Focusing The Fundus Camera: A Clinical Approach

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Abstract: *Ophthalmic photography is a system of information transferral. In fundus photography, a visual description of the three-dimensional retinal and choroidal tissues is transferred to film. This two-dimensional representation is used by the physician to make judgments concerning the health and treatment of the patient's retina. An accurate representation of the retinal and choroidal tissues is the goal of the ophthalmic photographer. To this end, a sharp, well focused fundus camera image is essential. This paper describes the fundus camera's aerial image focusing system and its correct use. The well focused fundus photograph is defined and proper focusing technique is linked with retinal anatomy and pathology. Focusing obstacles are discussed. Suggestions for achieving proper focus in difficult clinical situations are provided. Special techniques for optimizing sharpness in stereo images are noted.*

The Fundus Camera's Focusing System

In their most basic form, optical systems require light, a subject, a lens, and a receiving plane. Light reflects off of the subject, is refracted by the lens, and is projected onto a receiving plane as an image. Clinically focusing the fundus camera consists of adjusting the relationship between the subject and lens so that the subject lies within the lens' depth of field and the receiving plane lies within the depth of focus of the image. In fundus photography, the patient's retina becomes the subject, the optics of the fundus camera and the patient's eye replace the simple lens, and film becomes the receiving plane (Fig. 1).

Most fundus cameras utilize a single lens reflex viewing system. Your ability to maximize focusing skills will be enhanced if you are familiar with the single lens reflex (SLR) design and the fundus camera's aerial image viewing system.

THE SLR VIEWING SYSTEM

The objective lens of the fundus camera transmits light for both viewing the subject and exposing the film inside the SLR camera body (Fig. 2). The hinged mirror is positioned differently for viewing and taking the picture (Fig. 3 a,b). The image is seen on the focusing screen in the viewfinder when the mirror is down. The hinged mirror then flips up and out of the way to allow film exposure.

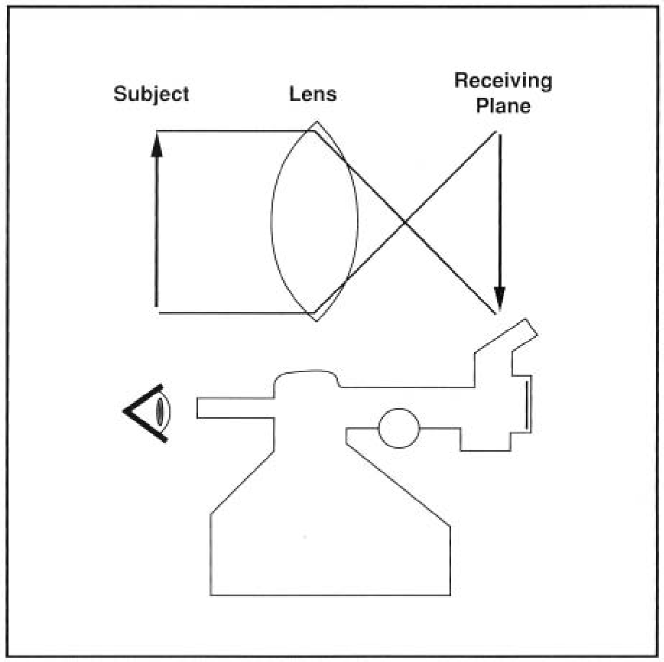


Figure 1: A sharp fundus photograph is created when a specific retinal layer is the subject, the fundus camera optics serve as a lens, and the film plane coincides with the plane of sharp focus.

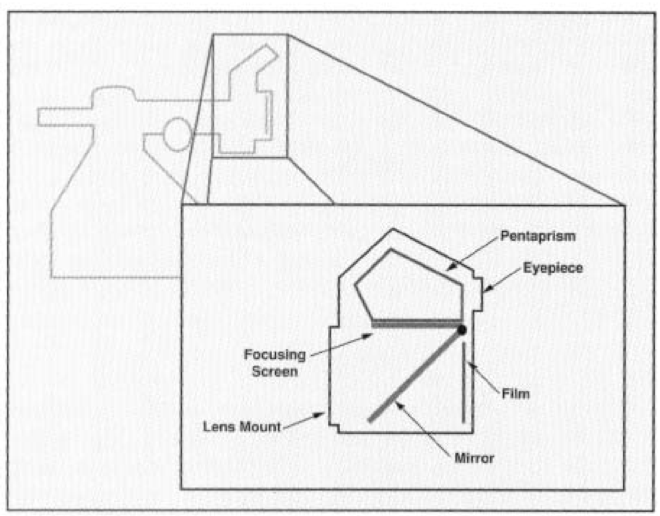


Figure 2: A simplification of the fundus camera's SLR viewing system. Standard components of a single lens reflex camera system are identified. Most modern fundus cameras use an SLR system for viewing the fundus image.

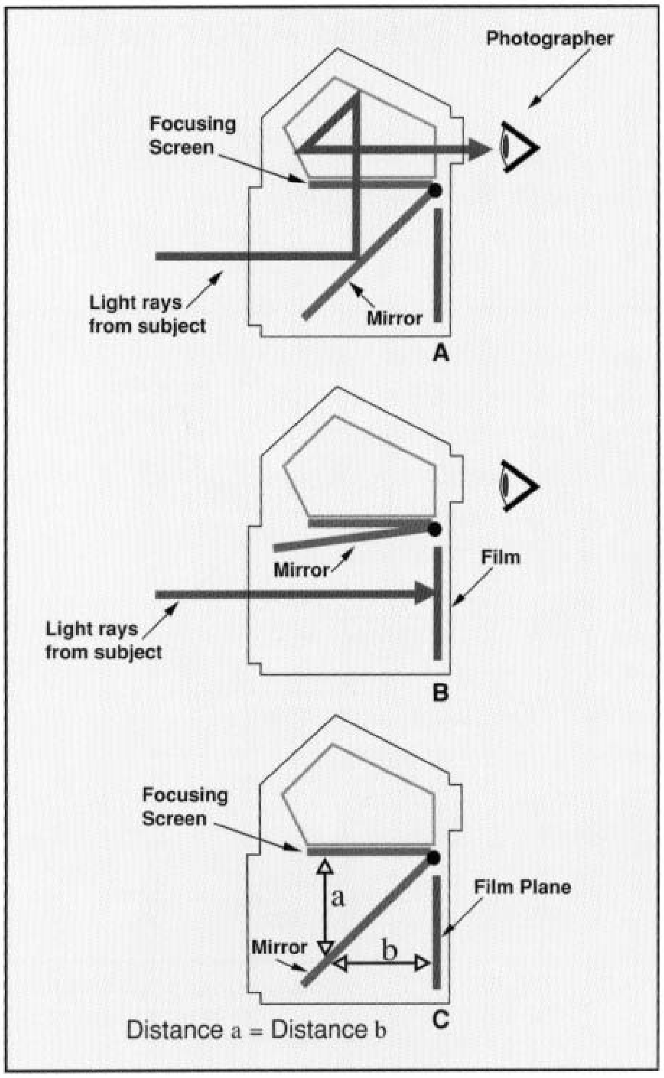


Figure 3: Before a photograph is taken, the photographer previews the scene. Light from the lens enters the camera body, reflects off of the hinged, 45° mirror and up into the focusing screen. The photographer views the image on the focusing screen through the viewfinder (A). When the photographer chooses to expose an image, the shutter release is depressed. This initiates a sequence of events (these events may vary according to the specific camera and flash utilized) which include the mirror flipping up and out of the way, momentarily darkening the viewfinder. This allows the same light which has just been viewed to expose the film (B). An SLR system is basically a "what-you-see-is-what-you-get" system. The distance between the focusing screen and the lens system is equal to the distance between the film plane and the lens system (C). When the image appears sharp on a single lens reflex camera's focusing screen, it will also appear sharp on the film.

In a single lens reflex system, the focusing screen helps the photographer judge image sharpness before exposing the film. A standard focusing screen is usually constructed of ground glass and is always located the same distance from the objective lens as the film plane (Fig. 3 c). When an object appears sharp on the focusing screen, it will also be sharply imaged at the film plane and therefore will be in sharp focus on the film.

The photographer focuses by adjusting the objective lens to achieve the sharpest image on the textured focusing screen. Unfortunately, even when an SLR incorporates the finest ground glass manufactured, the intensity of the light decreases as it passes through the focusing screen. A ground glass focusing system will always dim the view of the object being photographed. This darkening of the focusing screen is of little importance to most photographers. However, in fundus photography, a number of restrictions preclude the use of a ground glass focusing screen:

1. *Relatively small amounts of light must be used when viewing the eye.* The possibility of retinal damage is increased as the quantity and duration of illumination increases.' In addition, many patients are sensitive to bright lights, making examination with high intensity light difficult.

2. *High magnifications (for example 2.5x in a 30° fundus image) are used to photograph the retina.* A fixed amount of light is reflected off of the subject. This light energy (from a small portion of the subject) is distributed over a physically greater area on the film when the image is magnified. This results in a lower level of light available for imaging any particular portion of the subject.

3. *The grainy structure of a ground glass focusing screen breaks up the fine detail of the fundus image.* The large size of the grains in a ground glass focusing screen makes it difficult to focus on small detail, including fine blood vessels.

