

Anatomy of the Anterior Eye for Ocularists

ABSTRACT: *The anterior chamber of the human eye is of vital importance to ocularists for numerous and obvious reasons. One of the many functions of the American Society of Ocularists (ASO) (through its education committee and Board Certification process) is providing courses and resources regarding the anatomy of the human eye. The majority of the ASO's continuing education seems to surround the entire orbital contents, including the muscles, structures of the globe, and the ocular implant. This paper is presented to help educate ocularists in the practical human anatomy they use every day: the anterior anatomy of the human eye. Both visible and invisible (or transparent) structures are discussed, with particular attention paid to the iris*

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INTRODUCTION

The visible portion of the human eye is of universal interest. The so-called "window to the soul" has been the focus of many disciplines, from a primordial-past interest in psychodynamics (fear, anger, sadness, love), through individual depiction (portraiture), to mystic interpretation (iridology), and even personal identification via computer analysis of the iris (biometrics).¹ For ocularists, depicting the anterior aspect of the human eye is our work.

As we all know, ocularists make custom prostheses to match a fellow eye. Such prostheses are often still called "glass eyes," although they are usually made of acrylic (polymethylmethacrylate).² The emphasis is on reproducing a natural appearance for cosmesis. While there are numerous techniques used to fabricate ocular prostheses, ocularists are limited in media by production methods and U.S. Food and Drug Administration (FDA) standards. Yet ocularists require accuracy in their pursuit. Basic knowledge of the anatomy of the eye is necessary. It helps us to understand the factors contributing to the eye's appearance and allows us to look differently at the structures of the iris and sclera, thus making a more natural-appearing prosthesis. It is also imperative to know the correct terminology when conversing with physicians, patients and insurance agencies, as ocularists do on a regular basis.

We will focus here on those structures that are always visible: the cornea, iris and pupil, sclera, and conjunctiva. All eyes depicted in this article are the right eye.

KEY WORDS:

cornea, iris, pupil, sclera and limbus

Highlights

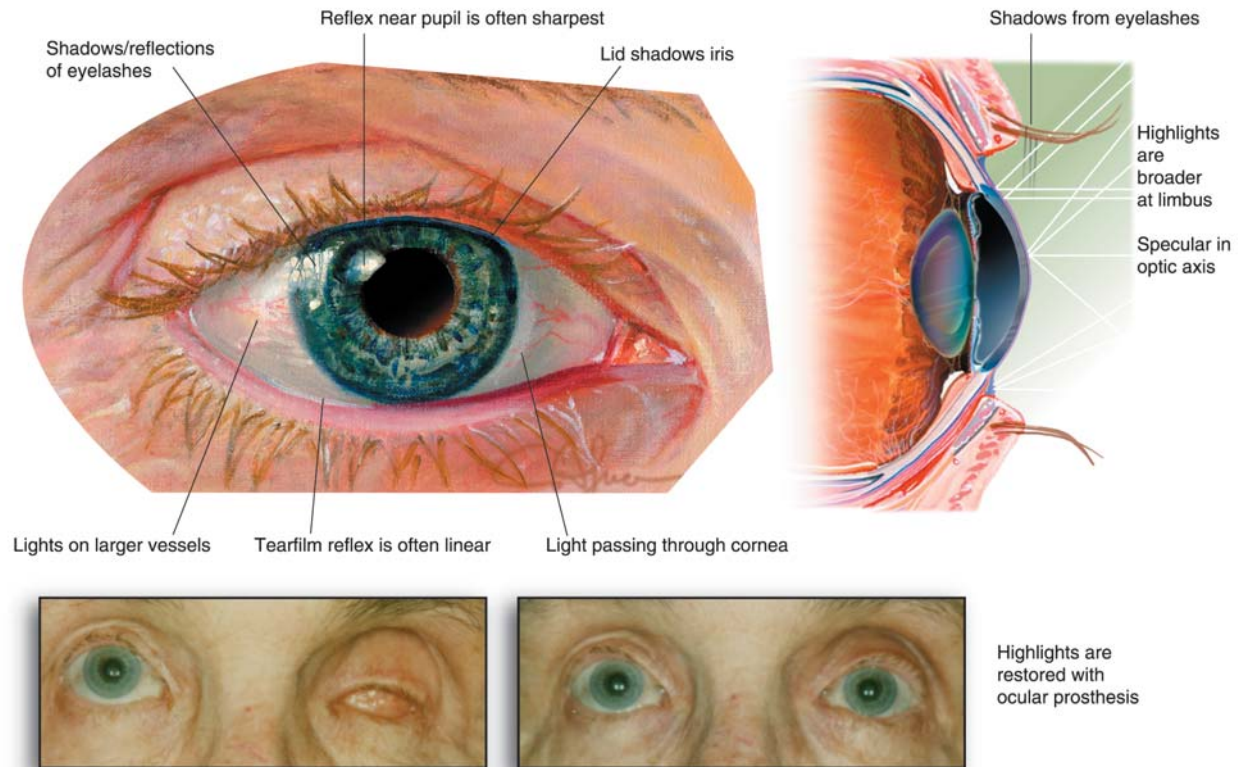


FIGURE 1: Highlights

THE CORNEA AND ITS HIGHLIGHTS

While this most-refractive element is essential in the function of vision, the cornea's role in the realistic appearance of a prosthesis is sometimes overlooked. While several formulae have been offered for drawing the cornea, there is very little reference material for ocularists.³ Ocularists will recognize that the cornea's shape is the most important element in the reflection of light, and thus to its contribution to a natural appearance in photographs. This aspect of the cornea becomes particularly noticeable in sectional illustrations (see above).

