

THE EARLY SIGNS AND SYMPTOMS OF PRESBYOPIA



RONALD A. SCHACHAR
 Honorary Professor to the Faculty of Science,
 Engineering & Computing
 Kingston University, London, UK
 Adjunct Professor, Department of Physics
 University of Texas at Arlington
 Arlington, Texas, USA

PRECIS

Everyone will develop presbyopia by the fifth decade of life; however, the age of onset for the signs and symptoms of presbyopia varies between individuals. Refractive error, preferred near working distance, an individual's stature and ambient lighting all impact the timing of presbyopic signs and symptoms.

Keywords: accommodation, presbyopia, symptoms and signs, onset

Presbyopia is the loss of the ability to read at a normal working distance when fully corrected for distance vision. Presbyopia affects 100% of the population by the fifth decade of life. The anatomy and optics of the eye are crucial for understanding the basis for presbyopia and the onset of its related signs and symptoms.

ANATOMY OF THE EYE

A cross section of the eye is shown in Fig. 1. The eye has an axial length of approximately 23 mm. The clear front part of the eye is the cornea. Similar to the glass of a watch, it is transparent which allows light to travel into the eye. The cornea, with a central thickness of approximately 550 microns, consists of an outer epithelial layer, a middle collagen layer and an inner endothelial layer. The epithelial layer, a barrier that prevents water from entering the cornea, is constantly being replaced every 7 to 10 days. The middle layer consists of collagen

fibers that are uniformly arranged making the cornea transparent. In contrast to the cornea, the sclera, the white part of the eye, appears white because light is scattered from its unorganized cross-linked collagen fibers. On the inner surface of the cornea there is a single layer of endothelial cells. These cells do not regenerate and the number of endothelial cells slowly declines with age. The function of the endothelial cells is to pump water out of the cornea. If the endothelial cells are damaged then the cornea swells and becomes cloudy causing a marked decrease in visual acuity.

Located behind the cornea are the anterior chamber, iris, lens, posterior chamber and retina. The anterior chamber is filled with a clear fluid, aqueous humor, containing salts and amino acids to supply nutrients to the cornea and lens. The aqueous humor is constantly being produced by the ciliary body and drained from the eye through the trabecular meshwork. If drainage of the aqueous humor is blocked, the pressure within the eye increases which can result in glaucoma. The iris, the colored part of the eye controls the size of the pupil, constricting in bright light and dilating in dim light. Suspended behind the iris is the crystalline lens. The lens, a transparent, encapsulated biconvex spheroid, consists totally of epithelial cells; however, unlike the epithelium of skin, which sheds, the lens is encapsulated so it continues to grow throughout life. At birth the lens has an equatorial diameter of approximately 6 mm that increases in the adult to approximately 9 mm.