Fundus cameras replace the ground glass of a standard 35mm SLR camera system with a clear glass focusing screen containing etched lines (Fig. 4). The clear glass maximizes the light entering the photographer's eye. The etched black lines (called the focusing reticle) allow the photographer to focus on the plane of the focusing screen and to therefore achieve sharp focus at the film plane.

Because the image in the viewfinder is not `captured' by the ground glass, but rather floats in the air space both in front of and behind the clear glass focusing

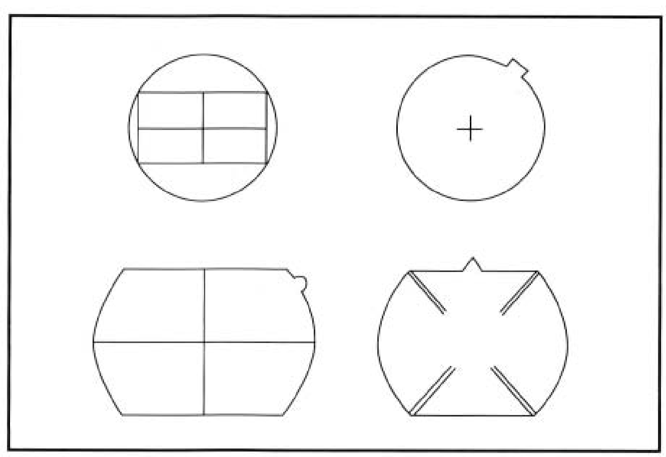


Figure 4: Various designs of focusing plane reticles are illustrated. The reticle for your specific camera may vary according to manufacturer and date.

screen, it is termed an aerial image. Learning to focus this aerial image using the reticle is essential to obtaining sharp images with a fundus camera.

VIEWING THE AERIAL IMAGE

An opthalmic photographer looking through the fundus camera's viewfinder with his or her best corrected vision, sees one of four possible views. The image inside the viewfinder may be totally out of focus, without distinct reticle lines or sharp areas of retina. The image alone may be in focus, only the black reticle lines may be in focus, or both the image *and* the black reticle lines may be in focus. Only in the last case will a sharp image be recorded on film.

If both the focusing reticle and the fundus image are completely out of focus, then one of two conditions may exist. The first is that the photographer's eyes may not be corrected for best visual acuity. A routine eye exam is recommended at the beginning of, and at regular intervals throughout the fundus photographer's career. The second is that the fundus camera's reticle and focus adjustment may be improperly set. If this is the case, the user is referred to the section `Obtaining a sharp fundus photograph' below. Of course, a combination of these circumstances may occur.

If the retina is in focus, but the reticle is not (Fig. 5 a), then the photographer has achieved a clear image focused in front of the focusing screen. This situation occurs when the photographer does not concentrate on seeing the reticle but instead focuses his or her eyes (instead of the fundus camera) in an effort to see sharp retinal detail. The photographer's eye accommodates and focuses above the focusing screen (Fig. 5 b). In this instance, the lens system to aerial image distance is greater than the distance between the lens system and the film plane. The distance between the lens system and the aerial image seen by the photographer must be identical to the distance between the lens system and the film plane in order to produce a sharp fundus photograph. Any discrepancy between these distances results in unsharp photographs, and even though the photographer sees a clear image in the viewfinder, the resulting photograph will be blurry (Fig. 5 c). A correct setting of the camera's eyepiece (see below) and a conscious effort to be aware of both the reticle *and* subject throughout the photographic session will result in sharper photographs.

The black reticle may be in focus for the photographer and the subject out of focus, as when first looking through the viewfinder after aligning a patient (Fig. 5 d). In other words, the photographer's eye is focused on the proper plane, but the lens system of the camera has not yet been adjusted to achieve maximum sharpness (Fig. 5 e). If a picture is taken, it will be just as unsharp as seen by the photographer (Fig. 5 f).

Only when the photographer adjusts the camera to obtain a critically sharp image, while retaining sharpness in the black lines of the focusing reticle (Fig. 5 g), will the resulting photograph be sharp. A sharp, well defined reticle indicates that the photographer's eye is focused to the correct distance (that is, on the focusing screen). A sharp image of the patient's eye indicates that the lens system has been adjusted properly (Fig. 5 h). Both the retina *and* the reticle must be well defined in order to generate a sharp fundus photograph (Fig. 5 i).

ACCOMMODATION

Accommodation is the normal mechanism the eye uses for focusing on near objects. In simple terms, the ciliary muscle tugs or releases tension on the lens zonules, modifying the refractive power of the human lens. At the same time, the pupils constrict (decreasing the visual field) and both eyes turn inward. The ability for our eyes to accommodate lessens with age.

A significant cause of unsharp fundus photographs can be accommodation by the photographer during the focusing procedure. If the photographer accommodates to perceive a sharp image of the retina, then the optical system of the photographer's own eye is utilized to obtain sharpness, rather than the optical system of the fundus camera. When photographers look through the camera eyepiece and accommodate, they see a sharp image of the retina, but do not see a sharp image of the focusing reticle. The fundus camera focusing knob may be used to sharpen the image, but a blurry photograph will result if the focusing reticle is not perceived as sharp. The tendency to accommodate when focusing is especially prevalent in fatigued or novice fundus photographers, and in experienced photographers who are under 40 years of age. Multiple strategies for safeguarding against accommodation during fundus photography procedures are outlined below.

Highly trained photographers can `feel' themselves accommodate. You may want to test this yourself. Find a quiet room with no distractions. Fully relax your mind and body while focusing your eyes on infinity. Bring your index finger about eighteen inches from your nose. When you focus on your index finger, the background will become unsharp. Keeping your finger in focus, move it toward your nose slowly. You will notice a number of changes. The background will become increasingly less sharp and the edges of your visual field will constrict. You will feel your eyes converge and you may feel a sensation in the anterior section of your eyes. Focus on infinity again and then repeat the near focusing exercise. After multiple repetitions, you will become more aware of your personal sensation during accommodation. Awareness of this sensation during fundus photography will alert the photographer to the possibility of accommodation and resultant unsharp photographs.

If you think you are accommodating during a procedure, look away from the eyepiece. Merely blinking or closing your eyes may help reset their focus. When looking back again into the viewfinder, try to focus first on the thin black lines of the focusing reticle, rather than on the fundus. Intentionally blurring the fundus image (by moving the plane of focus into the vitreous

