

Ocular Geometry and Topography

Before Sam Clemens became Mark Twain, he had been, among other things, a riverboat pilot, a placer miner, and a newspaper reporter, occupations in which success is related to keen observation. He knew perfectly well from his own experience that neither flies nor nail heads can be seen from a distance of 100 yards. James Fenimore Cooper, on the other hand, was not an acute observer of the world around him. And because of his impoverished perception, Cooper's frontier romances were often silly, contrived, and implausible (and badly written, as Twain gleefully pointed out). The accuracy of a Kentucky rifle in a frontiersman's hands is legendary, but only a marksman invented by Cooper would boast that he could see an object we know to be invisible and then hit it with a rifle ball.

It isn't possible to hunt flies with a rifle, even if there were a reason for trying, but how badly did Cooper err? How big would the target have to be at a 100 yards for a marksman just to see it and make a remarkable shot? If the best eyes cannot see a housefly 100 yards away, at what distance *can* a fly be seen? (I recall a samurai movie in which the character played by Toshiro Mifune snatched flies out of the air with his chopsticks. That's believable, though surely very difficult.) What is the difference between the best eyes and all the others? What are the limits of human vision, and to what extent is the eye a limiting factor? In short, what is it about the eye's optics that affects how well we see fine detail?

Elements of Ocular Structure

The human eye is a simple eye

All vertebrate eyes are simple eyes with a single optical system that forms a single image. (Simple eyes may form only one image, but the image-forming properties may vary depending on the part of the optical system that is utilized. Thus, the "four-eyed fish" of South and Central America, *Anableps anableps*, uses one part of each eye's optical system for aerial vision and another for vision below the waterline.) The single image is examined by many photoreceptors, and the more photoreceptors that examine an image of given size, the finer will be the detail extracted from the image.

How far can the best eyes see a common house-fly? A hundred yards? It is quite impossible. Very well: eyes that cannot see a house-fly that is a hundred yards away cannot see an ordinary nail-head at that distance, for the size of the two objects is the same. . . .

"Never mind a new nail; I can see that, though the paint is gone, and what I can see I can hit at a hundred yards, though it were only a mosquito's eye. . . ." The rifle cracked, the bullet sped its way, and the head of the nail was buried in the wood, covered by the piece of flattened lead.

There, you see, is a man who could hunt flies with a rifle.

■ Mark Twain, *Fenimore Cooper's Literary Offenses*

The advantage of simple eyes is that they can have apertures large enough to avoid the diffraction limits of compound eyes (see the Prologue) and to have large images for the photoreceptors to sample. The human eye is a fairly representative vertebrate eye; its macroscopic anatomy is quite simple, in the everyday sense of the word. The eye is a fluid-filled chamber enclosed by three coats, or layers, of tissue. It is an optical system made of leather, water, and jelly, as Gordon Walls once put it.

The outermost of the three coats of the eye consists of cornea, limbus, and sclera

The transparent **cornea** makes up about 16% of the eye's outer coat; the white, opaque **sclera** accounts for most of the rest (Figure 2.1). Both tissues consist mainly of densely woven collagen fibers, which make the tissues rigid, resistant to penetration, and able to protect the more delicate inner layers. The cornea is the eye's principal refractive element, and it owes its transparency to the regularity of its structural organization.

The **limbus** is the region of transition from cornea to sclera; it is an annulus of tissue about 1.5 mm wide around the cornea. The limbus is of interest because it contains specialized structures for removing fluid (the aqueous humor) from the eye. Since improper drainage of aqueous humor may be associated with glaucoma, which is a potentially blinding disorder, discussions of the limbal structure and function inevitably center on the problem of aqueous drainage.

The middle coat—the uveal tract—includes the iris, ciliary body, and choroid

Most of the blood vessels of the eye and most of its melanin pigment are located in the **uveal tract**. (The Latin word *uvae* means “grapes”; the posterior surface of the iris and the folds of the ciliary body apparently reminded early investigators of grapes.) The uveal tract is not structurally homogeneous; it contains three distinct, but continuous, structures: from front to back, the **iris**, the **ciliary body**, and the **choroid** (see Figure 2.1).

