrattan et al. 1994).

Generally, the choroid is divided into four layers:

- Haller's layer is the outermost layer and consists of posterior ciliary arteries and large lumen veins
- Sattler's layer contains intermediate size blood vessels
- Choriocapillary layers consist of capillaries
- Bruch's Membrane is the innermost layer.

Retina

It is a circular disc of about 30–40 mm in diameter (Kolb 1991), and 0.5 mm thick. The retina is the light-sensitive area at the back of the eye consisting of millions of

cells tightly packed together. It is divided into three basic groups based on the cell type: photoreceptor cells, neuronal cells, and glial cells.

Photoreceptor Cells

Photoreceptor cells consist of cones and rods. The rods are narrower than the cones, highly sensitive to light, work in dim light, while cones function only in bright light (Baylor et al. 1979). There are three types of cones based on level of response to short, medium or long wavelength thus leading to color separation. Each rod and cone contain a photoreceptor element and an axon. Each photoreceptor consists of an outer segment containing a photon-capturing photo pigment (opsin) and an inner segment containing mitochondria and adenosine triphosphate (ATP).

Neuronal Cells

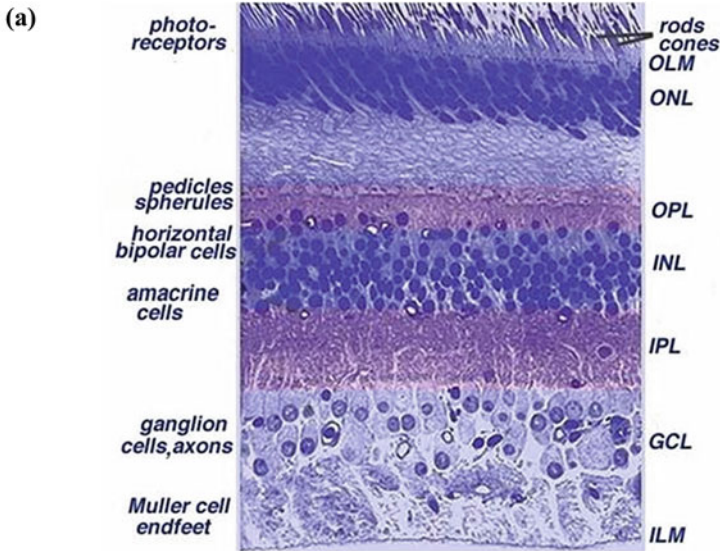
Neuronal consist of bipolar, ganglion, horizontal and amacrine cells. The bipolar cells connect the photoreceptors to the ganglion cells that has dendrites synapse with bipolar cells. The horizontal cells that are responsible for allowing the eyes to adjust to seeing well connect the bipolar cells together. Neurons present in the outer plexiform layer of the retina are also interconnected by the horizontal cells. Amacrine cells connect the bipolar and ganglion cells with each other, there are about forty types of amacrine cells. It functions within the inner plexiform layer.

Glial Cells

Glial cells also are known as supporting cells (Muller cells, astrocytes, and microglial cells) are interspersed between and among the axons in the ganglion cells of the retina and the optic nerve. Muller cells, the principal glial cells of the retina, form a supporting matrix radially across the thickness of the retina and form the inner and outer limiting membranes of the retina. Muller cell bodies sit in the inner nuclear layer and project irregularly thick and thin processes in either direction to the outer limiting membrane and to the inner limiting membrane. Muller cell, found between cell bodies of the neurons in the nuclear layers and envelope groups of neural processes in the plexiform layers. Retinal neural processes allow direct contact at their synapses.