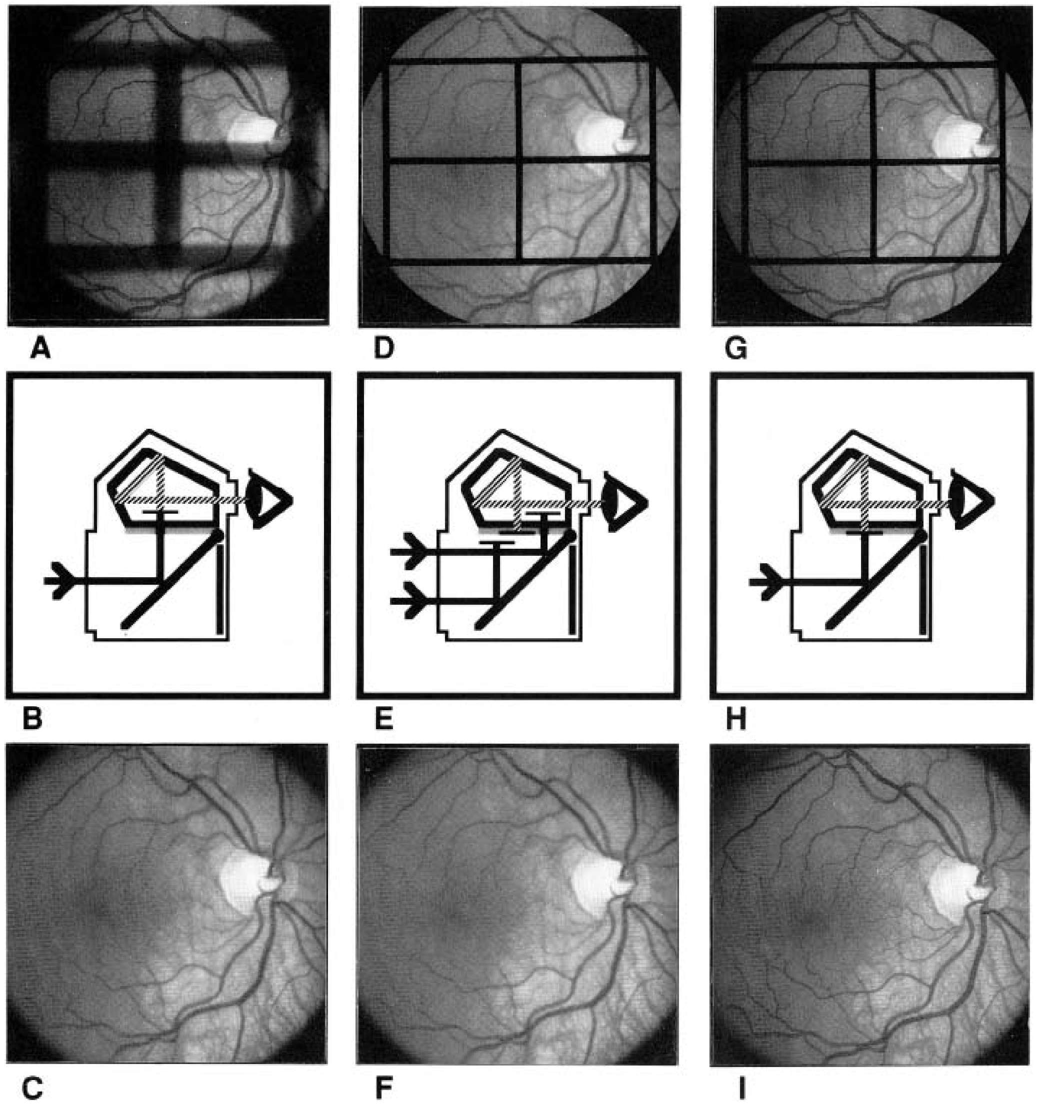


Figure 5: The relationship between sharpness in the reticle and the photographer's fundus view and the sharpness in the final fundus photograph is illustrated here. When the photographer focuses the image without regard to the sharpness of the focusing reticle, the fundus image is perceived as sharp and the reticle image appears blurry (A). The image the photographer sees is focused by the photographer's eyes above the focusing screen, closer than infinity (B). Even though the photographer sees a sharp image in the viewfinder, the exposed photograph will be blurry (C). When the photographer views through a correctly adjusted eyepiece before the fundus has been focused on, then the fundus appears blurry while the reticle is distinctly sharp (D). The photographer has correctly focused on the reticle, but has not yet adjusted the fundus camera image to coincide with the receiving plane (E). The resulting image will be as unsharp as the photographer views it (F). After correct adjustments of the eyepiece and the fundus camera's focusing mechanism, both the fundus image and the reticle appear sharp and clear (G). The photographer's eyes are focused on the reticle, and the image from the fundus camera corresponds with the film plane (H). Only this final combination will yield a sharply focused fundus photograph (I).

through a rotation of the focusing knob) may help you concentrate on the reticle image.

Since both eyes work together, it is advantageous to keep both eyes open throughout the procedure, preferably with the non-eyepiece eye focused across the room. A well placed visual (of a landscape or distant scene) on the opposite wall of the fundus photography room will promote distance focusing. If the room is especially small, a mirror (or the glass from the above print) may be used to reflect the image from a visual hanging directly behind the photographer. Glancing at this reflection will better approximate distance focusing in a small room. Viewing exciting scenery through a window in the fundus camera room may seem tempting. However, the darkness necessary during procedures precludes this option.

A full day of fundus photography may distort the normal accommodative process, causing the eye to be `stuck' in near focus. Accommodative excess is the result of "prolonged and intense periods of near work. "2 Eyestrain and headaches may be experienced. [3] Persistent focusing on infinity may help retard this near focus fatigue. Consciously focus across the distance of the waiting room (or down a long hall) when you call patients. Practice focusing on infinity out a window during breaks or at lunch. Make a point of looking at distant scenery or buildings while commuting to and from work.

Of course, the photographer's eyes should be corrected to their best visual acuity. You may find that one eye is sharper than the other. Keep your eyeglasses or contacts scrupulously clean.

Certain physiological conditions may also distort the focusing process. Extreme changes in blood sugar may alter the thickness of the diabetic photographer's lens, making distance vision unsharp. Certain drugs may produce pseudopresbyopia. [4] Maintaining a healthy diet and good physical condition are suggested for optimal focusing ability.

The Sharp Fundus Photograph

DEFINITION

Sharpness in a photograph is a visual phenomenon which is difficult to quantify. Both contrast and resolution play a role in our subjective evaluations of sharpness. An image is described as sharp when the borders defining the subject are distinct and clear. An unsharp Image contains borders between adjacent areas which are fuzzy or overlap. For this paper, sharpness will be defined as the clear visual representation of a subject as judged by an experienced ophthalmic photographer or ophthalmologist. A sharp fundus photograph results when the fundus camera's plane of sharp focus coincides with the specific pathology in question.

When photographing the retina, it is essential to recognize that, like most photographic subjects in our three dimensional world, the posterior segment of the eye has depth. The vitreous, retina, and choroid may be described histologically as overlapping layers of gel, tissue, and blood vessels which are located at specific levels** within the eye (Fig. 6).

Five distinct levels (the vitreous, inner retina, central retina, outer retina, and choroid) may be distinguished using white-light 30° stereo fundus photography in many patients with diseased or swollen retinas (Fig. 7).

The utilization of short wavelength color filters (such as exciter and barrier filters for fluorescein angiography, blue filters for retinal nerve layer photography, and green filters for `red-free' photography) enhances the photographic separation of retinal levels. [5] Thickened, diseased retina and narrow angle fundus camera optics facilitate the photographer's recognition of retinal levels, and expedites their differential focusing.

Monocular (single image) photography, wide angle fundus cameras, and inaccurate focusing inhibit the viewer's ability to distinguish five separate retinal levels. The levels' thinness combined with the depth of field of the fundus camera may make it difficult to distinguish each of the five levels in patients with normal or thin retinas.

A sharp fundus photograph is precisely focused upon a specific subject within a specific level of the retina. The objective appearance of clear, distinct borders in a fundus photograph does not in itself certify the sharpness of that photograph. A fundus photograph may be sharp, but not at the appropriate retinal level. Not every fundus photograph exhibiting objective sharpness may be described as a `sharp fundus photograph' (Fig. 8). Focusing too far forward (into the vitreous), or too far backward (into the outer retina or choroid) results in a fundus photograph which may not accurately document the appropriate pathology.

How can we, as photographers, achieve optimal focus at the appropriate layer within the eye? An understanding of retinal anatomy is essential to achieving sharp fundus photographs.

LAYERS AND LEVELS

Accurately adjusting the fundus camera's focus requires an awareness of the layered aspect of the eye's anatomy. The vitreous gel fills the posterior chamber of the eye. The retina is a three dimensional tissue which is described histologically as ten separate layers. The choroid contains two layers of blood vessels.

The vitreous is positioned anterior to the retina. In the normal eye, an image of the vitreous cannot be captured with a standard fundus camera. However, when documentation of a diabetic neovascular frond, a retinal detachment, or asteroid hyalosis is necessary, the fundus camera should be focused `up' into the vitreous, rather than `down' on the retina (Fig. 9, set 1).

The internal limiting membrane, the nerve fiber layer, and the ganglion cell layer combine to form the inner retina. The photographer visualizes the inner retina as the nerve fiber layer and reflections from the large retinal blood vessels. Cotton wool spots, nerve fiber defects, myelinated nerve fibers, and flame-shaped hemorrhages occur at this level (Fig. 9, set 2).

The inner and outer plexiform layer, and the inner and outer nuclear layer form the central portion of the retina. The central retina contains the smaller blood vessel branches, hard exudates, and diabetic microaneurysms. The capillary net surrounding the foveal avascular zone is imaged during fluorescein angiography when the focus of the fundus camera is properly adjusted on this middle level of the retina (Fig. 9, set 3).

The outer retinal level includes the rods and cones, the pigment epithelium and bruch's membrane. Subretinal neovascular membranes, drusen, presumed ocular

**(FOOTNOTE: This paper uses the term layers' when referring to histological sections, and reserves the term levels' for discussion of the fundus camera image.)