In ophthalmology, the cornea is usually made a perfect partial-sphere primarily because of production limitations and convenience. This is perfectly acceptable. In actuality, the cornea is spherical only in its central optical axis portion. Outside the central 3 mm to 6 mm diameter (0.3 mm to 0.5 mm thickness) to the

periphery, its curvature is somewhat flatter, and the curvature at the limbus reverses this. In other words, toward the limbus (0.8 mm to 1.0 mm thickness), the curvature of the cornea is flattened. This flattened curvature is the reason reflections here widen out and become irregular. Thus, anatomical descriptions of the cornea as having a single radius are simplistic. To a general medical audience, this may have little meaning, but to an ocularist or illustrator, it can make the difference between believability and error.

Remember that the cornea (and other transparent tissue) appears "clear" because water is actively pumped out of it. When it absorbs water (or is injured), it puffs up and clouds, thus affecting the appearance of a healing cornea. This condition must be considered by the ocularist when matching the appearance of a fellow eye, which may not be "healthy."

The shape of the cornea is revealed by "highlights." These highlights are the brightest reflections we see in

another person's eyes, also known as "reflexes," "wet-lights," or "catchlights." This highlight is in the same place on both the corneas, thus telling the viewer that the eyes are looking in the same direction. Otherwise, the eyes appear to diverge or converge, making the sitter look cross-eyed (suboptimal at best). Highlights at the margin of the lid tell us whether the eye is wet or dry (Figure 1).

In oculistry, if the highlight appears "off," there are two possible reasons. Perhaps the prosthesis is ill-fitted, making the iris planes of the two eyes unparallel, the axes divergent. Also, the prosthesis may have less mobility than the normal eye, thus lagging behind. The effect on appearance in both cases is negative. As predators, humans have evolved to be visually oriented, particularly to