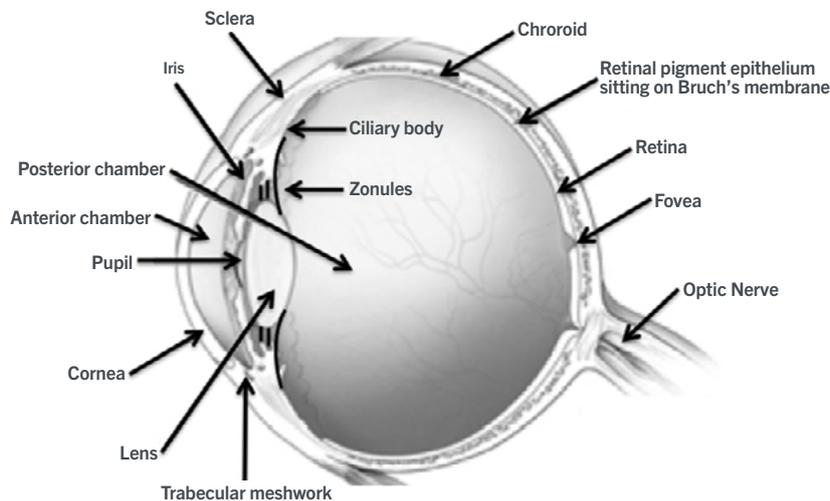


FIG. 1 | Schematic drawing of the eye

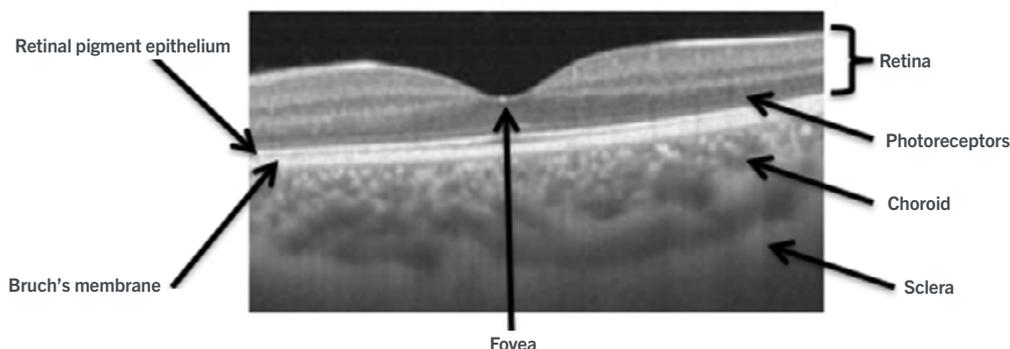


FIG. 2 | Optical coherence image of the fovea

The lens is held in position by zonules. Zonules are small fibers made up of elastic collagen filaments. The zonular fibers are attached to the ciliary body, which contains the ciliary muscle. When the ciliary muscle contracts, tension is applied to the zonules which pull on the lens capsule causing a change in the thickness and surface radii of curvatures of the lens. This change in shape of the lens, induced by ciliary muscle contraction, permits the eye to accommodate; i.e., to increase the optical power of the eye so it can change focus from distance to near.

Behind the lens is the posterior chamber, which is filled with vitreous, a gel-like transparent structure that is adherent to the retina. The retina is a transparent neural tissue containing multiple layers of neurons, supporting cells and cone and rod photoreceptors. Light passes through the retina and impinges on the rods and cones. Cones are concentrated in the center of the retina (fovea) and are responsible for color and sharp vision. Rods, located outside the fovea, respond to the intensity of light (not color) and are responsible for peripheral vision and motion detection. When the photoreceptors are stimulated by light, electrical signals are sent to the retinal neurons for processing and transmission to the brain via the optic nerve. The retina is essentially a minicomputer that translates the image into an electrical code for the brain to interpret. Under the retina is the retinal pigment epithelium, which is a single layer of pigmented cells that maintains the function and integrity of the photoreceptors. Below the retinal pigment epithelium is a supporting membrane and the choroid, a capillary network that supplies nutrition to the retinal pigment epithelium and retina, Fig. 2.

OPTICS OF THE EYE

Distant rays of light travel in straight lines. In order to bring rays of light to a sharp focus the optics of the eye (cornea and lens) bend the peripheral rays to meet at the fovea; however, the very central rays do not require bending and are in focus at all distances. This is how pinhole vision works. By looking through a small aperture, only central rays are permitted to enter the eye while peripheral rays are blocked. Since the central rays are in focus at all distances, objects are in focus independent of refractive error or whether the object is distant or near. Pinhole vision, which reduces contrasts and significantly limits peripheral vision, occurs when squinting, using bright lights to constrict the pupil, or by looking through a pinhole.

The cornea and lens comprise the optical components of the eye. The cornea has a curved surface with a mean radius of curvature of 7.8 mm. The large refractive index difference between the cornea and air makes it the most powerful optical surface of the eye. The refractive indices of air and the cornea are 1.00 and 1.337, respectively. The cornea has an approximate optical power of 43 diopters. A diopter is a unit of measure of optical power and is defined as:

$$\text{Diopters} = 100\text{cm}/\text{focal length cm}$$

After passing through the cornea, light enters the aqueous humor. Since the refractive index of aqueous humor, 1.336, is similar to the cornea, the aqueous humor does not significantly affect the optical power of the eye. Light then passes through the pupil into the lens. The adult lens has a central thickness of 3.5 mm and anterior and posterior surface radii of curvatures of 10 mm and 7 mm, respectively. The lens has an average refractive index of 1.42; however, since the difference between the refractive index of the aqueous humor is significantly less than between the air and the cornea, the effective optical power of the lens is only 20 diopters; i.e., approximately half that of the cornea. The total effective optical power of the cornea and lens in the unaccommodated eye is approximately 63 diopters.