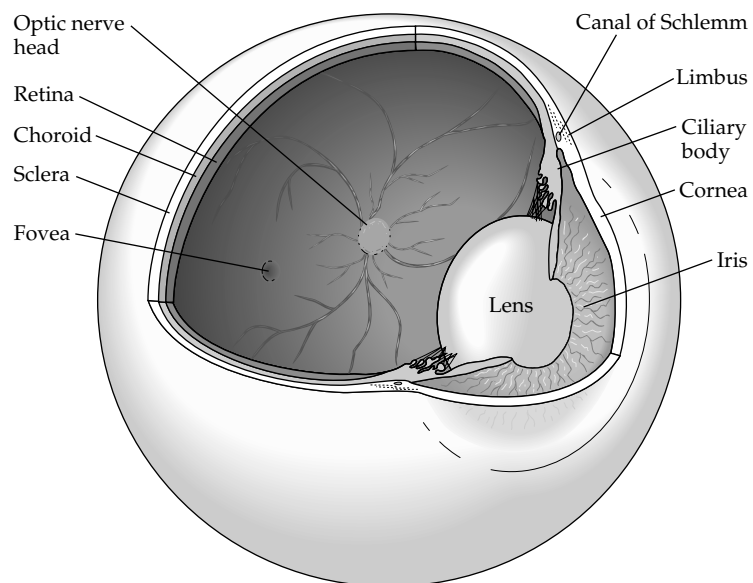


Figure 2.1
Major Structures and Regions
of the Eye

The right eye, viewed from the lateral side and slightly above, with the entire lateral-superior quadrant removed.

The iris, visible through the cornea, is the part of the uveal tract most accessible to direct inspection. It is not a complete layer, however; the hole in its center is the **pupil**. Because of its melanin pigment, the iris is opaque and light can enter the posterior portion of the eye only through the pupil; thus, the iris is an aperture stop for the eye's optical system. Two muscles in the iris, the **sphincter** and the **dilator**, allow the size of the pupil to be varied, thereby regulating the amount of light entering the eye and modulating the image-degrading effects of diffraction and aberration, which are discussed later in the chapter.

The ciliary body is adjacent to and continuous with the iris. It can be visualized as a ring, or annulus, of muscle encircling the anterior portion of the eye just inside the sclera, with a set of highly vascular folds, the **ciliary processes**, on the inner side of the muscular ring. The musculature is part of the system for altering the refractive power of the lens (**accommodation**), while the ciliary processes, collectively, are the site at which the **aqueous humor** (also known simply as aqueous) forms; the watery aqueous is the fluid that fills the anterior portion of the eye.

The remainder of the uveal tract, which is well over half of it, consists of the choroid, the main components of which are blood vessels, including an extensive capillary bed (the **choriocapillaris**), and dense melanin pigment. The melanin pigment serves the same role as the matte black interior of a camera: It absorbs and thus eliminates scattered light that might otherwise degrade the image. Most of the choroidal blood vessels supply or drain the choriocapillaris, which lies on the inner side of the choroid and is the blood supply for the photoreceptors in the retina.

The eye's innermost coat—the retina—communicates with the brain via the optic nerve

If the eye were a camera, the **retina** would be the photosensitive film, but this analogy very much understates the function of the retina. Perhaps a better way to think of it is as something like a computer that receives inputs from 100 million photodetectors that are sampling the pattern of light and dark in the image formed by the eye's optical system. The retina processes the information it receives and transmits it to the brain via the million or so neurons of the **optic nerve**, which exits through the sclera on the posterior-nasal aspect of the eye.

Both functionally and anatomically, the retina is by far the most complex structure in the eye. Although the retina contains only three major classes of cells—neurons, glial cells, and epithelial cells—the neurons can be divided into about 50 to 100 anatomically, physiologically, or histochemically distinguishable cell types. The possible ways to interconnect these cell types are more numerous still, and since the way in which cells are connected is thought to be related to what the retina does, understanding the connectivity is a major concern.

In general, the job of the retina is, first, to detect light in the retinal image and, second, to inform the brain about the features of the image that can be used to construct a mental image of the external objects that were imaged on the retina. But the retina's art is abstract, and it does not send the brain a snapshot of the retinal image. There is no point-by-point representation of the image. Understanding the retina will require a discussion about what is being abstracted from the retinal image and how it is done.

For clinicians, the concern is not so much how the retina works, but the kinds of things that can interfere with its normal operation and how they can be prevented or alleviated. Since good vision requires an in-focus retinal image, the list of possible problems begins with the operation of the eye as an optical system, and continues with almost anything that affects the milieu of the retina: intraocular pressure, integrity of the vascular systems, and so on.

Most of the volume of the eye is fluid or gel

To complete this brief overview of ocular structure, we must consider the **lens**, which lies about a third of the way between the front and the back of the eye; it is held in place by a suspensory ligament, the **zonule**, that attaches to the ciliary body. Functionally, the lens contributes about a third of the eye's total refractive power for distance (unaccommodated) vision, with the capacity, in young persons, for another 12 diopters (D) or so during accommodation.

Most of the volume of the eye is optically and structurally empty. The **anterior chamber**, between the cornea and the iris, and the **posterior chamber**, between the iris and lens, are filled with aqueous; the **vitreous chamber** behind the lens is filled with the gel-like **vitreous humor**. Despite their paucity of well-defined structure, however, both the aqueous and the vitreous have significant clinical problems associated with them. As mentioned earlier, one form of glaucoma is associated with an imbalance between aqueous formation and drainage. And the vitreous, for all its apparent stability, can change sufficiently to predispose the retina to detachment, thus separating the photoreceptors from their blood supply such that they could be lost.