CHAPTER 10

Myopia and Pathologic Myopia

Highlights

- Pathologic myopia and its consequences are increasingly among the most common causes of vision loss and blindness throughout the world.
- Posterior segment manifestations of pathologic myopia include macular schisis, choroidal neovascularization, staphyloma, and retinal detachment.
- Retinal and scleral thinning are important posterior segment surgical considerations in patients with pathologic myopia.

Definition, Prevalence, and Epidemiology

There has been a dramatic increase in the prevalence of myopia around the world. Although the more severe manifestations of myopia, variously termed *pathologic myopia* or *high myopia,* are found in a small proportion of the population, this subset accounts for many of the vision problems that occur in eyes with myopia. Moreover, pathologic myopia and its consequences rank at or near the top of the list of causes of vision decrease or blindness in many countries (Table 10-1). Pathologic myopia may be defined as the development of the pathologic changes associated with myopia. However, most studies use a myopic refractive error of –6.00 diopters (D) or greater or an axial length of 26.5 mm or more as the threshold for pathologic myopia. Currently, pathologic myopia is found in 1%–2% of individuals in the United States; approximately 5%, in Italy; 5%–8%, in Japan; 15%, in Singapore; and 38% of university students in Taiwan, China.

Many factors may contribute to the occurrence of myopia, but determining a cause has proved difficult as findings from one study have not necessarily been replicated in other studies. A genetic association with the occurrence of pathologic myopia has also been difficult to prove. Common factors among patients with pathologic myopia include a lack of outdoor activities at a young age and concentrated near work.

Prevention of Pathologic Myopia

Prevention of pathologic myopia is a complex and evolving topic. Participation in outdoor activities is thought to be a contributing factor in reducing the incidence of myopia. This finding is supported by experimental animal model data showing that periods of blue light

Table 10-1 Classic Findings Associated With Pathologic Myopia

Lattice degeneration
Vitreous degeneration
Retinal tear/hole/detachment
Retinal thinning
Retinal vascular traction
Macular schisis/hole
Lacquer crack
Choroidal neovascularization
Choroidal thinning
Fundus tessellation
Peripapillary intrachoroidal cavitation
Chorioretinal atrophy
Scleral thinning
Staphyloma
Inferior staphyloma syndrome, or tilted disc syndrome
Glaucoma
Dome-shaped macula (anterior bowing of the macula associated with posterior staphyloma; see Fig 10-8B)

exposure decrease the amount of myopia that develops. Some theories posit chromatic aberration in the eye as a cause of myopia; red light is focused at a deeper level than blue light.

McBrien and colleagues demonstrated that atropine could slow the development of form-deprivation myopia via a mechanism that was independent of accommodation. Numerous studies have been conducted using atropine eyedrops, including eyedrops at very low concentrations, and suggest a decrease in the amount of myopia progression but a possible rebound in myopia progression after discontinuation of treatment.

Chia A, Chua WH, Cheung YB, et al. Atropine for the treatment of childhood myopia: safety and efficacy of 0.5%, 0.1%, and 0.01% doses (Atropine for the Treatment of Myopia 2). *Ophthalmology.* 2012;119(2):347–354.

Chia A, Lu QS, Tan D. Five-year clinical trial on atropine for the treatment of myopia 2: myopia control with atropine 0.01% eyedrops. *Ophthalmology.* 2016;123(2):391–399.

McBrien NA, Moghaddam HO, Reeder AP. Atropine reduces experimental myopia and eye enlargement via a nonaccommodative mechanism. *Invest Ophthalmol Vis Sci.* 1993;34(1): 205–215.

Pineles SL, Kraker RT, VanderVeen DK, et al. Atropine for the prevention of myopia progression in children: a report by the American Academy of Ophthalmology. *Ophthalmology.* 2017;124(12):1857–1866. doi:10.1016/j.ophtha.2017.05.032

The Retina and Choroid

The Retina

In the central macula, the retinal thickness in eyes with pathologic myopia is not substantially different from that in emmetropic eyes, particularly in younger individuals. In older persons with marked thinning of the choroid, there may be loss of the outer retinal bands and apparent thinning of the central macula (Fig 10-1). Outside the macula, the

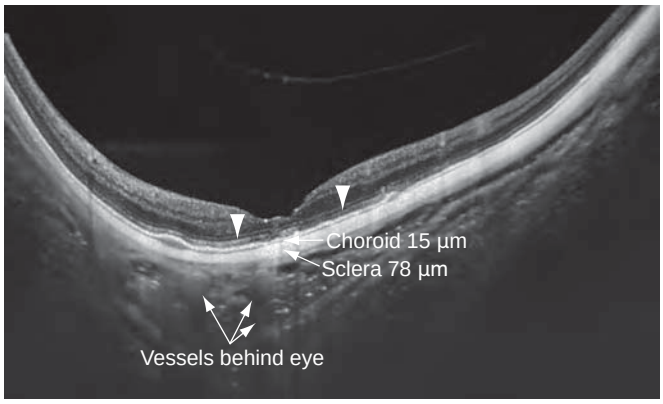

Figure 10-1 Swept-source optical coherence tomography (SS-OCT) image demonstrates some of the many abnormalities that can be present in a highly myopic eye. The magnitude and thickness of the reflection from the ellipsoid layer *(arrowheads)* show a rough correlation to the thickness of the underlying choroid but do vary with the location in the image because of a number of factors, including defocus of the illumination beam and astigmatism. The subfoveal choroid is 15 µm thick; the subfoveal sclera, 78 µm thick. Both measurements are less than 10% of their expected values. The layers of this eye are so thin that it is possible to image structures in the orbit behind the eye, including blood vessels. Note the unusual shape of the eye, which is due to the presence of a staphyloma. *(Courtesy of Richard F. Spaide, MD.)*

retinal thickness in eyes with pathologic myopia is reduced compared with that in emmetropic eyes.