After being refracted by the lens, distant light rays pass through the vitreous and are brought to a sharp focus at the fovea. To see a near object, the eye must accommodate. This occurs when the ciliary muscle contracts, which changes the shape of the lens and increases its optical power and consequently, the total optical power of the eye. An infant can accommodate 15 diopters changing the focus of the eye from infinity to 7 cm in less than a second. The ability to accommodate declines with age as a consequence of the continuous equatorial growth of the lens. As the equatorial diameter of the lens increases, the ability of the ciliary muscle to change the shape of the lens decreases resulting in the linear decline in accommodative amplitude with age. This decline in accommodation causes the near point, the point nearest to the eye at which an object is accurately focused, to recede at approximately 1cm/year. By 50 years of age, presbyopia is fully developed because the near point has receded to approximately 50 cm; however, even though the rate of accommodation universally declines at the same rate, the age that initial symptoms occur is dependent on multiple variables. The major determinant is refractive error.

There are four refractive errors:

1. Emmetropia (normal), distant parallel rays of light are brought to a focal point on the retina without an optical correction, Fig. 3. Since the rays of light from a near object are divergent, an emmetrope must accommodate to increase the optical power of the eye to bring the divergent rays to a focal point on the retina.

2. Myopia (nearsighted), the eye has a longer axial length than an emmetrope causing distant parallel rays of light to be brought to a focal point in front of the retina, Fig. 3. To see clearly at distance, a myope requires a concave lens (negative lens) to shift the focal point onto the retina, Fig. 4. As an object is brought closer to the uncorrected myopic eye the focal point shifts towards the retina so a myope can see a near object sharply without accommodating. The distance that an uncorrected myope can see a near object sharply depends on his or her refractive error. For example a -3 diopter myope will see a near object sharply at 33 cm ($100\text{cm}/3\text{D} = 33\text{ cm}$) while a -10 diopter myope will need to bring the object to 10 cm ($100\text{cm}/10\text{D}$) to see it sharply.

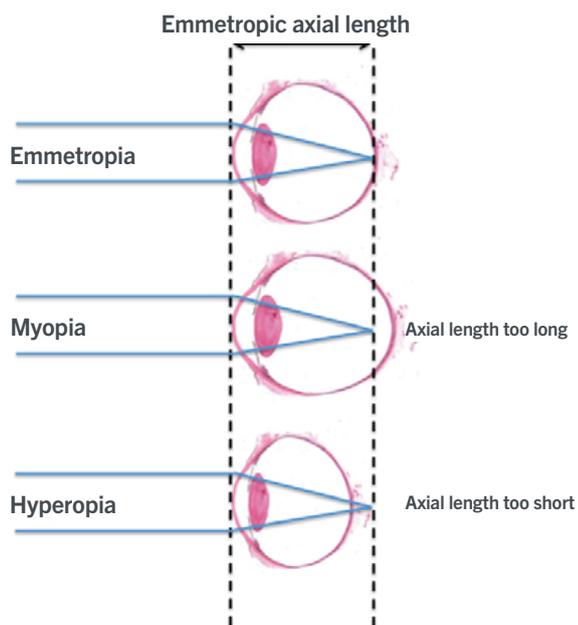


FIG. 3 | Cross-sections of emmetropic, myopic and hyperopic eyes. The axial length of the myopic eye is longer and the hyperopic eye shorter than the emmetropic eye. The focal point of distant rays of light is in front of the retina in the myopic eye and behind the retina in the hyperopic eye.

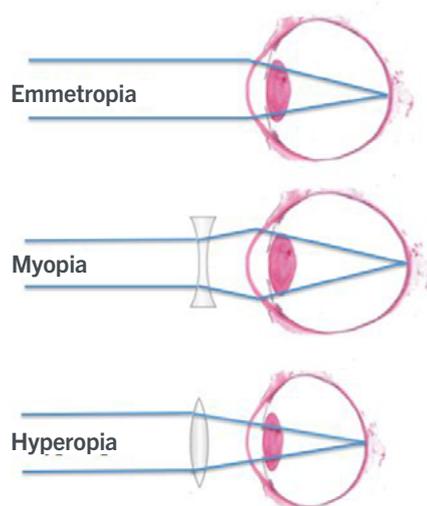


FIG. 4 | Cross-sections of emmetropic, myopic and hyperopic eyes. An emmetrope can see clearly at distance without a correction. A concave lens is required for a myope and a convex lens for a hyperope to see clearly at distance.