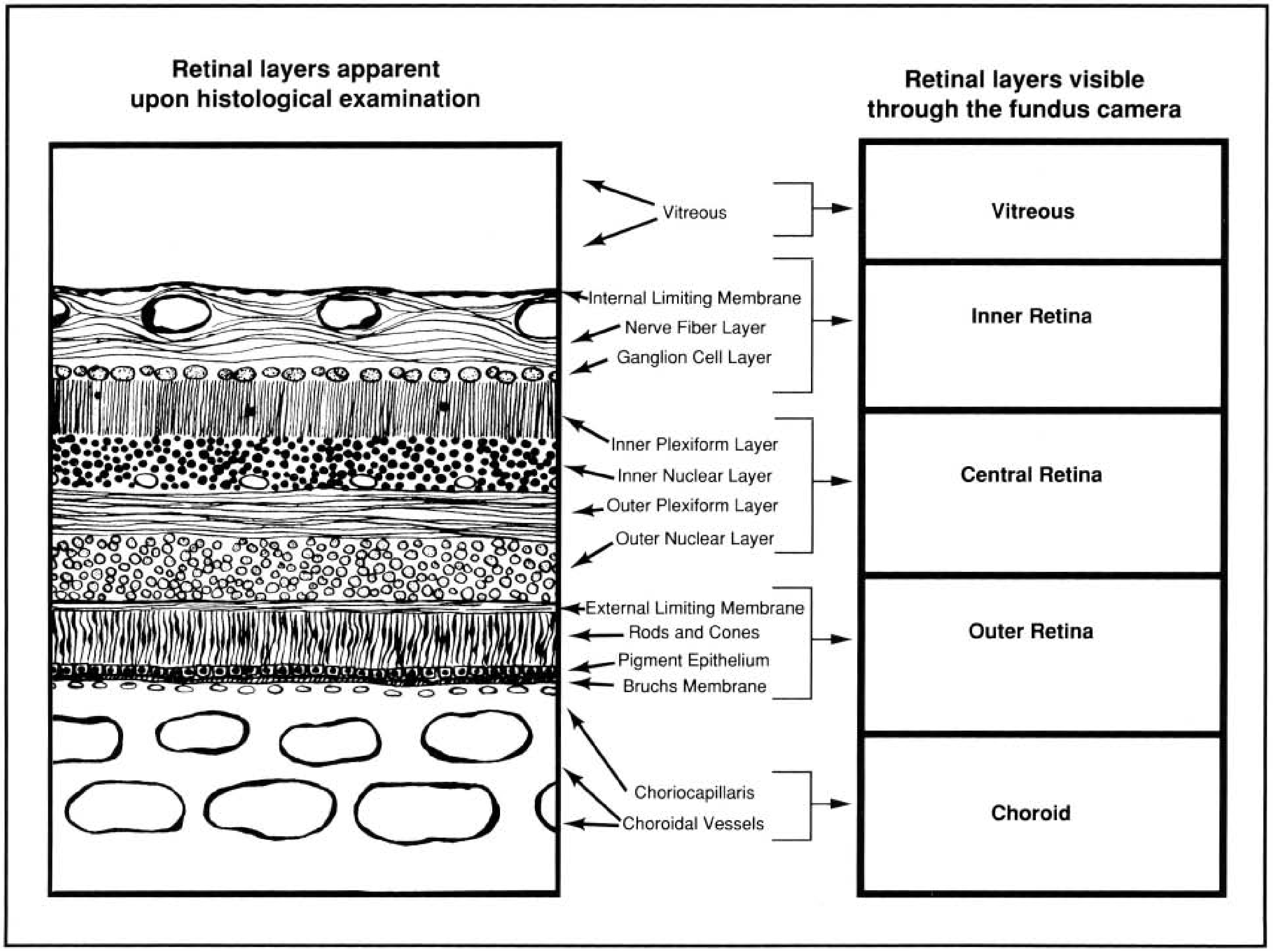


Figure 6: A ten-layer histological representation of the retina and choroid is related to the five levels of the retina which may be distinguished when viewing either through a narrow-angle fundus camera viewfinder or the final stereo fundus photograph. Each of these five levels may or may not be able to be distinguished depending on the thickness and pathology of a particular patient's retina.

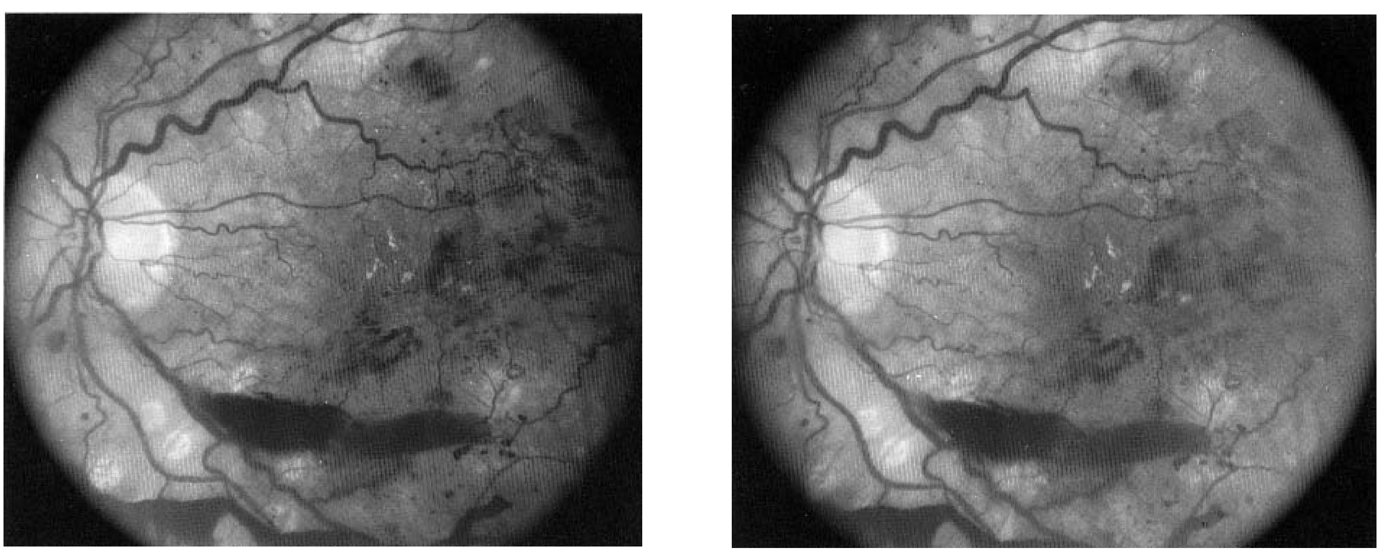


Figure 7: Multiple retinal levels may be distinguished when this photograph is viewed in stereo.

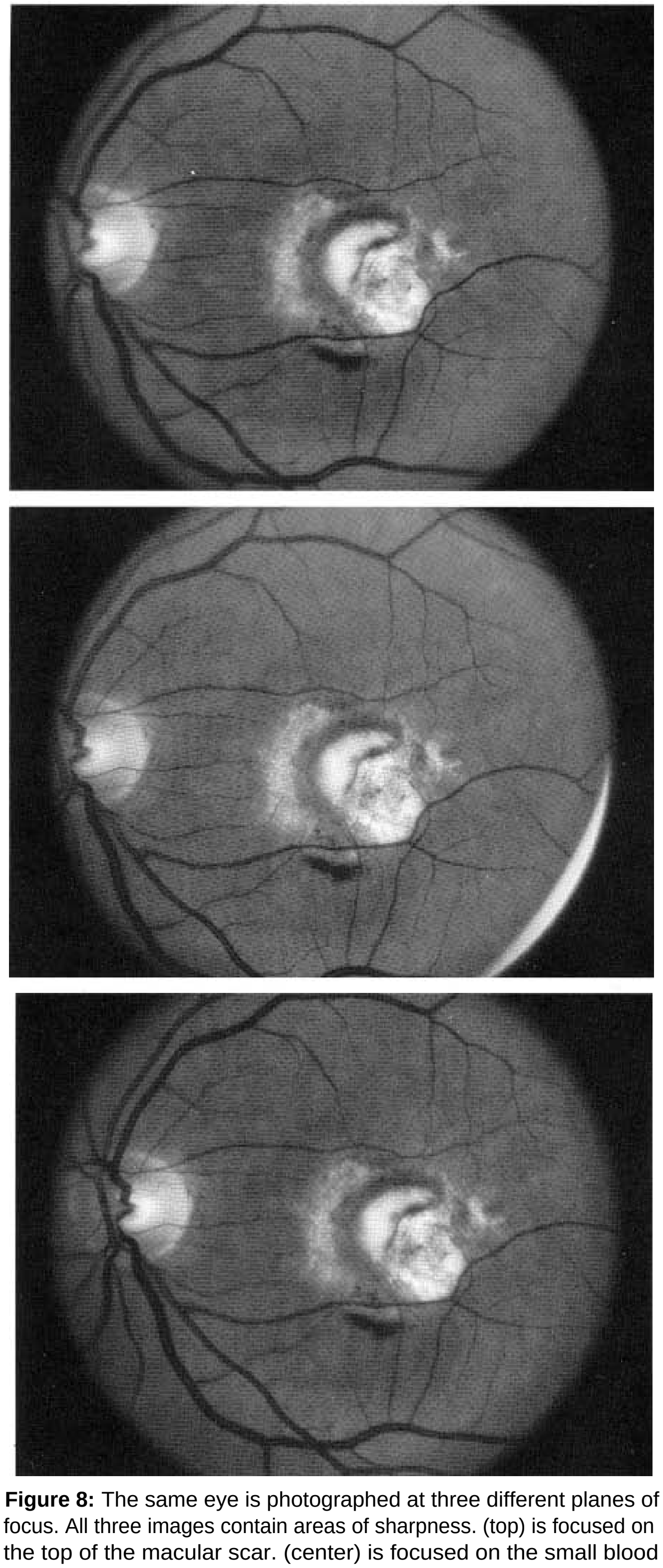


Figure 8: The same eye is photographed at three different planes of focus. All three images contain areas of sharpness. (top) is focused on the top of the macular scar. (center) is focused on the small blood vessels near the macula. (bottom) is focused deep within the disc. If the macula of the eye is the intended subject of the photograph, then only the center photo can be judged to be a sharp fundus photograph.

histoplasmosis scars, and angioid streaks occur at this level (Fig. 9, set 4).

The choroicapillaris and major choroidal blood vessels lie below the retina. The surface of nevi and choroidal tumors can be imaged by focusing `down' into the choroid (Fig. 9, set 5).

TARGETING FOCUS

When looking through the eyepiece of the fundus camera, it is difficult to visually distinguish each of the ten retinal layers. However, various levels within the retina may be discerned in stereo fundus photographs. As photographers, we can target the focus of the final fundus photograph to a specific level by recognizing its visual contents. Table 1 relates common retinal disorders, the affected retinal level and examples of possible corresponding retinal abnormalities which, when focused on, will yield a sharp fundus photograph.

Focusing on the highlights reflected from the large blood vessels will result in a sharp photograph of the inner retina. The central retina will appear clear in the fundus photograph if the photographer first seeks sharpness in the larger blood vessels, then their branches, and their branches, and so forth. If the granular appearance of the pigment epithelium is focused on, then the outer retina becomes the subject of the photograph.

Focusing on a specific anatomic feature will generate a photograph in which a single level of the retina is sharp. Targeting focus to a specific level is a matter of recognizing retinal pathology and optimizing the focus to the appropriate retinal depth.

When photographing a subretinal neovascular membrane (located in the outer level of the retina), an unsharp photograph of the offending blood vessels will result if the camera is focused on the larger, main retinal blood vessels (found in the inner level of the retina). Focusing on the drusen (if present) which lay directly on the pigment epithelium will result in a sharp image.