Lattice degeneration is more commonly found in myopic eyes than in emmetropic eyes. With increasing age, the vitreous starts to detach, with small areas of detachment bordering areas of attachment; this occurs in all eyes, including those with myopia. Vitreous traction in areas of persistent attachment can cause retinal tears and then retinal detachment or may cause subretinal fluid to occur in association with small atrophic holes in lattice degeneration. The proportion of retinal detachment secondary to holes increases with higher degrees of myopia, as compared with that secondary to retinal tears. In patients with high myopia, repair of retinal detachment may be more difficult because of the thinner retina, the higher prevalence of lattice degeneration, the thinner sclera (which can complicate buckle placement), the more posterior location of retinal breaks, and the possibility of multiple retinal defects.

In eyes with larger amounts of myopia, traction on the retina can affect broader areas of the retina, independent of vitreous attachment. However, the posterior portion of the retina can remain attached to the retinal pigment epithelium (RPE) despite broad areas of traction. Retinal thickness increases because of the fluid accumulation within the retina and distention of the cellular elements in the retina.

Myopic macular schisis most commonly involves Henle fiber layer but can also involve the inner nuclear layer, the ganglion cell layer, and the region underneath the internal limiting membrane (ILM). The traction can be related to vitreous traction from attached vitreous, but eyes with myopic macular schisis can still have vitreous traction with posterior vitreous detachment (Fig 10-2). After posterior vitreous detachment, a

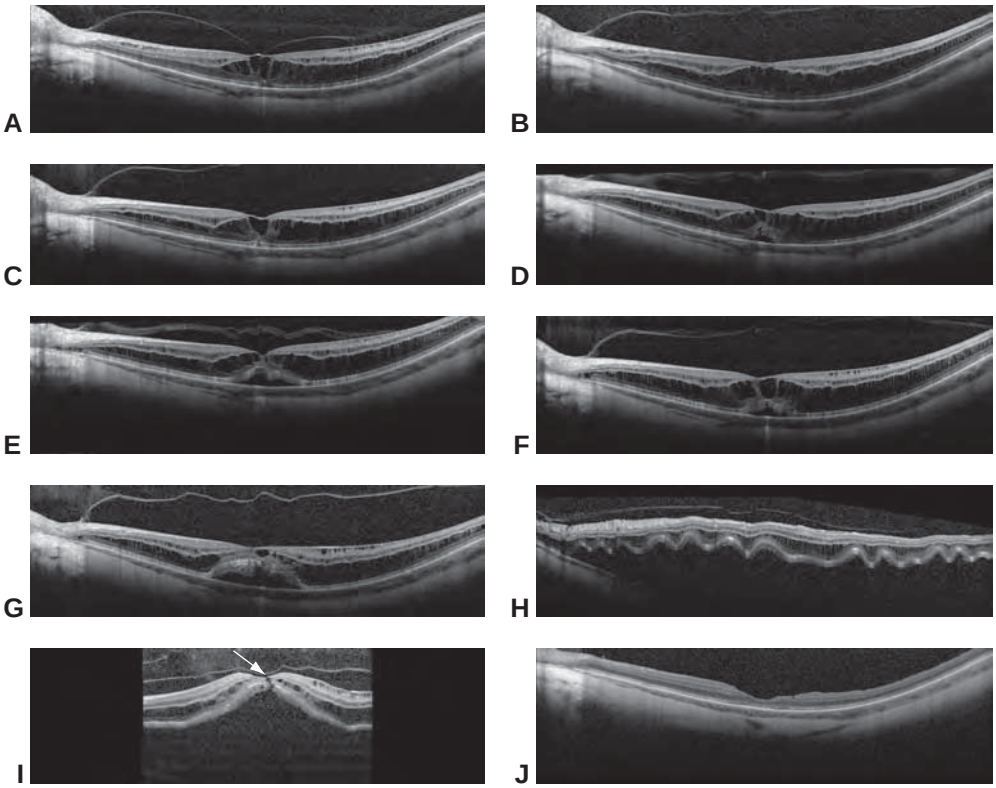

Figure 10-2 Successive OCT examinations of a female patient with myopic macular schisis. At presentation, the patient had a perifoveal vitreous detachment **(A)** that separated **(B). C,** Four months later, a larger foveal cavitation developed. **D,** One month after that, a localized detachment of the fovea occurred. **E–F:** One month after the image in **D** was taken, the detachment was slightly larger **(E)** and persisted **(F). G,** At 4-month follow-up, the macular detachment had increased in size. **H,** One month later, she returned with a substantial loss of central vision. Imaging revealed a large retinal detachment with edematous folding of the outer retina. **I,** A small macular hole caused the larger detachment *(arrow)*. **J,** The macular hole was repaired by vitrectomy with internal limiting membrane removal, which resulted in resolution of the retinal detachment and the myopic macular schisis. *(Courtesy of Richard F. Spaide, MD.)*

skim coat of vitreous remains on the surface of the retina and appears to cause traction. Varying amounts of epiretinal membrane may also contribute to the traction. Peeling of the ILM results in resolution of the schisis, typically near the area where the ILM was peeled; this has led to the conclusion that the ILM may be altered in eyes with myopic macular schisis. Another possibility is that many of these eyes have progressive myopia with continued ocular expansion. The ILM may not necessarily be remodeled, and therefore it may not expand like the outer retina.