Iris Painting

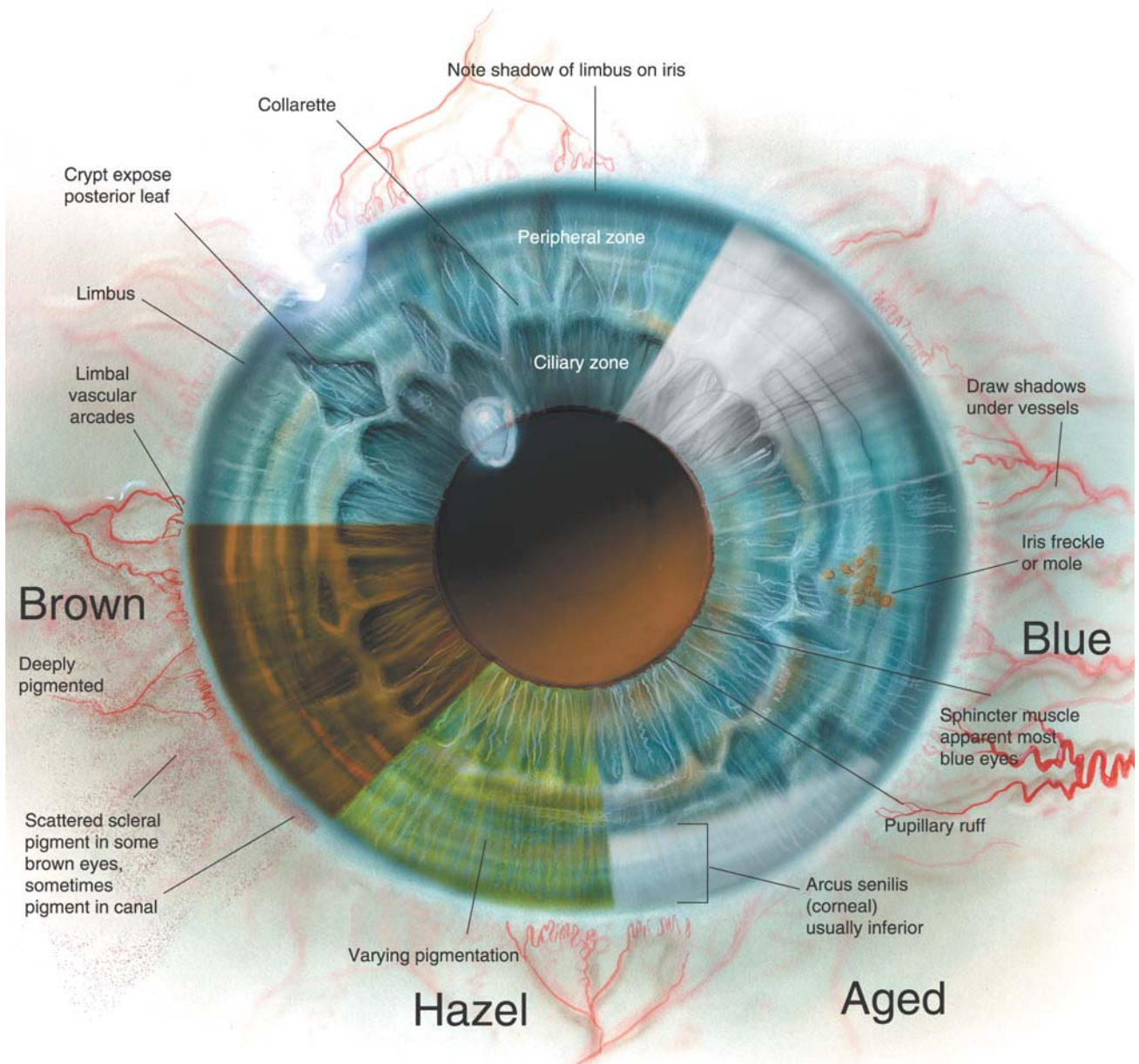


FIGURE 2: Iris painting

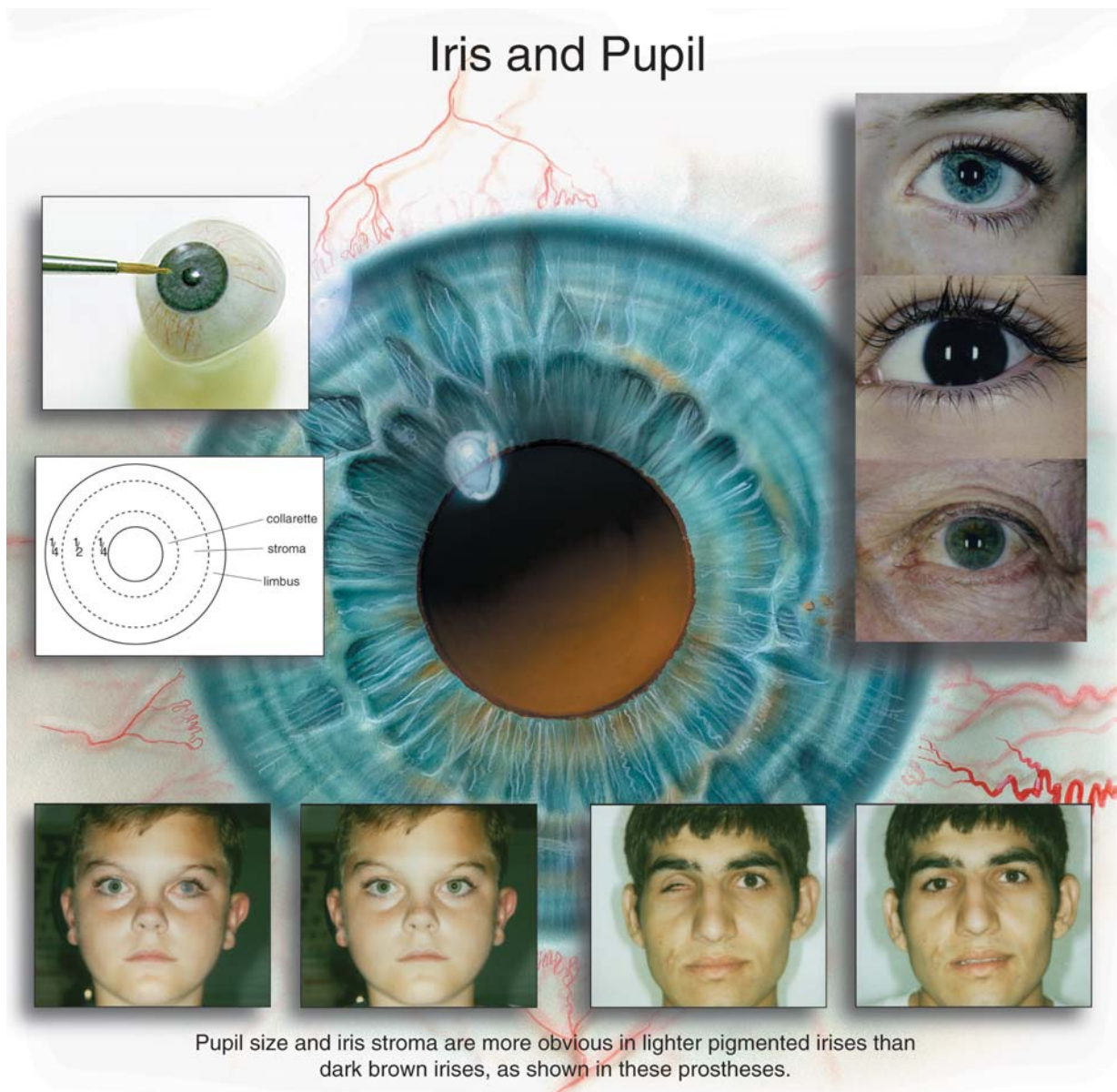


FIGURE 3: Iris and pupil

identify the two rings of the eye - the pupil and iris. Evaluation of these structures in an opponent acts as a kind of target analysis, and direct eye contact can be construed as a threat (Figure 3).

While a point source of light, such as a camera flash, is seen as a point in the central portion of the cornea, it spreads in the periphery, and makes a sclera-corneal reflection that is usually wider and less uniform because of the changing curvature of the cornea and conjunctiva being flattened at the limbus.

THE PUPIL

The pupil can simply be thought of as the circular hole in the iris, allowing light to pass through. Though the pupil is anatomically slightly nasal and superior in the visible iris, it is precisely in the center of the anatomical iris. Its size is generally altered only by actions of the sphincter and dilator muscles, although it can be changed by medications and surgery. An average size can be estimated at 2 mm to 4 mm. Halfway to the limbus is a wide-open pupil, and

most of the active ciliary area, which is inside the iris collarette (see below). It seems to disappear in a darkened room because the pupil becomes larger to admit more light (Figure 2).

In making the prosthesis, the circle of the pupil is mechanically created. There are two main types of pupils in corneal "buttons" or blanks. To recess the pupil from the iris plane, one button uses a "pupil" cast extending past the iris plane from the back of the button. This pupil can be ground smaller to change its diameter, if necessary (Figure 6). Another is drilled into the back of the button; unfortunately, this "pupil" appears to move forward as a solid and cannot be changed in size easily (Figure 6). Both are painted black. Alternatively, one method uses a flat (sometimes curved) gray (or brown) plastic cornea button for *both* pupil and iris, especially in cases where thin-

ness is essential as in a scleral cover shell (Figure 6). An alternative to the above method would be to simply center a "punched out" pupil (of thin emulsion or vinyl) of average diameter onto the base of the iris (button).^{4,5}

THE IRIS

Ranging in size from 11 mm to 13 mm, the visible shape of the iris is determined by the clarity of the clear cornea.⁶ Limiting factors include the position of the limbus and normal senescent changes with age (arcus senilis). Although the anatomical iris is round, the normal visible iris is slightly ovoid, being covered more on the top and bottom by the limbus. This occurs more so in older eyes and is seen primarily on the bottom of the cornea (Figure 3).