Multiple levels of focus may be chosen in a retina with diabetic macular edema. If the focus is adjusted for the inner surface of the retina, the photograph will document the elevation of the retina, but will render most of the posterior pole blurred. A deeper focus will render the surface of the swollen macula unsharp, but will reveal any hard exudates and/or blot hemorrhages. Focusing in the central retina will accurately document the leaking retinal blood vessels in a fluorescein angiogram.

It should be noted that fundus cameras, as do all optical systems, exhibit depth of field. When a fundus camera is focused, only that single level which has been targeted will actually be in critically sharp focus. When we view the photograph though, more than one level may appear acceptably sharp. This range of acceptably sharp focus extends both in front of and behind the actual plane of sharp focus. Wide angle fundus cameras produce a greater depth of field than do narrow angle

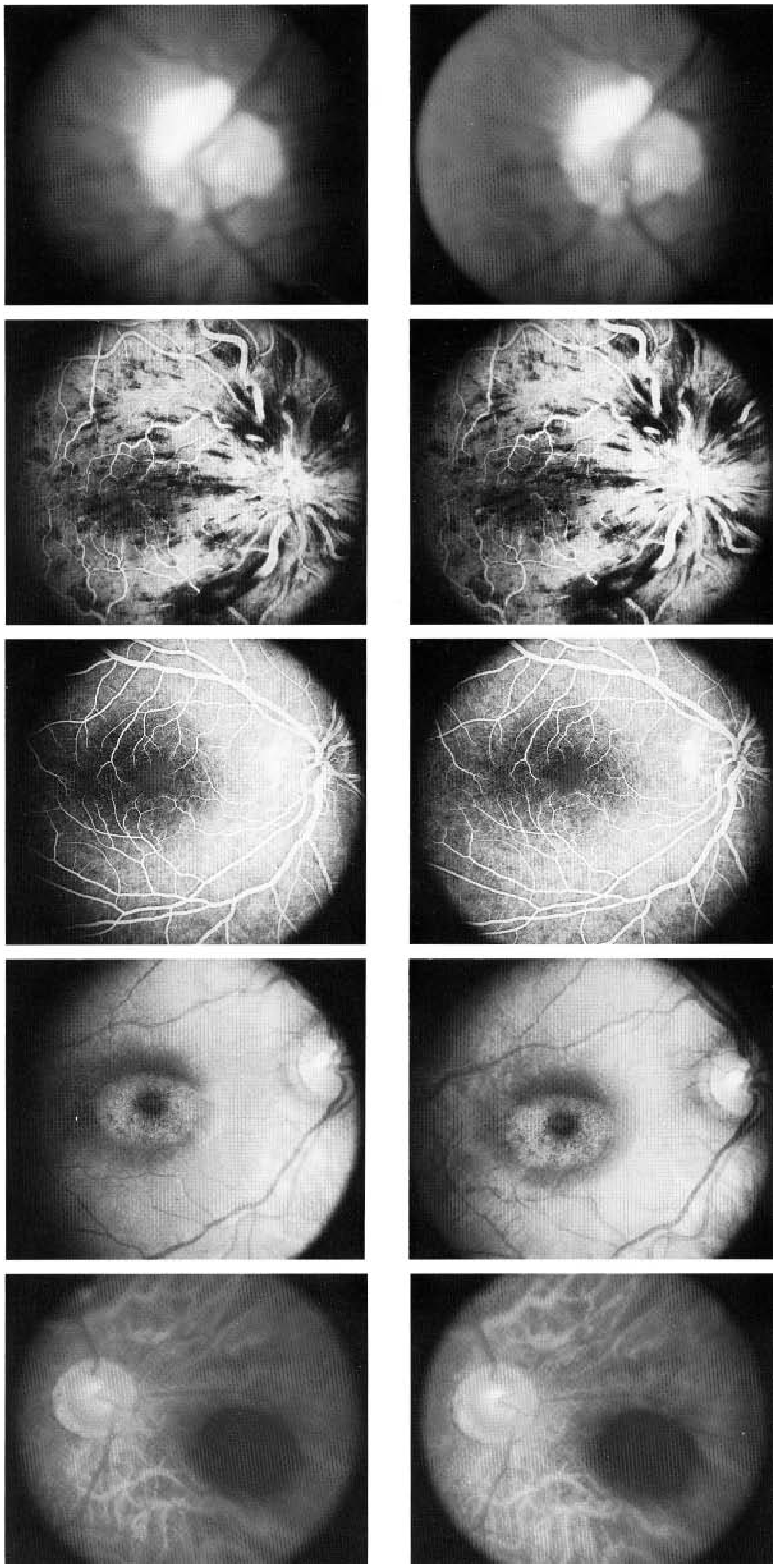


Figure 9: Clinical examples of focusing on different levels of the retina are shown in these stereo pairs. From the top First set—Focusing the fundus camera in the vitreous allows the ophthalmic photographer to document various opacities. Second set—The flame-shaped hemorrhages found in the inner retina are in sharp focus in this photograph. Third set—The avascular zone surrounding the fovea may be best appreciated when the central portion of the retina is the object of focus. Fourth set—The outer retina has been focused on for this stereo pair of a young girl's bull's eye maculapathy. Fifth set—Maximum information at the level of the choroid is achieved through the use of a red (650 nanometer) filter and careful focusing on the choroidal nevus.

Retinal Layers Visible Through the Fundus Camera	Patient's Diagnosis	Examples of Possible Corresponding Retinal Abnormalities
Vitreous	Asteroid Hyalosis Diabetic Retinopathy Operculated Macular Hole Retinal Detachment	Lipid deposits Neovascular fronds Small piece of retina floating in vitreous Elevated retina
Inner Retina	Diabetic Retinopathy Glaucoma Hypertensive Retinopathy Macular Hole Pre-Retinal Membrane Retinal Hemorrhage Retinal Vein Occlusion	Cotton wool spots Nerve fiber layer defect, optic disc borders Cotton wool spots Edges of hole Cellophane maculopathy Pre-retinal hemorrhage, sub-hyaloid hemorrhage Flame shaped hemorrhages
Central Retina	Cystoid Macular Edema Diabetic Retinopathy Retinal Artery Occlusion Retinal Vein Occlusion Retinitis Pigmentosa	Swelling Microaneurysms, hard exudates, dot & blot hemorrhages, macular edema Blocked artery Neovascularization Bone-spicule-like pigment
Outer Retina	Age-Related Macular Degeneration Central Serous Retinopathy Hereditary Abnormalities Presumed Ocular Histoplasmosis Syndrome	Subretinal neovascular membranes, drusen Pigment epithelium defect Angoid streaks Subretinal neovascular membranes, punched out hypopigmented areas
Choroid	AMPPE Nevus Optic Nerve Head Drusen Choroidal Tumor	Choroidal disturbance Surface texture Drusen under disc Surface texture

Table 1. Sample patient diagnoses are listed and related to the retinal layers visible through the fundus camera. Examples of possible retinal abnormalities (which may or may not be evident in each specific patient) are correlated. To target the focus of the fundus camera to a specific layer, the patient's diagnosis is noted, and then the retinal abnormalities are distinguished and focused upon. The same retinal field may be able to be focused at different levels, if the retina is abnormally thick. Care is taken to check the focus with each field change.

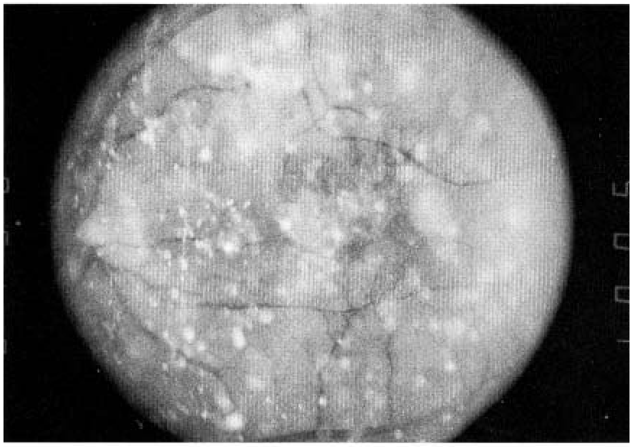
cameras, if the same eye is photographed and the exposed film area is identical (Fig. 10). It is not the angle of the optics, but rather the decrease in magnification which contributes to the increased impression of sharpness.6

A working knowledge of depth of field will help the photographer accurately document the retina. Focusing on the central retina (in a normal, clear eye) will yield a final photograph in which the outer and possibly the inner retina are acceptably sharp. On the other hand, if the granular appearance of the pigment epithelium is focused on, the inner retina will most likely not be in sharp focus.

Depth of focus is found at the film plane, and usually mirrors the depth of field located at the subject plane. The depth of focus in most traditional imaging systems is relatively flat. This corresponds with the flatness of the film which is used as a receiving plane (Fig. 11 a). The depth of field in most fundus camera lens systems is curved to mimic the shape of the normal retina. In well corrected fundus camera optical systems, the curved plane of the subject's detail is translated into a flat plane for maximum interface with the film plane (Fig. 11 b). In less well corrected fundus camera lens systems, the plane of the depth of focus is just as curved as the depth of field (Fig. 11 c). Fundus cameras which exhibit this curved depth of focus will yield film images which are unsharp at the edges when the camera is focused centrally, and vice versa. If such a camera is used, care must be taken to compose and focus the photograph so that the intended subject will appear sharp in the film image.