More advanced tractional changes can lead to retinal detachment over staphylomas and to myopic macular holes. For macular holes, the rate of successful repair is lower in eyes with high myopia than in emmetropic eyes. Also, macular holes in high myopia frequently require use of the inverted ILM technique, in which the ILM is folded over the hole prior to fluid gas exchange. In addition, in eyes with high myopia, macular holes

may lead to extensive or complete retinal detachment (see Chapter 16, Fig 16-20). Fovea-sparing ILM peeling may result in better visual outcomes when treating foveal retinal detachments caused by myopic traction maculopathy.

Traction appears to affect the retinal vessels in pathologic myopia. These vessels, particularly the maculopapillary bundle, can straighten, with occasional microaneurysm formation, and slight elevation of the arcade vessels is possible. Paravascular cavitations and lamellar holes may also be found, but these defects do not appear to have any clinically meaningful effect.

Bruch Membrane

Located between the RPE and the choriocapillaris, Bruch membrane forms early in the development of the eye and appears to undergo varying amounts of remodeling over time. However, this may not be true in eyes with higher degrees of myopia. In these eyes, the Bruch membrane opening shifts so that the nasal portion of the optic nerve head is undermined by Bruch membrane. The nerve fibers must course around the nasal portion of the Bruch membrane opening; this has been referred to as "supertraction" or "supertraction crescent." Corresponding temporal displacement of the posterior part of the Bruch membrane opening is related to the myopic macular crescent, which is typically located on the temporal side of the optic nerve. The lack of choroidal circulation in this region gives it a white appearance due to visualization of the sclera.

Ocular expansion in pathologic myopia puts stress on Bruch membrane, potentially leading to fine ruptures called *lacquer cracks.* The outer lamella of Bruch membrane is the basement membrane of the choriocapillaris. The cracks not only disrupt the avascular membrane but may also rupture the capillaries in the choriocapillaris, resulting in subretinal hemorrhages. These hemorrhages can be difficult to differentiate from those caused by choroidal neovascularization (CNV; discussed in the following section). Lacquer cracks offer a region of ingress for CNV (Fig 10-3). Extension of lacquer cracks through the center of the fovea can cause distortion and loss of visual acuity. If many lacquer cracks develop, a region of pigmentary granularity can form. In late-stage myopic degeneration, large dehiscences in Bruch membrane may occur.

Choroidal Neovascularization

Early manifestations of CNV in pathologic myopia include decreased or distorted vision. The clinical findings include subretinal hemorrhage, elevation and infiltration of the outer retina by vascular invasion, accumulation of subretinal fluid, and a localized area of pigmentary change. In highly myopic eyes, the findings can easily be overlooked on ophthalmoscopy.

Myopic CNV is often seen in close association with lacquer cracks (see the previous section), or it may occur as an extension from a region of chorioretinal atrophy. In the United States, it is not uncommon to find CNV in young women with myopia who show signs of multifocal choroiditis either concurrently or later. These eyes may develop damage from the CNV, from inflammation, or from both; each component requires careful treatment.

Myopic CNV was first treated with thermal laser photocoagulation; later, photodynamic therapy was used, but both approaches were suboptimal. The advent of injections