The iris is generally conical in shape, following

Iris Colors and Unique Textures

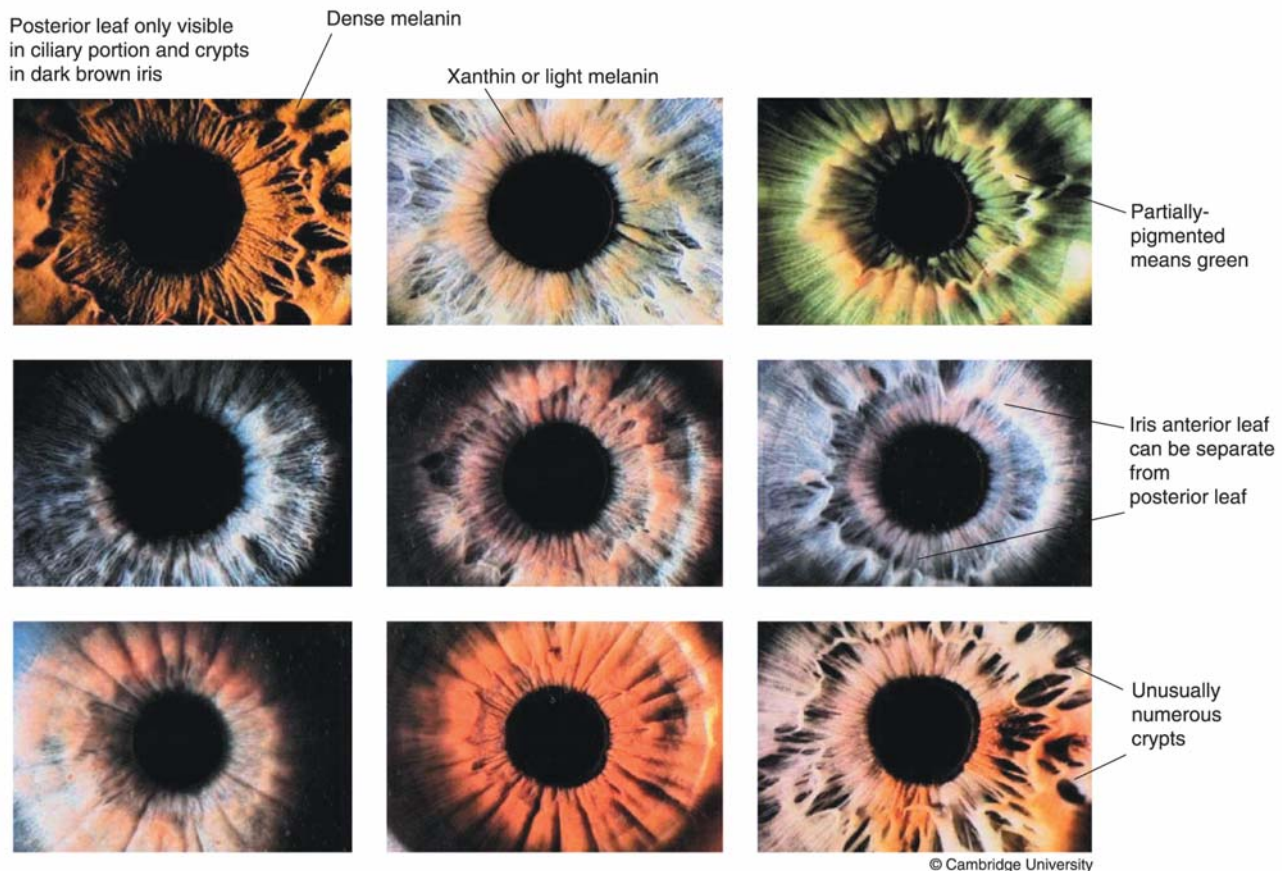


FIGURE 4: Iris colors and unique textures

the lens on which it rests. This rounded conical shape, however, does affect the way light strikes the surface of the iris. The traditional upper-left hand light source then will generally have more of the upper iris in light and the opposite iris in shadow.

The iris surface is not flat, and under biomicroscopy, it displays a cloud-like 3-dimensionality, which is under-appreciated until one looks at it under 40x magnification⁷ (Figure 4). The thickest portion is the collarette, and the thinnest areas are the pupillary margin and the iris root. Radial folds in the central pupillary portion are caused by the sphincter. Discontinuous circumferential folds in the peripheral

portion are caused by the action of dilator muscle cells, respectively.

Two layers of the iris are seen daily - the anterior and posterior layers. In the normal eye, discontinuity of the anterior layer shows the viewer the posterior layer, as seen in iris crypts in the periphery and a different texture of the iris nearest the pupil. In lighter eyes, the pupillary sphincter can be visible as a light pinkish band (0.5 mm to 0.8mm wide) near the pupil, behind the posterior layer. It is actually floating free in the posterior stroma, while the dilator cannot be visualized; much of the stroma is colorless and transparent.