→ **3. Hyperopia (farsighted)**, the eye has a shorter axial length than an emmetrope so the focal point of distant rays is behind the retina, Fig. 3. To see clearly at distance, the hyperope accommodates or a convex (positive) lens is used to increase the optical power of the eye to bring the focal point of the distance object to the retina, Fig. 4. To see at near without correction, a hyperope must accommodate more than an emmetrope.

4. Astigmatism occurs when the cornea is not perfectly spherical, resulting in two different perpendicular radii of curvatures. In this case distant rays of light are brought to focus at two different points, one in front of the other. To bring the distant rays of light to a single focal point, a cylindrical lens oriented in the meridian of the astigmatism is required. Astigmatism can occur with myopia or hyperopia.

ACCOMMODATIVE AMPLITUDE

Accommodative amplitude is defined as the near point of the eye when the eye is fully corrected for distance vision. This is important to understand. For example, a 60y/o, presbyopic -2.5 diopter myope, who has zero accommodative amplitude, cannot read with his/her distance correction in place; however, by removing the distance correction he/she can read at near. This is possible because the near point of this uncorrected -2.5 D myope is 40 cm ($100\text{cm}/2.5\text{D} = 40\text{cm}$), which is a normal working distance. However, when this myope is wearing their distance glasses, the near point is at infinity. Since this presbyopic myope has no accommodation, the only way to see at near is to remove the correction or add a convex lens to the distance correction; e.g., a bifocal. Myopes find themselves taking their glasses off to read as they approach presbyopia.

As hyperopes approach presbyopia, it becomes more difficult to see at distance and near. Without correction, hyperopes accommodate to see in the distance so there is less accommodative reserve for seeing at near. To see at near, hyperopes try to over accommodate and squint, which causes eyestrain and headaches. Consequently, hyperopes become symptomatic of presbyopia at an earlier age than emmetropes and myopes.

In addition to refractive error, physical height; i.e. arm length will affect the signs and symptoms of presbyopia. A tall individual generally holds reading material further from his or her eyes than a short person. Therefore, a tall person will not notice the inability to read at near as early as a short person. For example, a tall person may be very comfortable reading at 50 cm, while a short person may prefer reading at 30 cm. Consequently, as the near point recedes past 30 cm, a short individual will become symptomatic, while a taller person will not notice the recession of the near point until it exceeds 50 cm. Since women are generally shorter than men, women usually become symptomatic of presbyopia before men.

To read comfortably, patients generally require twice the required amplitude of accommodation. This explains why a 45 y/o emmetrope with 3.5 diopters of accommodation becomes symptomatic. To read comfortably at 40 cm this individual requires a total optical power of 5 diopters and therefore needs +1.5 diopter reading glasses.

Hyperopes frequently manifest presbyopic symptoms at 35y/o. For example a +2.5 diopter 35y/o hyperope who has an accommodative amplitude of 7 diopters is using +2.5 diopters of his/her accommodative amplitude to see in the distance leaving only 4.5 diopters for near vision. This hyperope requires at least an additional +0.50 diopters to read comfortably at 40 cm.

An individual's refractive error, preferred near working distance, and stature play a role in the timing of the appearance of presbyopic symptoms. All individuals will find that brighter lights and squinting make it easier to read because of the induced pinhole effects of the pupils and lids. Emmetropes and hyperopes will squint and the myopes will start removing their distance correction to read. Hyperopes require wearing their distance correction more to see in the distance and notice eyestrain and may develop headaches with reading as early as 35y/o. Although by 45y/o all individuals will develop symptoms of presbyopia, there are rare individuals who are emmetropic in one eye and myopic in the other eye who do not develop presbyopic symptoms because they use the emmetropic eye for distance vision and the myopic eye for near vision. Since these individuals use each eye independently, stereopsis is usually reduced.

In summary, the tall emmetrope may not manifest symptoms of presbyopia until after 45y/o while the short hyperope will manifest presbyopic symptoms of squinting, eye strain and headaches as early as 35y/o. The myope will be less symptomatic, but will be constantly removing their distance correction to read. 

REFERENCES

Schachar RA. The Mechanism of Accommodation and Presbyopia. Kugler Publications, Amsterdam, The Netherlands, 2012.