Focusing Technique

Conscientious use of the reticle during focusing and a



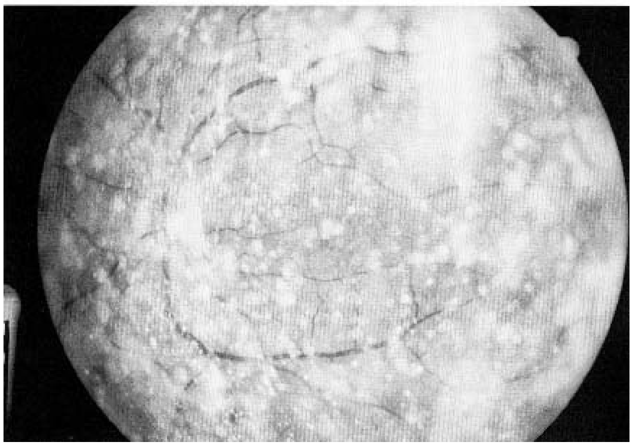


Figure 10: When narrow angle (Top) and wide angle (Bottom) photographs of this patient with asteroid hyalosis are compared, the wide angle image appears to have a greater depth of field because of its smaller magnification.

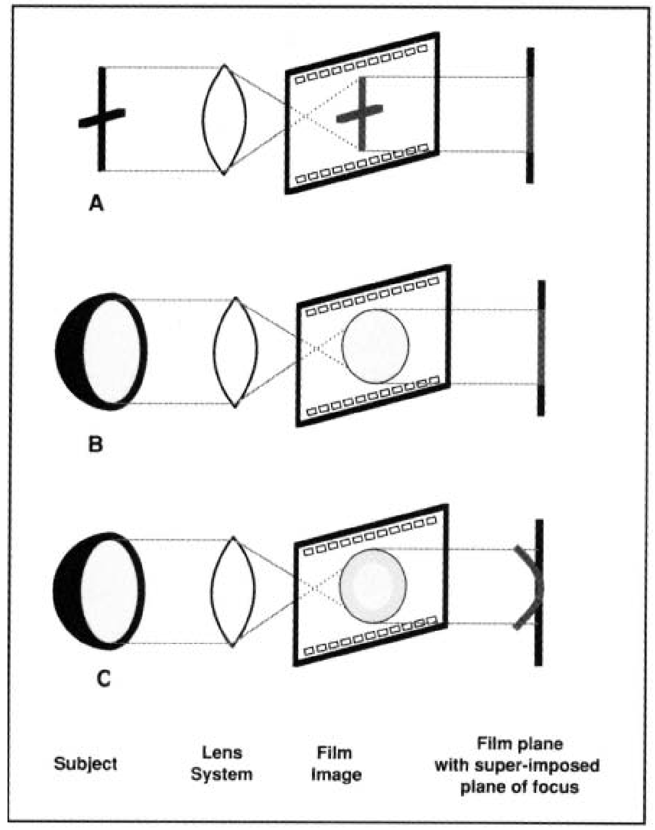


Figure 11: The optics of traditional photographic lens systems translate a relatively flat real world image onto a flat piece of film. The final image is sharp when the film plane and the depth of focus overlap (11 a). Fundus camera optics translate a curved retinal image onto a flat piece of film. If the fundus camera optics are well corrected, then the depth of focus is flat and corresponds to the film plane (11 b). If the fundus camera optics are not well corrected, then the depth of focus may be curved. A fundus image with unsharp edges may result, as the curvature of the depth of focus does not match the flat film plane (11 c). This effect may be seen when diopter compensation lenses are utilized.

deliberate focusing procedure will result in consistently sharp fundus photographs. Instructions for correctly adjusting the eyepiece and a suggested focusing procedure are outlined below.

ADJUSTING THE EYEPIECE

In order to obtain a sharp view of the reticle, the eyepiece must be correctly set. Here is a step by step procedure for eyepiece adjustment:

1. *Have your eyes corrected for their best visual acuity.* Those photographers with spherical correction *only* may choose to photograph with or without correction, however the correct eyepiece setting will be different depending on whether the photographer wears corrective lenses. Photographers with corrected astigmatism must wear corrective lenses while adjusting the eyepiece. Another option for those with astigmatism is to correct the eyepiece itself and not wear corrective lenses. This is accomplished by securing a cylinder trial lens of the correct power directly over the eyepiece.[7] Reading glasses should not be worn.

2. *Eliminate any subject matter from the camera's field of view.* Set your camera to the farthest focusing extreme and hold or tape a piece of white cardboard in front of the objective lens. When you look through the viewfinder, you will probably see a blurry reticle on a white field. The illumination level should be adjusted to approximately the same intensity as when viewing the retina. Too bright a picture may cause the photographer's pupil to constrict, bringing depth of field into play.

3. *Set the eyepiece adjustment to the maximum plus diopter setting.* This will blur any image of the focusing reticle. When looking through the viewfinder, you should see an evenly illuminated white blur.

4. *Relax your eyes.* Blink and look at something far away. If a window is unavailable, look down a long hall, or at a reflection. It is extremely important that your eyes be focused on infinity to obtain the correct setting. Keeping both eyes open may help keep you from accommodating.

5. *Peer through the viewfinder and begin turning*

the eyepiece ring towards the zero setting. Smoothly rotate the ring. Rotate at a slow enough rate that you perceive the reticle becoming sharper, but not so slowly that your eyes accommodate for the change. Remember to keep both eyes open and focused at infinity.

6. STOP rotating when the reticle is *JUST* in sharp focus. If you continue to rotate the reticle after you achieve sharp focus, or if you begin to search for sharpness by rotating the reticle back and forth, then accommodation may influence your decision. If your eyes are at their best correction, your setting should be somewhere near the zero mark. If the diopter setting is a high minus, chances are that you have accommodated. If you are wearing no correction, the setting should be somewhere near the power of your best correction.

7. Repeat, Repeat, Repeat. Multiple settings of the eyepiece should be performed until three successive, near-normal settings agree. Make a note of the most consistent position of the eyepiece ring and be certain that the camera is set correctly before each patient session.

New photographers should repeat this exercise daily until they are confident that their eyepiece setting is accurate.

Each fundus camera should be set individually by each photographer. The correct setting for each camera (especially if brands vary) will be slightly different for the same photographer, and the correct setting for a single camera will vary between photographers in the same office. If an instrument has more than one user, a signal should be developed to alert alternate users of possible eyepiece setting changes (perhaps an empty film box placed over the eyepiece).

8. Check the eyepiece setting and reticle before each patient. It cannot be over emphasized that once your personal setting has been ascertained, it is imperative to check it before each patient. Be aware of the focusing screen's reticle throughout each photographic procedure. Only conscientious use of the eyepiece/reticle focusing system will assure consistently sharp fundus photographs.

FOCUSING THE FUNDUS CAMERA

The ophthalmic photographer views the retina through the eyepiece and judges sharpness prior to committing the image to film. The following is a suggested procedure for focusing the fundus camera.

1. Review the patient's photo request form and prior photographs. Note the working diagnosis.
2. Seat the patient at the instrument. Explain the procedure. A comfortable and informed patient is a cooperative patient.
3. Adjust the headrest, chinrest, joystick and camera head height while looking around the side of the camera. The patient and the camera are adjusted to a level position so that the retina and the film plane are parallel. The fundus camera is grossly aligned by obtaining a sharp image of the viewing light's filament on the cornea or closed outer eyelid. Project the donut of light into the center of the dilated pupil.
4. Turn out the room lights. The view through the viewfinder will brighten, and the depth of field of the photographer's eyes will decrease as a result of slightly dilated pupils. The photographer may discriminate between retinal layers more effectively with this shorter depth of field. In addition, the darkened room enhances the figure/ground relationship between the external fixation light and its background. This allows the patient to follow the external fixation device more easily.
5. Establish patient fixation. Focusing on a moving target is difficult.
6. Look through the ocular and visualize the focusing reticle. Constant awareness of this reticle throughout the focusing procedure is necessary for obtaining sharp fundus photographs. Dust specks may be visible in the viewfinder. If these dust specks are on the same plane as the etched lines, they may be used in addition to the reticle to help keep focus at infinity. If you are unable to ascertain the specific plane on which the dust specks rest, consult a knowledgeable service technician.
7. Adjust the image for maximum color saturation and minimum artifacts. If the desired retinal field or dominant pathology can be distinguished, adjust the fixation to grossly approximate the intended view.
8. Begin turning the focusing knob. The retinal image will begin to sharpen. Check the sharpness of the focusing reticle and decide on which retinal level to focus.

Myopic, hyperopic, and aphakic patients may require an adjustment of the compensation lens system (diopter control) before their retinal images become sharp. Patients with long anterior/posterior dimension may need a minus diopter compensation, those with short anterior/posterior dimension, a plus correction. Patients without their natural lenses may require plus correction.

9. As the plane of sharpness travels inward with the rotation of the focusing knob, the vitreous, inner retina, central retina, outer retina, and then finally the choroidal levels become sharp in turn. The focusing reticle should remain constantly sharp.
10. Stop focusing inward as the targeted level is passed and becomes unsharp again.
11. "Rock" the focus toward and away from the desired subject until the sharpest focus has been obtained. Check the sharpness of the focusing reticle. If a blood vessel is the subject of focus, then the photographer may want to progressively focus on various sized blood vessels. The largest blood vessels are focused on first, then their branches, then their branches, and so forth—until focus is judged to be correct.
12. Patient fixation or camera position is adjusted

until the desired field of view is obtained. Recheck the focus.