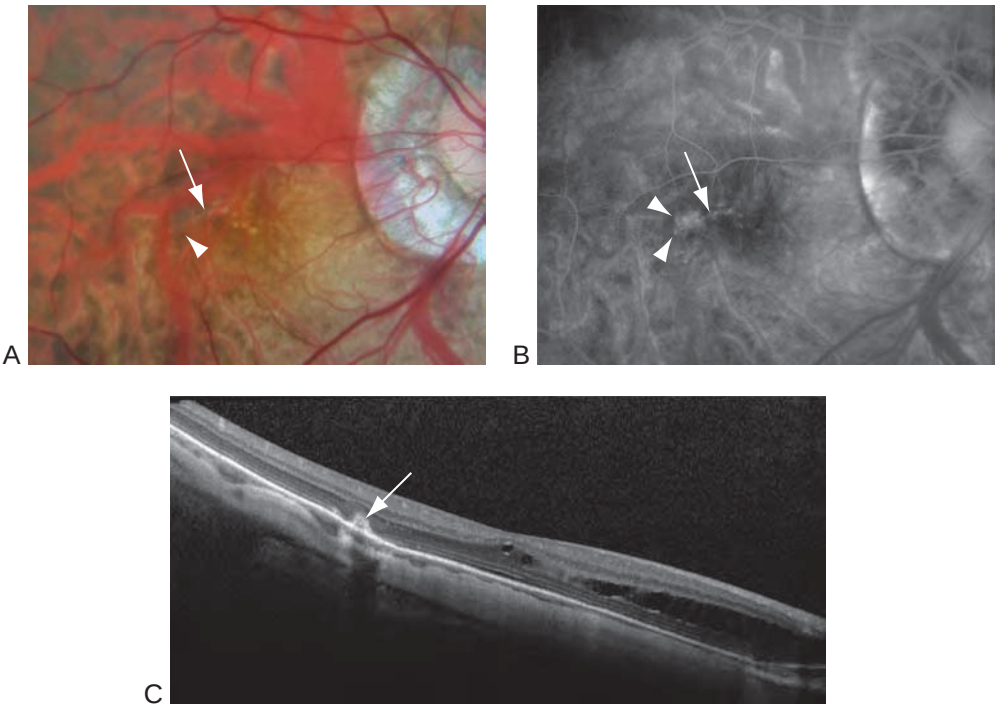

Figure 10-3 Myopic choroidal neovascularization (CNV) emanating from a lacquer crack. **A,** In a patient with –16.00 diopter myopia, a small scotoma developed near the center of the visual field. Note the lacquer cracks *(arrow)* and associated pigmentary changes *(arrowhead)*. **B,** Fluorescein angiography image shows hyperfluorescent leakage *(arrowheads)* consistent with CNV and the window defect of the lacquer crack *(arrow)*. **C,** OCT scan shows a small elevated lesion *(arrow)* and also nonassociated macular schisis. *(Reproduced with permission from Springer Nature. Spaide RF.* Pathologic Myopia. *Copyright 2014.)*

of anti–vascular endothelial growth factor (anti-VEGF) agents, which allow regression of neovascularization without causing immediate collateral damage, was a major advancement (Fig 10-4). To control the CNV, episodic reinjection of medications may be necessary. Compared with CNV secondary to age-related macular degeneration, myopic CNV generally requires fewer injections. With or without treatment, CNV in pathologic myopia may become hyperpigmented (known as a *Fuchs spot*). With longer follow-up, areas of atrophy often develop at or adjacent to the pigmented lesions, and the atrophy eventually encompasses the central macula.

The Choroid

The choroidal circulation accounts for more than 80% of the total blood flow in the eye. The innermost layer of the choroid, the choriocapillaris, supplies the RPE and the outer retina. In addition, the choroid serves as a heat sink, absorbing stray light, participating in immune response and host defense, and playing an integral part in the process of emmetropization. Thinning of the choroid can impair function. Even small decreases in atmospheric oxygen tension can result in suboptimal visual function. Optical coherence tomography (OCT),