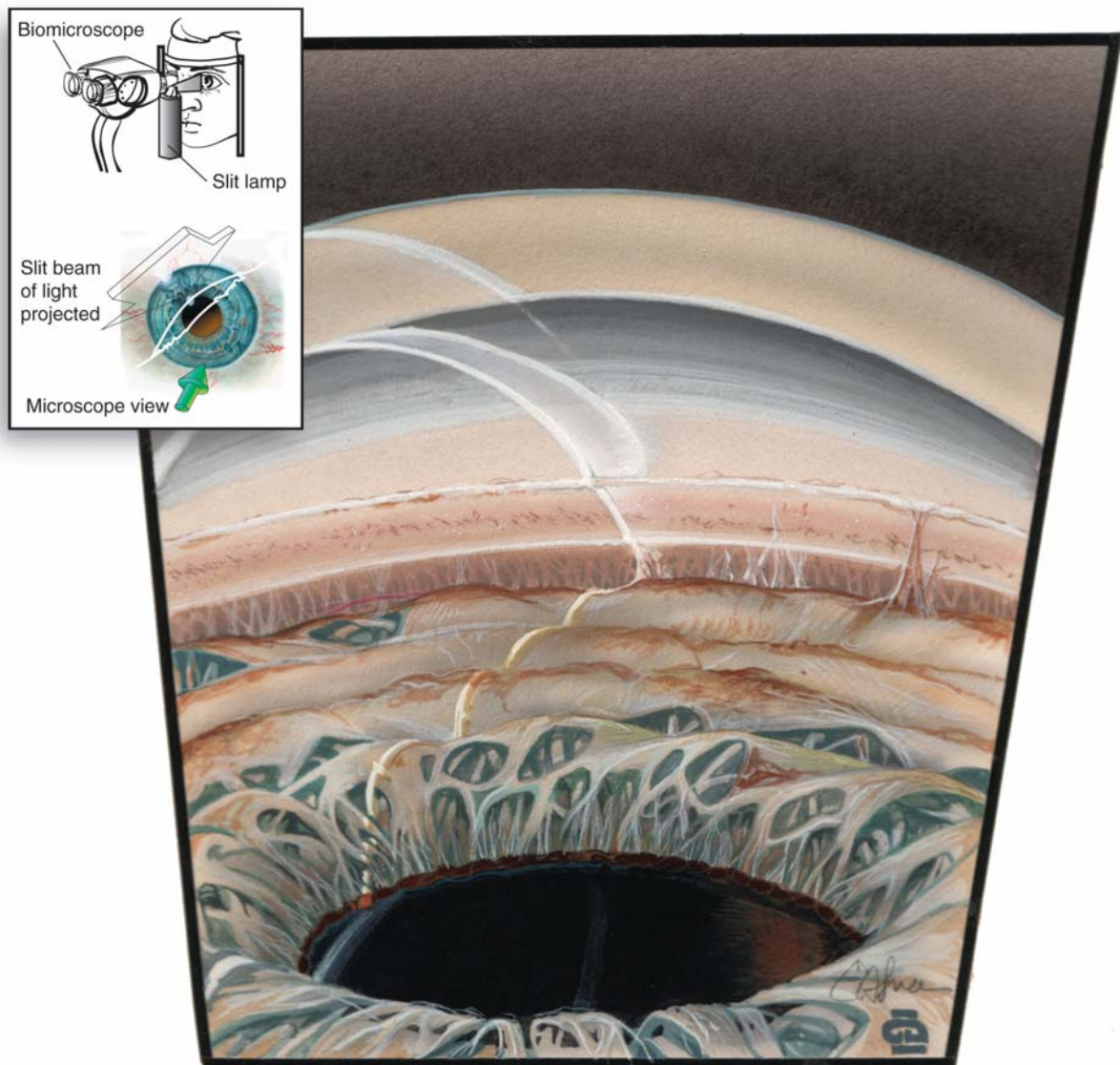


FIGURE 5: Gonioscopic view

Fabricating the Iris in Ocular Prostheses

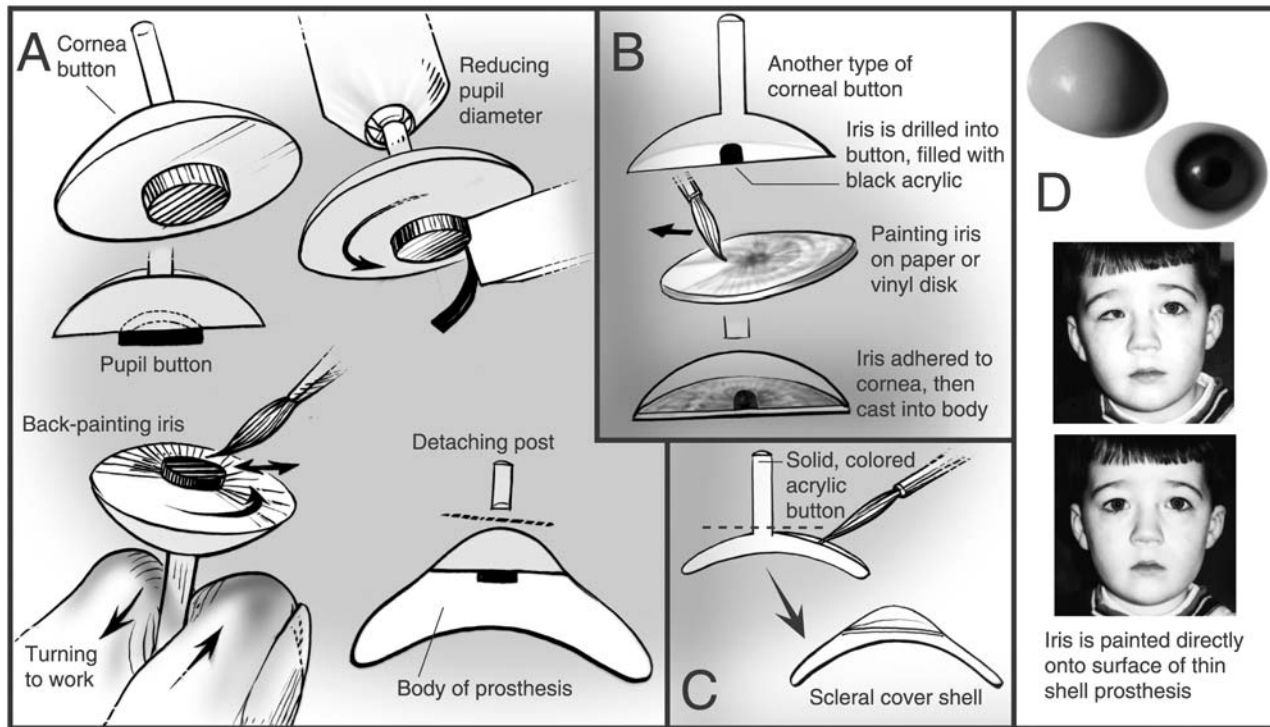


FIGURE 6: Fabricating the iris in ocular prostheses

While peripheral iris crypts are usually unremarkable because they are covered by the limbus, the ciliary nature of the posterior layer is highly evident in the region nearest the pupil (Figure 5). The vessels of the iris are covered by a thickened lamina propria and fibroblasts, surrounded by melanocytes and collagen fibrils. Occasionally a vessel will escape this matrix and be seen as pink, but only under magnification. This is not a concern for ophthalmologists.

The thickness of the iris stroma is often underappreciated, as the unpigmented portions are optically clear. Refraction within the iris vessel walls makes for the variation in coloration seen in someone's eye (against the dark brown pigment of the posterior iris pigment layer). A thinly pigmented iris thus appears blue, a thin stroma allows coloration from the brown pigment of the posterior iris (green or hazel eyes), and the anterior layer of a highly pigmented iris appears a

smooth, velvety-brown.⁸ Of course, the absence of pigment altogether makes the retinal reflex visible, resulting in pink eyes of the albino.

Identifiable elements in an individual eye include landmarks that a computer can use better than a fingerprint. Irregularities in the anterior layer make distinctive folds and furrows of the posterior layer evident. Aggregates of melanocytes appear as brown spot nevi, while clump cells can be seen as spherical brown spots in the peripheral stroma and near the sphincter muscle. While a dusting of xanthin yellow pigment can sometimes be seen on the surface of a light eye or Wolffian spots, almost all the pigment in the eye is from brown melanin granules, becoming darker with concentration.

There are several (iris) painting techniques, which include oil pigments, watercolors, and colored pencil, to duplicate the human iris. In back-painting directly