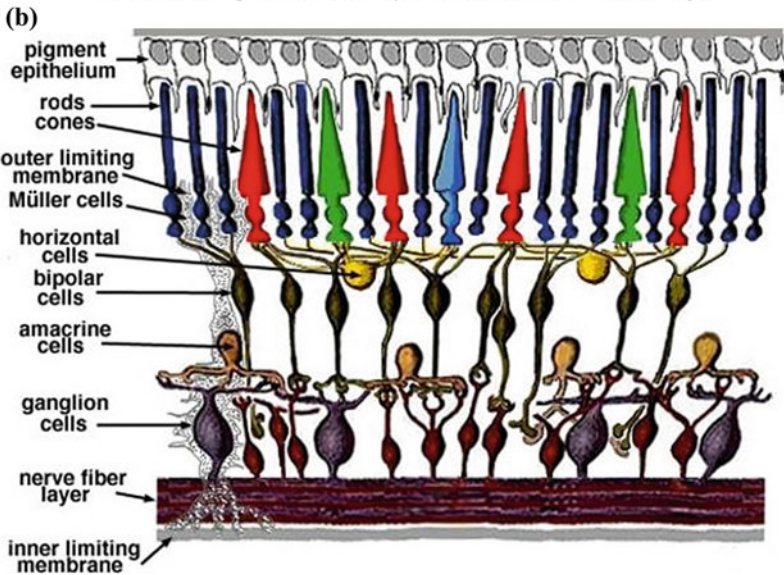
The retina consists of several different layers (Fig. 2.2a, b). Listed below are the layers from inside the vitreous outwards to the choroid:

- The inner limiting membrane is the boundary between retina and vitreous
- The nerve fiber layer contains axons of ganglion nuclei



Light micrograph of a vertical section through the human retina.

- OLM = Outer limiting membrane (separates inner segments of photoreceptors from their cell nuclei)
- ONL = Outer nuclear layer (cell bodies of the retinal rods and cones.)
- INL = Inner nuclear layer (nuclei of horizontal, bipolar and amacrine cells.)
- IPL = Inner plexiform layer (synapses between ganglion cells and bipolar cells)
- GCL = Ganglion cell layer
- ILM = Inner limiting membrane (boundary between the retina and the vitreous body.)



◀ **Fig. 2.2** **a** Light micrograph of a vertical section through the human retina. Adapted from Kolb H, Fernandez E, Nelson R, eds. The organization of the retina and visual system. Salt Lake City, UT: University of Utah Health Sciences Center; 1995. **b** Simple organization of the retina. Adapted from Kolb H, Fernandez E, Nelson R, ed. The organization of the retina and visual system. Salt Lake City, UT: University of Utah Health Sciences Center; 1995. Cited on 10th July 2016. Available on <http://webvision.med.utah.edu/book/part-i-foundations/simple-anatomy-of-the-retina/>

- The ganglion cells layer contains nuclei of ganglion cells, axons of which become the optic nerve with some displaced amacrine cells
- The inner plexiform layer contains the synapse between the bipolar cell axons and the dendrites of the ganglion and amacrine cells
- The inner nuclear layer contains the nuclei of horizontal, bipolar and amacrine cells
- The outer plexiform layer also known as the outer synaptic layer contains projections of rods and cones axons ending in the rod spherule and cone pedicle. Synapses of these with horizontal cells dendrites and bipolar cell dendrites occur in the macula region known as fiber of Henle
- The outer nuclear layer consists of cell bodies of rods and cones
- The outer limiting membrane is the layer that separates the inner segment portions of the photoreceptors from their cell nuclei
- The rod and cone layer contains the rods and cones photoreceptor cells
- The pigment epithelium is a single layer of cuboidal cells close to the choroid. It contains melanin that helps in absorption of light thus decreasing the intensity

The macula is an oval shaped pigmented area in the retina. The center of which is the fovea, which contains photoreceptor cones that make the fovea responsible for sharp vision necessary for driving and reading. Parafovea (inner) and perifovea (outer) belts surround the fovea (Iwasaki and Inomata 1986).

Optic Nerve

The optic nerve also known as cranial nerve connects the eye to the brain. The optic nerve carries the impulses formed by the retina, the nerve layer that lines the back of the eye, senses light, and creates impulses. It contains about 1.2 million nerve fibers, transfers visual impulses from the retina via electrical impulses to the visual center in the brain. The optic disc also known as blind spot due to absence of photoreceptor cells is the part of the retina where the optic nerve leaves the eye.