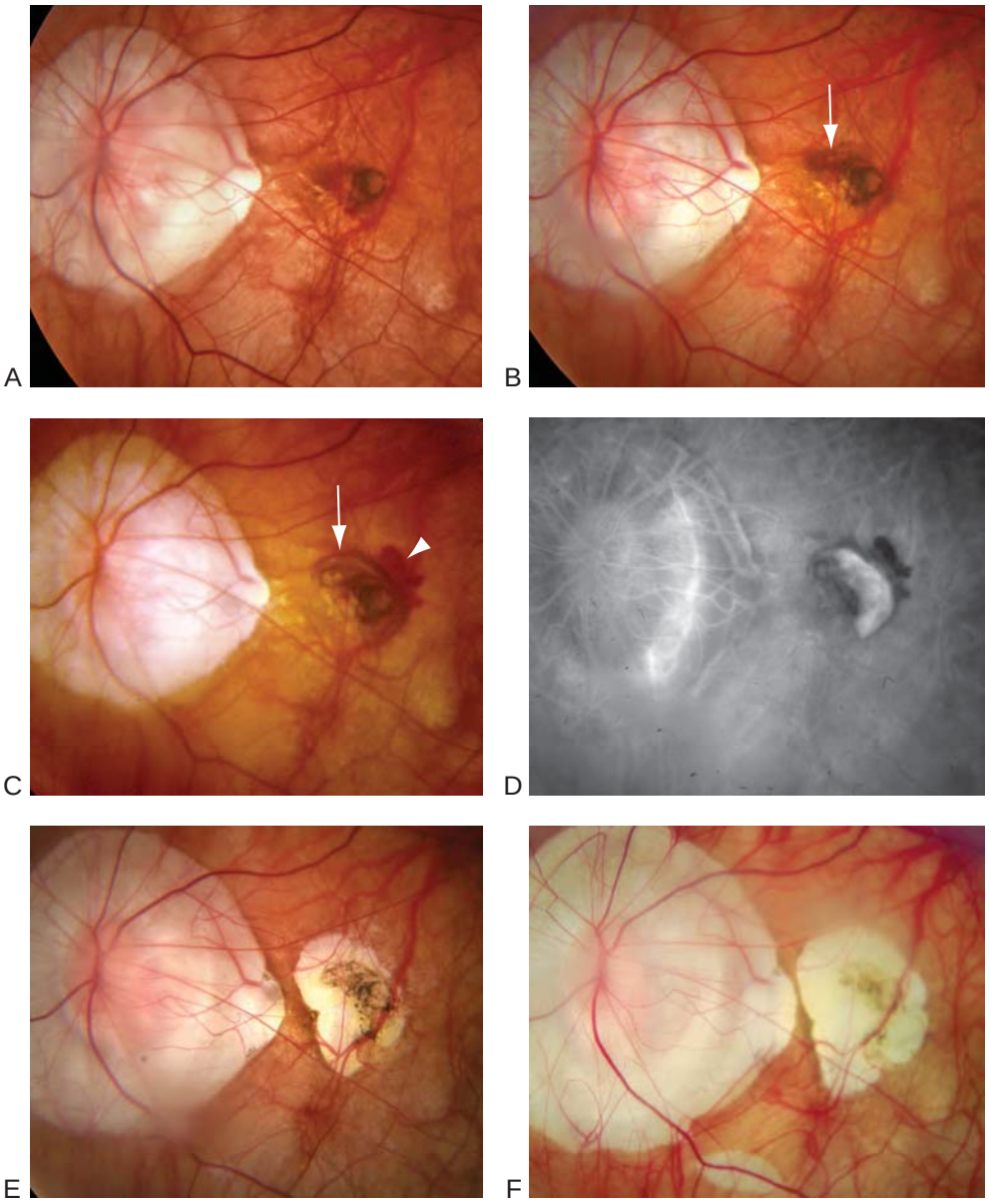

Figure 10-4 Expansion of CNV after treatment with photodynamic therapy (PDT) followed by bevacizumab. **A,** This patient was treated with PDT for myopic CNV with leakage. Note the rings of pigment centrally, indicating successive expansions of the lesion. **B,** After treatment, the lesion expanded even more. Note the increased pigment *(arrow)*. **C,** After several PDT treatments, the lesion expanded further *(arrow),* and a hemorrhage developed *(arrowhead)*. Visual acuity was 20/80. **D,** Fluorescein angiography image reveals the extent of the neovascularization. The patient was given an injection of intravitreal bevacizumab 1.25 mg. **E,** The patient received 2 additional injections over time. Six years after first being treated with bevacizumab, the patient had some residual hyperpigmentation, but also a wide area of pigmentary loss. Visual acuity was 20/60. **F,** Nearly 10 years after injection, the atrophy continued to expand. *(Courtesy of Richard F. Spaide, MD.)*

particularly either swept-source OCT or enhanced depth imaging using spectral-domain OCT, can image the full thickness of the choroid in myopic eyes.

With increasing age, the choroid becomes thinner. One study found that the mean subfoveal choroidal thickness in children aged 11–12 years was 369 ± 81 μm in girls and 348 ± 72 μm in boys. In contrast, the typical subfoveal choroidal thickness in an emmetropic 60-year-old is approximately 220–260 μm. Eyes with myopia, particularly with myopia progressing into the range of pathologic myopia, undergo expansion starting in late childhood, and this expansion is also associated with choroidal thinning (Fig 10-5). In another study, a group of myopic patients with a mean age of 59.7 years had a mean refractive error of –11.9 D and a mean subfoveal choroidal thickness of 93 μm, with a relatively large standard deviation of 63 μm. The thinning of the choroid per decade of life is approximately the same in myopic and nonmyopic eyes. Thus, older individuals, and individuals with higher amounts of myopia, may have remarkably thin choroids. The most significant predictor of visual acuity in highly myopic eyes with no macular pathology is subfoveal choroidal thickness. In patients with pathologic myopia, visual acuity is lost for many reasons, some of which are dramatic, such as retinal detachment. However, in comparison, a greater number of older individuals with high myopia have smaller amounts of visual acuity loss associated with decreased choroidal thickness.

When the choroid becomes very thin, the pigmentation of the RPE often becomes granular. The larger choroidal vessels are easily visible. The choroid may show a repeating pattern of pigmentation, blood vessel, pigmentation, blood vessel, referred to as *tessellation*. Eventually, the choroid may become so thin that the choroidal tissue and the overlying RPE are no longer supported (Fig 10-6). This produces ovoid areas of white, called

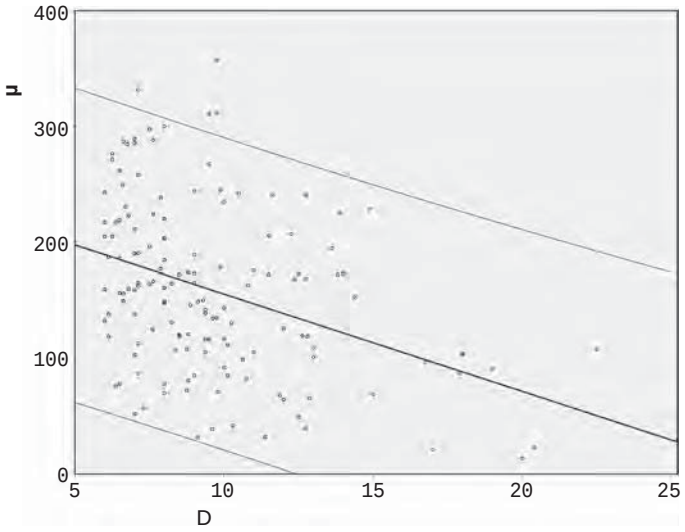

Figure 10-5 Subfoveal choroidal thickness versus myopic refractive error in a group of 145 highly myopic eyes with no macular pathology. The trend line demonstrates the decrease in choroidal thickness with increasing refractive error, and the thinner bordering lines show the 95% confidence interval of the trend line. *(Data from Nishida Y, Fujiwara T, Imamura Y, Lima LH, Kurosaka D, Spaide RF. Choroidal thickness and visual acuity in highly myopic eyes.* Retina. *2012;32(7):1229–1236.)*