It is suggested that the area of primary importance be photographed first, as the best Images are often obtained at the beginning of the photo session when the patient and the patient's eye are fresh.

Many patients require photographs of both the macula and disc. Focusing on the macula first will approximate more closely the general depth of the retina. If the disc is photographed first, there is a danger of focusing deep within the disc.

13. The need for the astigmatism control (if available) is evaluated. If the image of the fundus seems not quite sharp, or if the blood vessels appear elongated in a single direction, then a small rotation of the astigmatism control may be helpful. Sharp posterior pole photographs of patients with keratoconus or with large amounts of corneal astigmatism may require adjustment of this control. Additional discussion of the optical characteristics of the astigmatism control device may be found in the book *Ophthalmic Photography.* [8]

14. Monitoring the focus should be a constant concern throughout the fundus photography procedure. Focus is rechecked each time a field change is made. A diseased retina may be swollen in various areas, making focus adjustments necessary. Changes in camera position from side to side during stereo photography may also require readjustment of the focus. Peripheral fundus photography will require a change in the camera-cornea distance and may require an adjustment of the focusing knob. Because the imaging rays traverse an oblique cross section of the lens and cornea in peripheral fundus photography, adjustment of the astigmatism control may be necessary. The astigmatism compensation control is especially useful when the image appears `stretched' or `pulled' in a single direction.

The axial length of most patients' eyes will vary slightly from right to left. If alternating photographs of the right and left eye are required (as in a fluorescein angiogram), and a large focusing discrepancy exists between the two eyes, a small piece of tape on the right and left focusing knobs may be used to mark each side's correct adjustment. [9] These landmarks may help the photographer adjust the camera more quickly as the alternate eyes are photographed.

Focusing is an acquired skill. Practice and a keen awareness of the retinal landscape will transform the novice fundus photographer into a skilled ophthalmic photographer.

Clinical Focusing Techniques

Sharp fundus photographs are obtained through the mutual interaction and proper alignment of the photographer, patient, and camera. Sharpness in the final fundus photograph is limited by the clarity of the patient's ocular media, patient cooperation, the sharpness of the fundus camera's optical system and the skill of the photographer. Evaluating sharpness in a fundus photograph must take each of these factors into consideration.

Focusing a fundus camera on the retina of a cooperative patient with clear, widely dilated eyes will result in a sharp, evenly illuminated final photograph. Unfortunately, in many clinical situations, patients' eyes may not be ideal photographic subjects. For example, patients with glaucoma and diabetes may exhibit smaller pupils, elderly patients often present with cataracts and light sensitive patients have difficulty looking into the bright focusing light of the fundus camera. How can we maximize the sharpness of our photographs when less than optimal conditions exist? Common clinical problems and suggested solutions are outlined below.

MANAGING DIFFICULT PATIENTS

Maximum dilation of the pupil allows the entrance and exit of the illuminating and imaging light rays of the fundus camera without mutual interference and will result in the highest quality fundus photographs (Fig. 12). The photographer should work with the referring physician to establish a routine dilating regimen. Less than maximum dilation will make accurate focusing difficult, and images may be locally underexposed, especially with wide angle fundus cameras (Fig. 13).

Normally, the illuminating ring is centered on the pupil. This divides the pupil concentrically into illuminating/imaging areas (Fig. 14 a). Maximal focusing illumination through a small pupil may be obtained by decentering the illuminating ring. When the illuminating ring is centered on a small pupil, the illuminating light rays are blocked by the iris, while the imaging rays (which are negligible because of the lack of illumination) continue unimpeded through the center of the pupil (Fig. 14 b). Decentering the ring in order to again divide the pupil evenly will result in better focusing illumination and final exposure (Fig. 14 c). The imag-

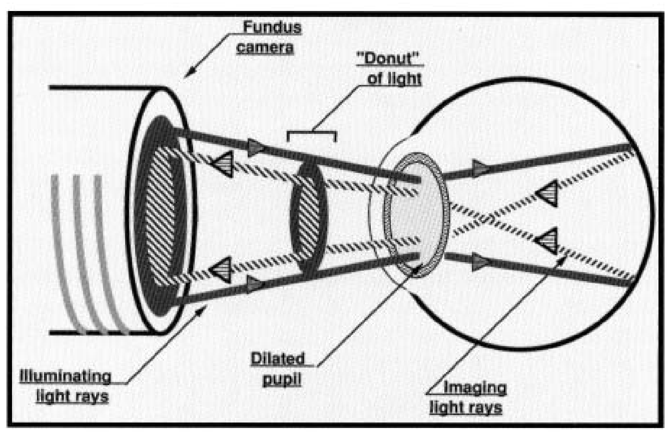


Figure 12: The fundus camera projects a "donut" of light through the dilated pupil to illuminate the interior of the eye. These "illuminating" rays reflect off of the retina, and pass back through the center of the "donut" and into the optical system of the fundus camera. These "imaging rays" continue back through the fundus camera optics which focus the image on the film plane.

Figure 13: Photographs of patients with small pupils are often unevenly illuminated, especially with wide angle cameras. Accurate focusing may be difficult under these conditions.

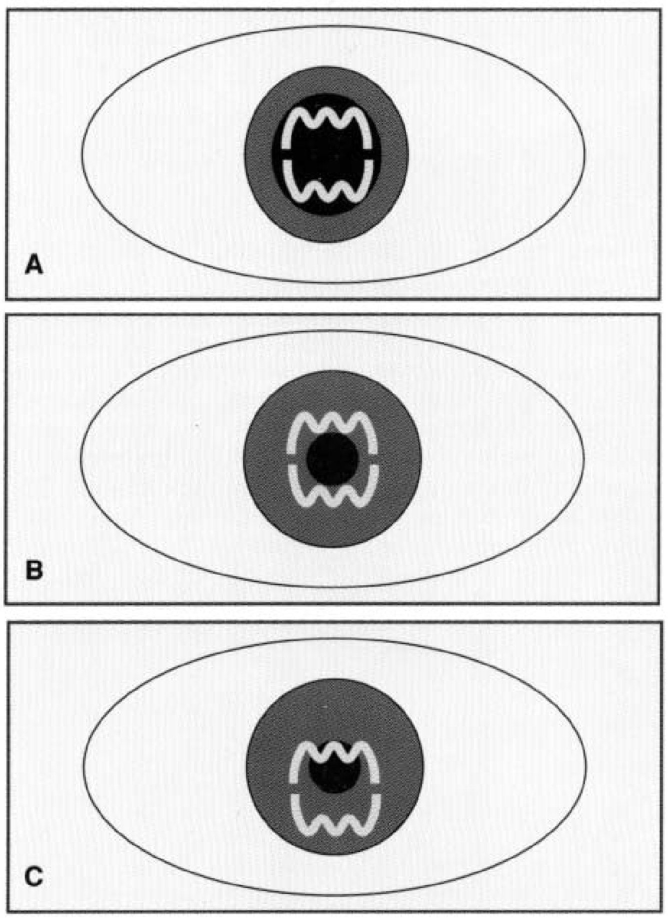


Figure 14: Decentering the fundus camera may help illuminate the fundus through a small pupil. Normally, the donut of the viewing light readily fits within the dilated pupil when centered (14 a). If the dilated pupil is too small, centering the donut may exclude the viewing light (14 b). Lowering or raising the camera axis (14 c) again divides the pupil evenly between viewing illumination and imaging rays. However, now the split is stacked rather than concentric.

ing rays will exit off center. Careful scrutiny through the viewfinder will limit the artifacts associated with off-center lens placement.

Creating two poorly illuminated halves of a stereo pair will allow the observer to fuse a final stereo image which is correctly exposed. Stereo photography relies on the observer fusing two slightly different images together. Usually, the component images are two sharp, evenly illuminated photographs taken from slightly different viewpoints. If local underexposure (often the result of imaging through a small pupil) is a problem, each single image of the stereo pair may be exposed with poor illumination alternately on each side. Taken individually these photographs may not be of the highest quality, but when the pair is fused with a stereo viewer, the resulting image represents the fully illuminated retina. In other words, two `wrongs' fuse to create one `right'.

A hazy view of the retina may be the result of many factors. Because the bundle of illuminating/imaging rays must pass twice through the patient's tear film, cornea, anterior chamber, lens, and vitreous, the clarity of the final fundus photograph is directly related to the clarity of each of these layers.

Specific areas of the cornea and lens may obstruct the passage of light. Corneal scars, pterygium, central cataracts and secondary cataracts represent local areas of potential unsharpness around which the photographer must maneuver. When this type of local unsharpness occurs, the key to obtaining a good photograph is to position the imaging light rays through a clear portion of the media. This requires spending time exploring all possible camera positions.