Common Diseases Affecting the Eye

Different types of diseases affect the eye and if not treated on time could eventually lead to blindness.

Dry Eye

Dry eye disease also known as keratoconjunctivitis sicca occurs when the eye does not produce tear or the consistency is not clear and it dries up quickly. Dysfunction of the Meibomian gland could also be associated with people having dry eye syndrome. Some of the symptoms are grittiness, ocular dryness, mucoid discharge, hyperemia and photophobia (Foster 2015).

Meibomian Gland Dysfunction (MGD)

Meibomian gland dysfunction (MGD) is blockage of the meibomian glands so they are unable to secrete enough oil into the tears, leading to fast evaporation of the tears. MGD is a leading cause of dry eye syndrome. It is associated with an eyelid problem called blepharitis. The symptoms of MGD are also similar to that of dry eye syndrome—red eyes, grittiness, itchy eyes and blurred vision.

Cataract

Cataract is clouding of the lens in the eye. This disease causes loss of vision in age 40 and above. It is the most common cause of blindness in the world. Clouding can occur at the back of the lens in people with diabetes or those taking steroids. Some of the symptoms of cataracts are cloudy or blurred vision, poor night vision, colors looking faded and multiple images.

Macular Degeneration

Macular degeneration leads to loss of vision and it is age related. It is also known as age-related macular degeneration (AMD or ARMD). AMD is a common eye condition among the leading cause of blindness in the world affecting over 25 million people worldwide, 8 million of whom have severe blindness. It steadily destroys the macula, which is the part of the eye responsible for sharp, central

vision. In some patients, AMD can advance rather slowly such that the loss of vision may not occur for a very long time. However, in others, it progresses rapidly leading to complete loss of vision. This disease makes it difficult to recognize faces, drive a car, read and other activities that require central vision (Jager et al. 2008; Coleman et al. 2008). Macular degeneration may be hereditary however smoking, high blood pressure, high cholesterol, obesity, and being light skinned, female, and having a light eye color are also risked factors for macular degeneration (National Eye Institute). There are two types of AMD, dry AMD, and wet AMD. Exudative (wet) AMD is more threatening than the dry type and is responsible for 90 % of cases of severe visual loss in elderly people (Jager et al. 2008).

Vision loss in AMD occurs because of damage to the macula, specifically to the photoreceptor cells (Beatty et al. 2000). Since the original study by Noell et al. showing that exposure of freely moving rats to continuous bright visible (green) light leads to selective degeneration of rod photoreceptor cells, there has been a growing concern that long-term exposure to sunlight may be a contributing factor to the development of AMD (Noell et al. 1966).

There is currently no cure for AMD, however, scientists are consistently working towards developing therapies that can slow the disease or even restore vision.

Hypertensive and Diabetic Retinopathy

Hypertensive and diabetic retinopathy occurs when there is damage to the tiny blood vessels supplying the retina. This could eventually lead to blindness.

Glaucoma

Glaucoma is associated with pressure build up in the eye leading to damage of the optic nerve and loss of vision. The normal eye pressure is known as intraocular pressure (IOP) is below 21 mmHg. There are different types: open-angle glaucoma, closed-angle glaucoma, normal tension glaucoma. Open-angle glaucoma occurs when there is slow drainage of the aqueous humor through the trabecular meshwork, leading to build-up of fluid in the eye, thus causing increase IOP. There is usually no symptom initially except gradual vision loss.

Closed-angle glaucoma occurs when the iris blocks the trabecular meshwork. This is a serious type of glaucoma that can lead to blindness. Some of the symptoms of acute attack are severe eye pain, sudden blurry vision, headache, nausea, and vomiting.

Normal tension glaucoma is when a person has IOP consistently below 21 mmHg, but there is still damage to the optical nerve and loss of vision.

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