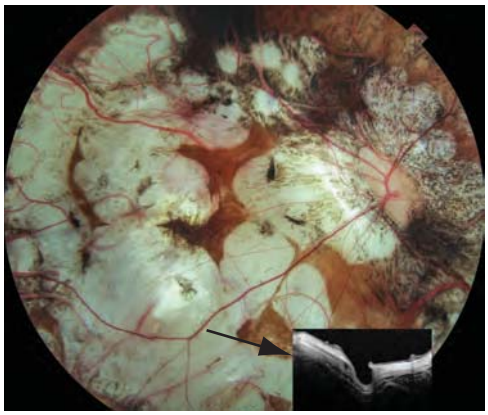

Figure 10-6 End-stage chorioretinal atrophy in pathologic myopia. Note the patches of full-thickness tissue loss; these appear white because of direct visualization of the sclera. The emissary openings in the sclera become enlarged. *Inset:* OCT image, taken at the origin of the arrow, demonstrates remarkable thinning of the sclera and near absence of scleral tissue in the emissary opening itself. *(Courtesy of Richard F. Spaide, MD.)*

patchy atrophy, in which the underlying sclera is visible. If the central macula is involved, the patient's vision will be poor. In eyes with larger areas of atrophy, even Bruch membrane can rupture, leaving a truly bare sclera.

Around the optic nerve, between 5% and 10% of highly myopic eyes have a yellow-orange pocket, which at one time was thought to be a localized retinal detachment, but more refined OCT imaging revealed it to be an acquired cavitation in the choroid (Fig 10-7). Therefore, these lesions are called *peripapillary intrachoroidal cavitations.* Enhanced depth imaging OCT demonstrated that these cavitations are associated with a posterior bowing of the sclera around the nerve.

Li XQ, Jeppesen P, Larsen M, Munch IC. Subfoveal choroidal thickness in 1323 children aged 11 to 12 years and association with puberty: the Copenhagen Child Cohort 2000 Eye Study. *Invest Ophthalmol Vis Sci.* 2014;55(1):550–555.

Nickla DL, Wallman J. The multifunctional choroid. *Prog Retin Eye Res.* 2010;29(2):144–168.

Ohno-Matsui K, Jonas JB, Spaide RF. Macular Bruch membrane holes in highly myopic patchy chorioretinal atrophy. *Am J Ophthalmol.* 2016;166:22–28.

Spaide RF, Akiba M, Ohno-Matsui K. Evaluation of peripapillary intrachoroidal cavitation with swept source and enhanced depth imaging optical coherence tomography. *Retina.* 2012;32(6):1037–1044.

The Sclera

The thickness of the sclera in a nonmyopic eye varies considerably with location; the thickest area, which is around the optic nerve, can be slightly more than 1 mm, whereas the area immediately under the rectus muscle insertions may be as thin as 0.3 mm. When ocular expansion related to myopia begins, the eye elongates, but the amount of material that makes up the sclera does not increase (see Fig 10-1). The collagen fibers become thinner, the typical gradient in fiber thickness in the sclera is lost, and the amount of extracellular matrix decreases. Over time, the sclera in a myopic eye shows more elasticity and greater viscoelastic creep than the sclera in a nonmyopic eye. These factors appear to be necessary to allow the myopic eye to expand, but why it expands is unknown.