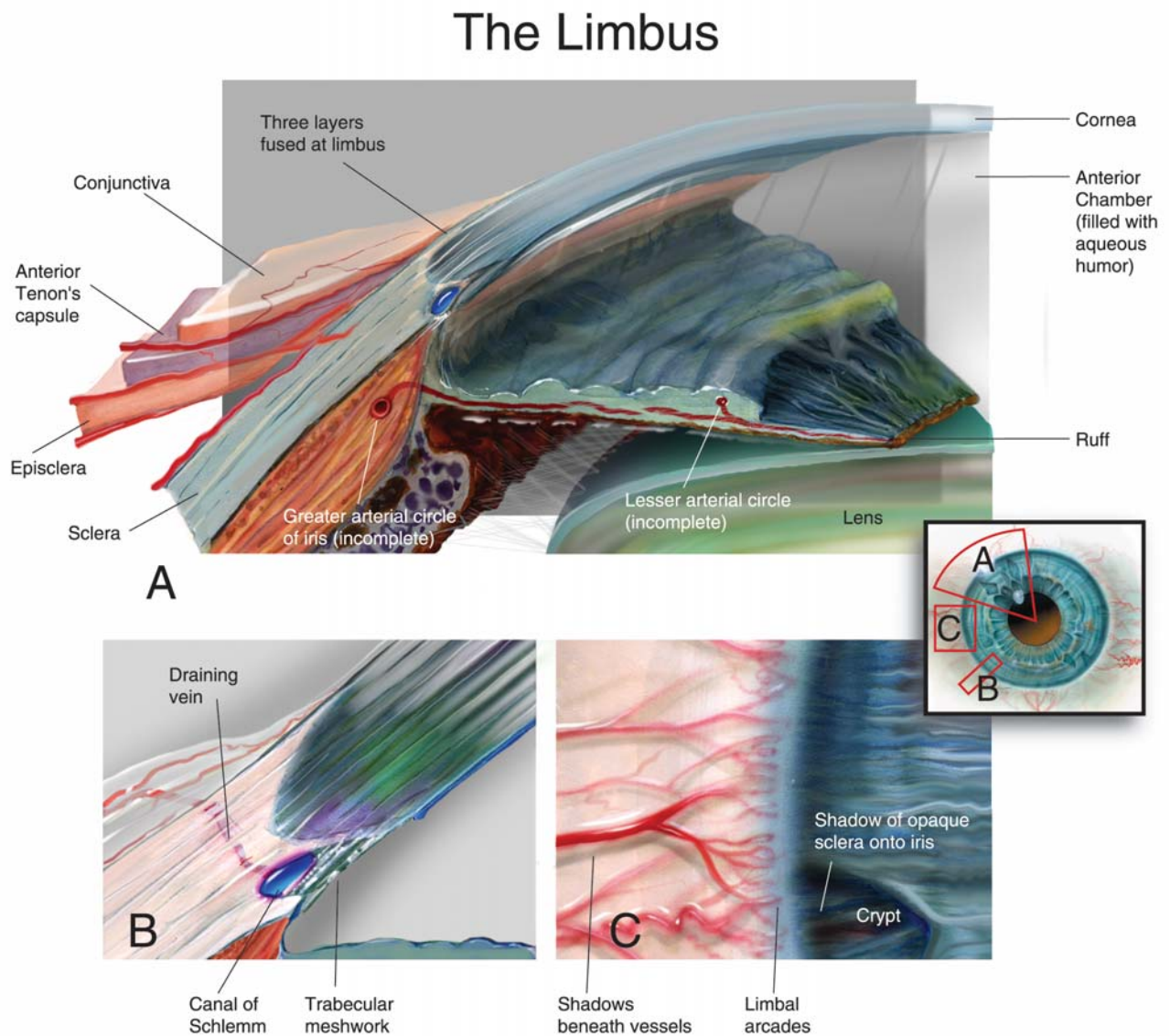


FIGURE 7: The limbus

onto a corneal button (the LeGrand Technique), ocularists can assemble these elements in a variety of ways (Figure 6) Yellowing or a hazy anterior iris color is laid in as a first coat. The fine detail in the pupillary iris is assisted by scraping back the darker background color with a blade and overpainting with coloration variants to assume a front-most position. Within the limited media available in real-time production, nevi can be painted first, or drilled out and back-filled. Painting in lacquers with an acrylic monomer makes this one of the fastest drying medium. The stem can be rotated to

expedite coverage, and a "scrubbing" of the brush leaves complex iris "stria" or lines in the pupillary region.

Commercial, mass produced iris buttons complete with painted or pigmented irises have been marketed over the years with minimal success. Hand-painted techniques with the patient present seem to win out in the long run. I personally feel that patients appreciate seeing all of the time-intensive steps that go into making the prosthesis; however, it's the end result that counts.

The collarette can be almost hazy in its atti-

tude in the lighter eye, though it is often very well-defined in the brown eye. It is scalloped mostly peripherally, just like the incomplete vessel arcade that it once was in the womb. If one thinks of how it was formed, the scallops in the collarette are pulling back from the pupil. It can be thought of as retreating, trailing strands behind it.

This point is a bit clearer when ocularists have a fellow eye to match. Actually, if the fellow eye is distorted by disease or surgery, some ocularists make the prosthesis look like it is the more normal (although distorted in color) eye, although the patient usually has a suggestion in this situation. Even when the fellow eye doesn't have a well-defined collarette, inserting one anyway can soften the pupil.

The peripheral iris is mostly characterized by circumferential folds, which are never complete circles. In a dark eye, pigment may be deficient in the base of the folds, seen as lighter arcs, which is a valuable detail for ocularists.

THE LIMBUS

The anatomical limbus contains the drainage angle, wherein resides the watery aqueous humor (produced in the ciliary body and filling the anterior chamber). This is just behind (and nourishing) the cornea. It drains into the venous system through the trabecular meshwork and into the Canal of Schlemm. This often means the blending of clear cornea into white sclera as seen from the front. This blending must be natural or the iris looks "cut-out." Thus, one speaks of a "soft" or "hard" limbus. A soft blue tint to this area is often necessary for a more natural-appearing prosthesis. Most ocularists do this mechanically as the limbus is cast in acrylic, and a few paint it (Figure 7).

Scattered internal reflection of light through the cornea can illuminate the far side of the iris and sclera at the limbus (as well as light reflected from the lower eyelid or nose). This is seen in the best portraiture and life-like illustration.

THE SCLERA AND ITS COVERINGS

The normally near-white sclera extends from the limbus to cover the rest of the globe. The sclera

coverings (sclera, episclera, anterior Tenon's capsule, and conjunctiva) are notable here only in that the blood vessels seen over the white sclera reside between these layers, thus causing a shadow effect on the opaque white scleral background.

This effect is conveniently handled in ophthalmology by using oils and dry pigments, making vessels out of silk threads or tracings of red pencil onto a clear covering layer, then adding a clear coating on top of them. The larger episcleral or conjunctival vessels will sometimes impress the external contour of the eye, thus making two highlights possible: just on (vessel highlight) and just above the vessel (reflection on clear covering conjunctiva).

The vessels to the anterior eye are seen between the three layers of tissue over the sclera: episclera, Tenon's capsule, and conjunctiva. These are generally transparent and fuse to the cornea near the limbus. Long posterior ciliary arteries are usually supplied to each quadrant of the anterior eye (visible in the conjunctiva). The straighter vessels are arteriolar and can be redder; the wavy ones are usually veins and are larger, usually deeper than the same-quadrant arterioles. The arterioles should not cross each other in the same layer. Additional, extremely fine vessel arcades can be seen at the limbus, just outside the clear cornea. These details must be considered in creating prostheses.

Evident in the portion visible in the open eye (Figure 8), the area of sclera usually seen is highly vascular, and can exhibit nevi and other coloration variants. This is presumably caused by the fact that atmospheric pressure is less than tissue turgor, so these substances are freer to express themselves; in other words, they collect here. Dark brown eyes will have a smattering of brown in the sclera throughout, but more so in the area of the limbus and conjunctiva. Icterus is a faint yellow-brown colorative element, due to deposited hepatic by-products. Thus, a slight yellowing of the sclera is usually seen in the older eye and having "clear eyes" is a characteristic of youth. Likewise, a baby's sclera (or in osteogenita imperfecta) often appears bluer because the thinness of the young sclera. "Pure baby-blue eyes" mean more than the iris.⁹ It is important to keep these facts in mind in order to create a natural appearance in prostheses.

Palpebral Fissure

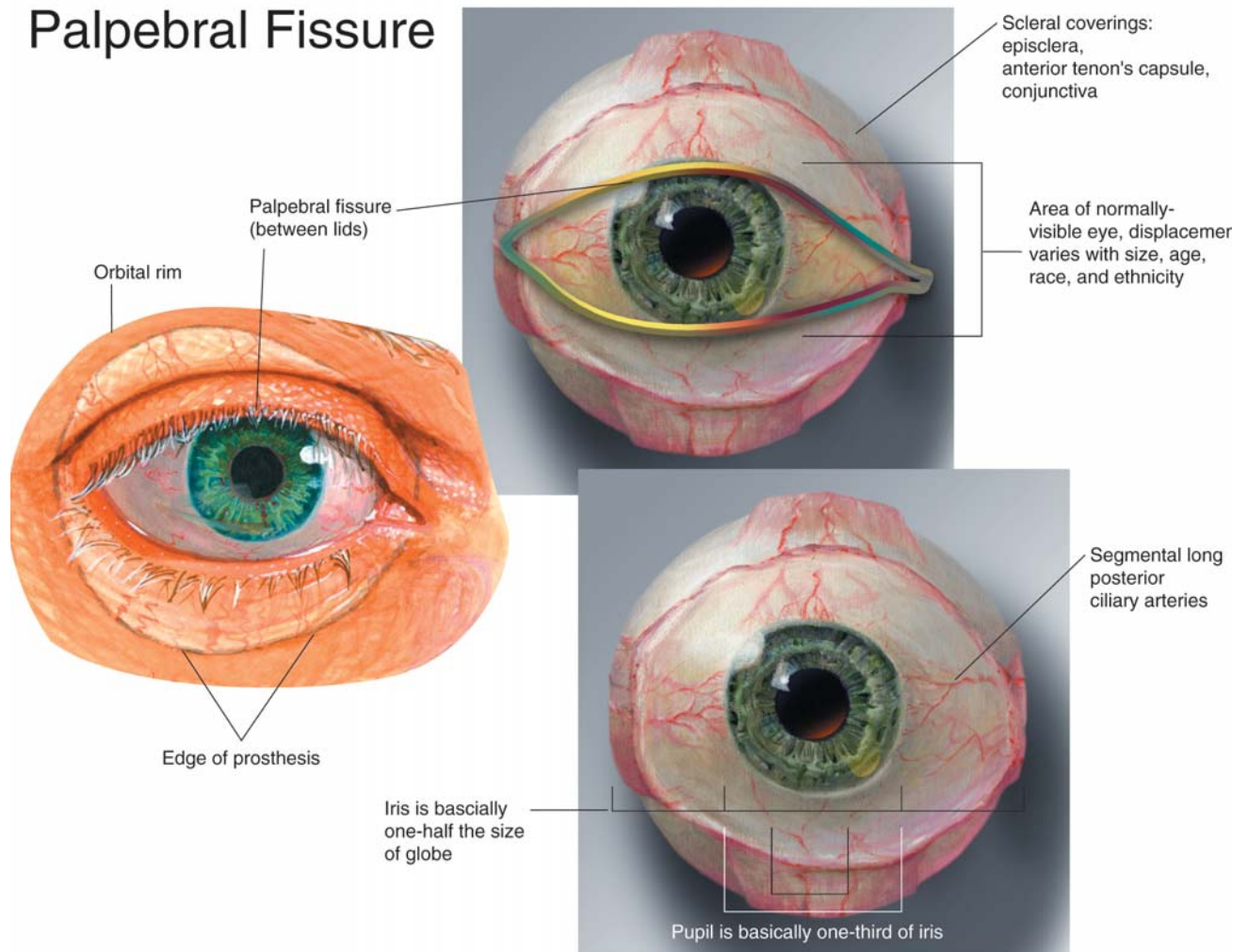


FIGURE 8: Palpebral fissure

In conclusion, it is obvious that a thorough knowledge of anatomy is helpful for the accurate reproduction of the structures of the eye for fabricating prostheses. The basic important structures - cornea, pupil, iris, limbus, sclera - have been noted, but it is difficult, if not impossible, to thoroughly cover the anatomy of the anterior eye in such a short article. It should be noted that every ophthalmologist adds his/her own "twist" to the "standard" techniques of making ocular prostheses. It is hoped that the material presented here entices the reader to further exploration and inspires the work currently being generated, thus making your prostheses more lifelike and, in return, your patients happier.

REFERENCES

1. Daugman J. Phenotypic versus genotypic approaches to face recognition. In: *Face Recognition: From Theory to Applications*. Heidelberg: Springer-Verlag, (1998), pp 108-123.
2. Ott K, Mihm S and Serlin D. *Artificial Parts, Practical Lives; Modern Histories of Prosthetics*. New York University Press, 2002.
3. Warren LA. *The Journal of Biocommunications (JBC)*, Basic Anatomy of the Eye for Artists, 1988, 22-31.
4. Instruction Booklet, Valley Forge Plastic Artificial Eye Program, Office of the Surgeon

- General, U.S. Army, Washington, D.C., September, 1944.
5. Erph SF, D.D.S., Wirtz MS D.D.S. and Dietz, VH, D.D.S. Plastic Artificial Eye Program, U.S. Army, *American Journal of Ophthalmology*, 1946, 29: 984.
 6. *Eugene Wolf's Anatomy of the Eye and Orbit*, W.B. Saunders Company, 1933. Seventh Edition, 1976.
 7. Daugman J. Biometric Decision Landscapes. Technical Report No. TR482 (1999), University of Cambridge Computer Laboratory.
 8. Galeski JS. Galeski Laboratories Prosthetic Eye Fitting Manual. *Iris Patterns*. Richmond, Virginia, 1950.
 9. *Ocular Anatomy, Embryology, and Teratology*, FA Jakobiec (ed), Harper and Rowe, Philadelphia, 1982.

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Color illustrations of these and other anatomy of the eye related to oculistry can be seen on the website:
<http://www.artificialeyeclinic/anatomypics.com>.

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