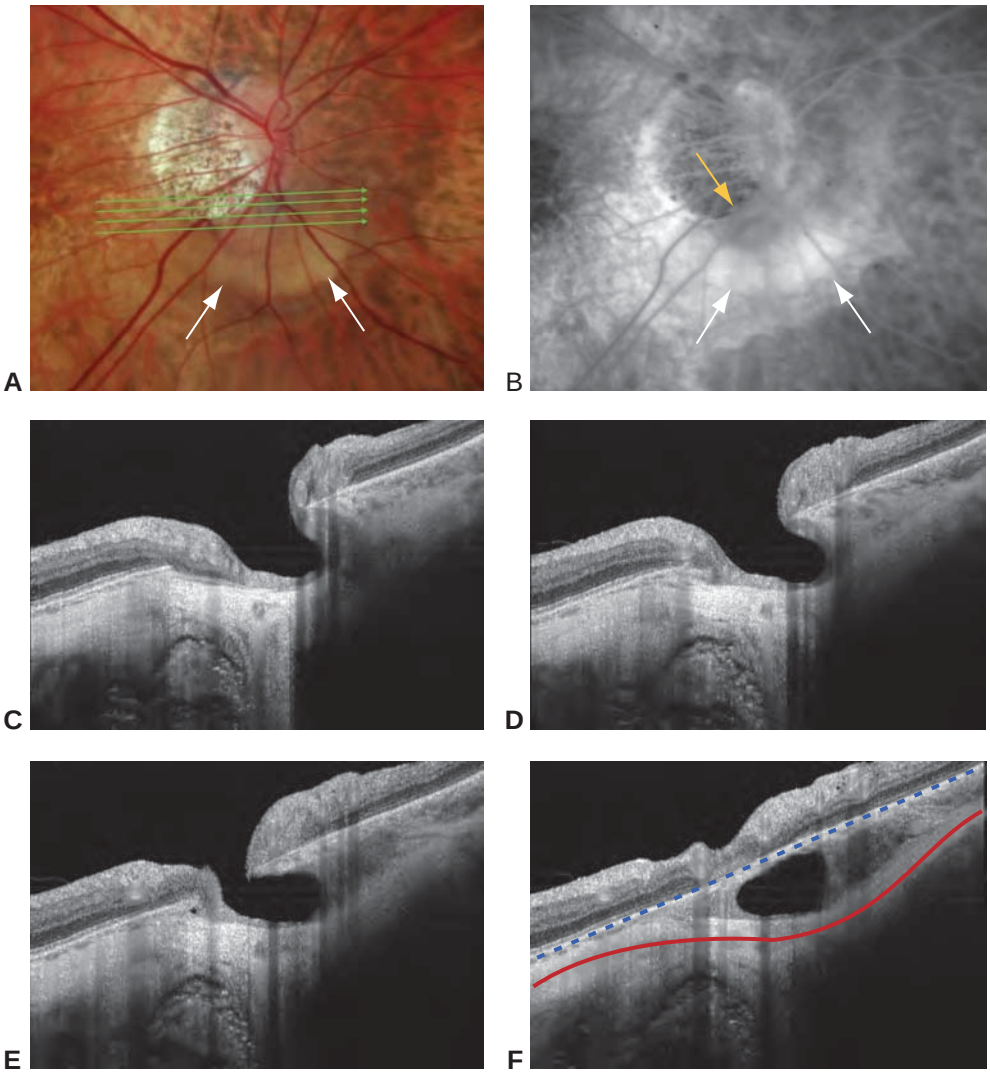

Figure 10-7 Peripapillary intrachoroidal cavitation. **A,** Color fundus photograph shows the yellow-orange region of the intrachoroidal cavitation *(white arrows).* The *green arrows* show the locations of subsequent OCT sections. **B,** Fluorescein angiography image shows a modest late collection of dye within the cavity *(white arrows).* Note the upper edge of the cavity is sharply demarcated *(yellow arrow).* The edge of the retinal defect is more clearly evident than in the color photograph. **C–F:** Successive serial sections taken using SS-OCT show the inner retinal defect and the extension of the cavitation into the choroid. A veil of tissue extends through the thickness of the choroid at the border of the cavitation. In **F,** the hyperreflective band that corresponds to the retinal pigment epithelium is nearly straight, as illustrated by the *blue dashed line.* The *red line* follows a posterior bowing at the center-point thickness in the sclera. *(Used with permission from Spaide RF, Akiba M, Ohno-Matsui K. Evaluation of peripapillary intrachoroidal cavitation with swept source and enhanced depth imaging optical coherence tomography.* Retina. *2012;32(6):1037–1044. doi:10.1097/IAE.0b013e318242b9c0)*

In animal models, form deprivation and lens-induced defocus result in abnormal changes in axial length. Neither optic nerve sectioning nor the destruction of the ciliary nerve prevents the development of experimental myopia. Form deprivation of a hemifield results in expansion of the eye that is conjugate with that hemifield, even if the optic nerve is sectioned. These findings support the hypothesis that remodeling of the eye results from local effects within the eye, beginning with signaling that originates in the retina and choroid and eventually affects the sclera. Connection to the brain does not appear to be necessary. Eyes that develop axial myopia lengthen, but in comparison to the posterior pole, the periphery becomes relatively hyperopic. Peripheral hyperopia can induce myopia in animal models, and curiously myopia can develop in eyes with peripheral hyperopia even if the posterior portion of the retina has been destroyed.

Ocular expansion can vary regionally, inducing formation of areas of the sclera that have differing radii of curvature. Bulging of the sclera and adherent uveal tissue in an area of thin sclera, or *staphyloma,* can result from regional expansion of the eye. These protrusions typically involve 3 general areas of the eye: (1) the area around the nerve; (2) the macular region, which leads to exaggerated thinning of the choroid and possibly myopic traction maculopathy; and (3) the inferior or inferotemporal portion of the eye (Fig 10-8). The superior portion of the eye has one radius of curvature, the inferior portion has another, and there is a visible border between these 2 curves. If the border occurs above the optic nerve, the optic nerve head will appear grossly tilted and rotated. If the border bisects the fovea, several alterations may be seen. In later life, there may be atrophy along the border that affects the RPE under the fovea, and either subretinal fluid without CNV or frank CNV may also develop in these eyes. Because a staphyloma involving the inferior or inferotemporal eye may be accompanied by a set of possible ocular manifestations, it has been referred to as *inferior staphyloma syndrome* or *tilted disc syndrome.*

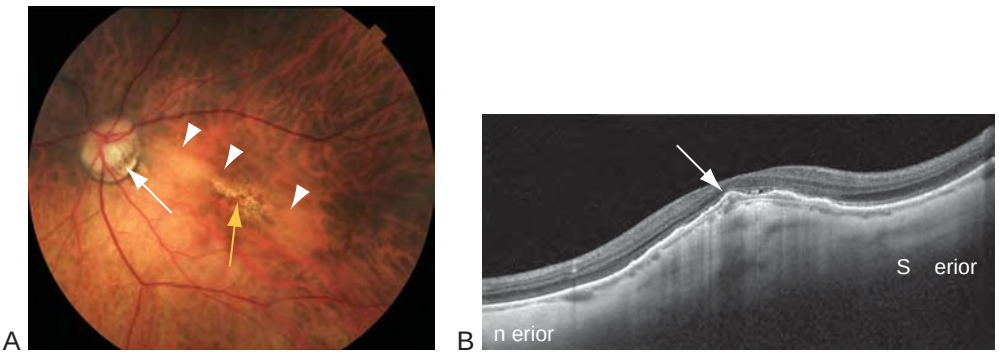

Figure 10-8 Inferior staphyloma syndrome, also known as *tilted disc syndrome.* **A,** Fundus photograph shows that the superior fundus is darker than the staphylomatous inferior fundus. At the border between the 2 regions *(arrowheads)* there is a pigmentary change in the macula *(yellow arrow).* Because this border runs through the superior border of the optic nerve head, the patient has a tilted disc *(white arrow).* **B,** Dome-shaped macula. Vertical OCT image taken through the fovea shows the 2 curves. At the ridge between them, there is CNV *(arrow)* associated with a small amount of submacular fluid. The sclera is typically thicker at the border zone *(asterisk)* than anywhere in the neighboring areas. *(Courtesy of Richard F. Spaide, MD.)*

Diether S, Schaeffel F. Local changes in eye growth induced by imposed local refractive error despite active accommodation. *Vision Res.* 1997;37(6):659–668.

Smith EL 3rd, Hung LF, Huang J, Blasdel TL, Humbird TL, Bockhorst KH. Effects of optical defocus on refractive development in monkeys: evidence for local, regionally selective mechanisms. *Invest Ophthalmol Vis Sci.* 2010;51(8):3864–3873.

Smith EL 3rd, Ramamirtham R, Qiao-Grider Y, et al. Effects of foveal ablation on emmetropization and form-deprivation myopia. *Invest Ophthalmol Vis Sci.* 2007;48(9):3914–3922.

Wildsoet CF, Schmid KL. Optical correction of form deprivation myopia inhibits refractive recovery in chick eyes with intact or sectioned optic nerves. *Vision Res.* 2000;40(23):3273–3282.

The Optic Nerve

In eyes with pathologic myopia, the optic nerve head is undercut by a shifted Bruch membrane opening (Fig 10-9), the scleral canal may be stretched and tilted, the circle of Zinn-Haller is greatly enlarged, and the optic nerve may appear stretched and pallorous.

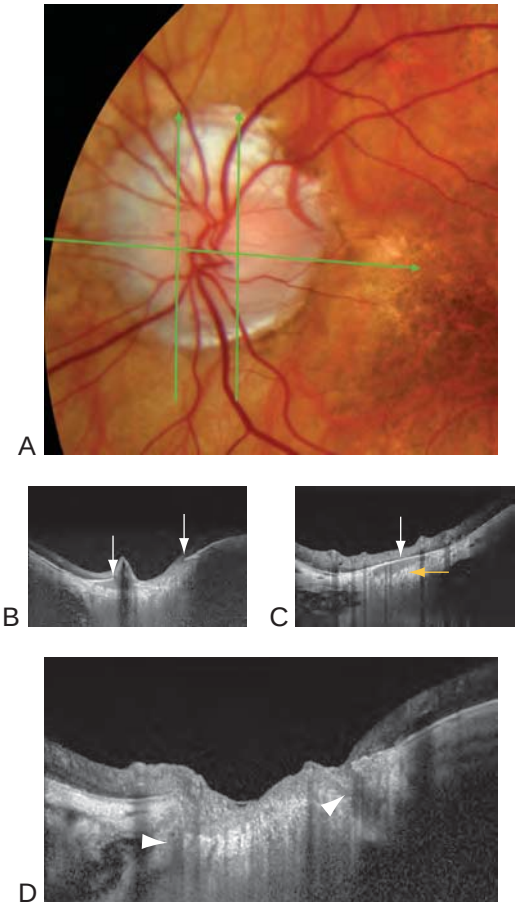

Figure 10-9 Optic nerve changes in pathologic myopia. **A,** The optic nerve head seen in the color fundus photograph does not accurately show the size of the Bruch membrane opening. **B,** Enhanced depth imaging OCT shows the actual Bruch membrane opening *(arrows)*. Note how far Bruch membrane extends into what appears to be the nerve *(left arrow)*. **C,** A vertical section through *2* in the color photograph shows the extent of Bruch membrane. The *white arrow* shows Bruch membrane extending into the nerve tissue. The nerve fibers have to arch nasally under Bruch membrane to reach the lamina cribrosa *(yellow arrow)*. **D,** A vertical section through *3* in the color photograph shows 2 dehiscences *(arrowheads)* in the lamina cribrosa. Although this is a common finding in both glaucoma and pathologic myopia, it is not known whether every patient with a lamina defect in high myopia also has glaucoma. When an eye with glaucoma develops a Drance hemorrhage, typically a lamina cribrosa dehiscence is apparent. However, in pathologic myopia, dehiscences in the lamina are not typically found to have any associated hemorrhage. *(Courtesy of Richard F. Spaide, MD.)*

Glaucoma is much more common in highly myopic eyes than in emmetropic eyes and frequently goes undetected. Measuring the retinal nerve fiber layer with OCT is problematic not only because of the varying shape of the eye and the potential for schisis, but also because normative databases were developed for eyes that are not pathologically myopic. Visual field tests may show defects because of the shape of the eye, some of which can be "fixed" by using a refractive correction for that portion of the eye. Dehiscences in the lamina cribrosa are common in eyes with high myopia (see Fig 10-9D).

Ohno-Matsui K, Akiba M, Moriyama M, et al. Acquired optic nerve and peripapillary pits in pathologic myopia. *Ophthalmology.* 2012;119(8):1685–1692.