A dry cornea, a swollen and hazy cornea, asteroid hyalosis and vitreous hemorrhage represent conditions which impart a general unsharpness to the complete fundus photograph. Tear film is an important element in obtaining a sharp fundus image. Frequent blinking by the patient *should* be encouraged. It may be beneficial to introduce artificial tears in the eyes of patients with dry corneas. Topically applying glycerin (under the physician's supervision and with a topical anesthetic) to an edematous cornea may sharpen the

Corneal manipulation during ophthalmic care may affect corneal clarity. Applanation tonometry disturbs the corneal epithelium and discolors the cornea with topical fluorescein. Examination of the `angle' or fundus by contact lenses may reduce clarity by causing slight corneal edema, and by introducing topical methylcellulose. It is suggested that physicians order fundus photography before a contact lens exam is undertaken. Patients who have undergone contact lens exams should have their photography procedures rescheduled. If post laser photographs are requested, multiple rinses with commercially available eyewash preparations may help clarify the image.

There is little a photographer can do to sharpen the final photograph if dense asteroid hyalosis, vitreous hemorrhage, or a mature cataract exist. Indeed, obtaining a view of the retina can be a feat in itself. When general haziness is a problem, focusing with a green filter (540 to 570 nm) may help increase the contrast between the blood vessels and the retina.[5] If blood vessels cannot be distinguished, begin by attempting to obtain a view of the disc. The disc may be visualized as merely a bright, blurry area in some very hazy eyes. Focus as best you can and then adjust the fixation or camera to include the requested field, using the disc as your landmark. The final photograph will almost always contain retinal details not perceived through the viewfinder.

Many photographers document hazy media or a small pupil by exposing an external photograph of the eye during the fundus photography session. The fundus camera is adjusted for external photographs by moving the patient's headrest away from the camera's objective lens, inserting the plus diopter setting into the lens barrel, and increasing the exposure (to a setting which has previously been determined through empirical testing). The plane of focus is adjusted to correspond to the level at which the opacity occurs. The cornea, lens or vitreous may be focused upon. When this external photograph is filed with fundus photographs produced on the same day, performance questions may be objectively evaluated.

Most people have a natural aversion to bright lights. Avoidance behavior by these patients may make focusing the fundus camera difficult. Light sensitive patients blink and tear excessively when looking at a bright light. Younger patients are often light sensitive. Aphakic and pseudo-phakic patients are generally more light sensitive as they have lost the filtering qualities of their natural lens. Patients with certain retinal conditions (e.g. cone dystrophy and albinism) exhibit extreme avoidance of bright lights.

Constant awareness of your patient's disposition is essential when adjusting the focusing illumination. Many fundus cameras have an illumination intensity knob which adjusts the focusing illumination from virtually nil to very bright. It is advisable to routinely use the lowest possible illuminating intensity when focusing, as retinal light toxicity increases with time and intensity.[1]

Some fundus cameras do not allow the illumination intensity to be completely extinguished. If, at its lowest possible setting, the intensity of the focusing illumination still bothers your patient, decentering the illuminating bulb may help (Fig. 15). The view through the eyepiece will be unevenly illuminated but the appearance of the usual visual cues will help determine proper camera placement. Even though the view is less than optimal, the final photograph will be evenly exposed because the location of the flashbulb has not been changed.

The light sensitive patient may more easily tolerate focusing with a green filter (540 to 570 nm) placed in the path of the illuminating light source. This filter may be quickly rotated out of position just before the exposure, if other than monochromatic green photographs have been requested.

Prepare your patients for multiple bright flashes by fully explaining the intended procedure. When difficulty with an individual is encountered, patience is dictated. Frequent rest breaks (between, not within stereo pairs) help keep the patient fresh. Tension relieving techniques (including relaxation breathing and humor) may be useful. Positive reinforcement will keep the patient working with you, rather than against you.

Remaining in control throughout the procedure is essential. Patients will often adjust their disposition according to your behavioral cues. If you exhibit calmness and patience, the subject will make an effort in that direction. If you exhibit threatening or obnoxious behavior, the patient will often react in a like manner. Do not be afraid to call a timeout if either you or the patient needs to regain composure.

If repeated attempts at focusing on the retina fail because the patient will not keep his or her eyes open, then eyelid restraint may be necessary. A cooperative light-sensitive patient will allow the photographer to lift the upper eyelid with a cotton tipped applicator. An uncooperative light-sensitive patient will require an assistant to hold both the upper and lower lids. Cotton tipped applicators are suggested for all lid manipulation, as some infectious agents (eg. the AIDS virus) have been isolated in human tears.[11] A speculum is rarely used, as there is a danger of corneal abrasion with an uncooperative patient. Requesting that the patient hold his or her own eyelids is not recommended. In my experience, patients are often more interested in not seeing the bright lights, rather than in ensuring that the procedure is successfully completed.

Eyelids may present a mechanical (rather than behavioral) barrier to fundus photography. Lid elevation is necessary for the patient with bleparoptosis. Cotton tipped applicators may be placed at the bottom of the upper lid, and rotated up and in to raise the lid. The cotton swab is rotated clockwise (as seen temporally) for the right eye, and counterclockwise for the left eye. Care must taken not to depress the globe during lid manipulation. Patients with excess eyelid skin may be managed with the creative use of paper tape (Fig. 16).

SHARPNESS LIMITATIONS OF THE CAMERA

The sharpness of a final fundus photograph is, of course, limited by the sharpness of the specific fundus camera's optical system. Unfortunately, objective tests comparing the relative sharpness of various fundus cameras are unavailable. However, experience with multiple cameras in a clinical setting has yielded some guidelines as to the sharpness of lens systems.

Resolution of fine detail decreases as the magnification decreases because less film area is used for creating an image of a particular detail. When two fundus cameras have imaging circles of equal size, the wide angle fundus camera (over 45°) will be less able to

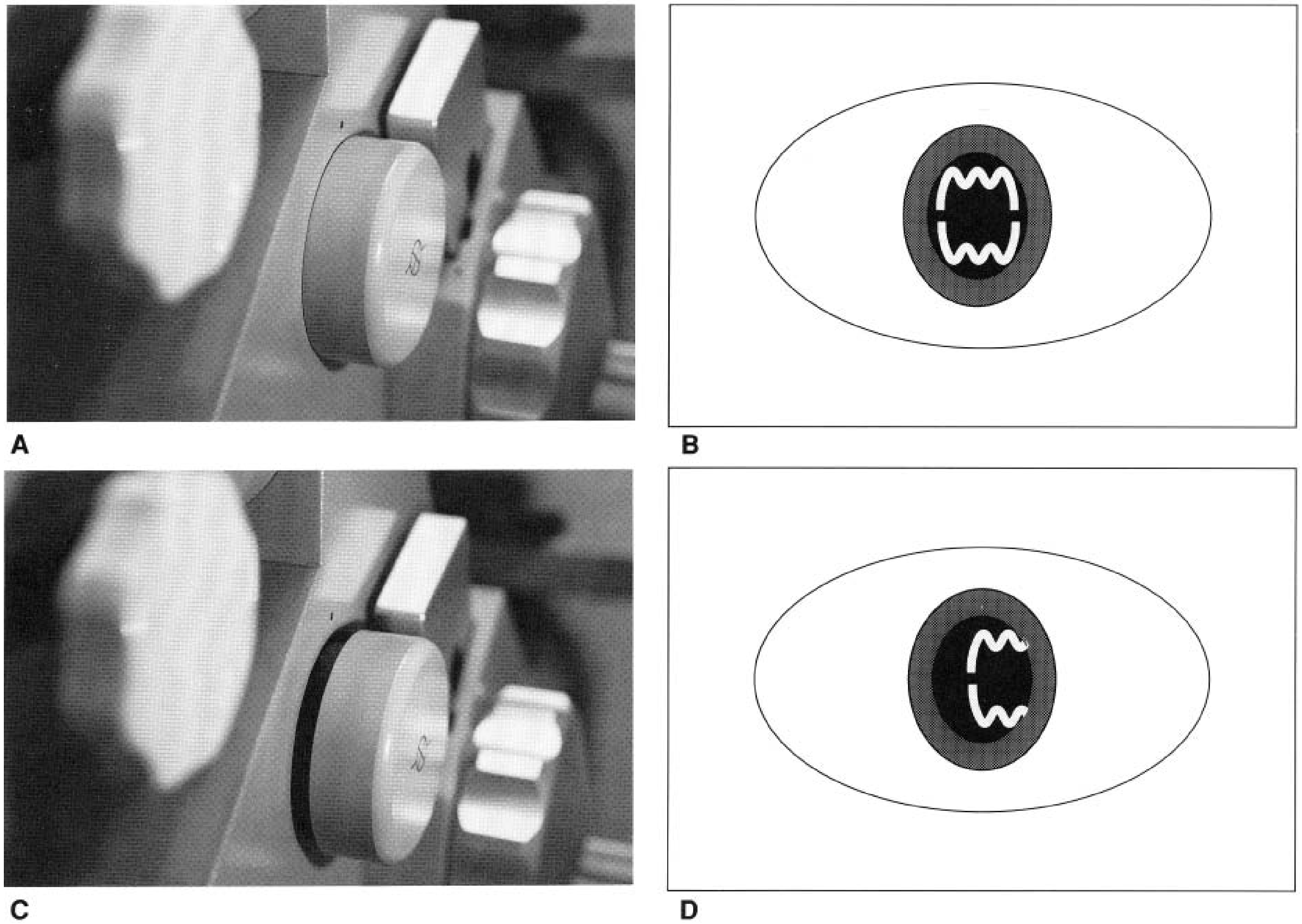


Figure 15: Displacing the illumination bulb slightly off-center within the optical pathway may provide relief for a light sensitive patient. When the illuminating bulb is correctly mounted (A), the illuminating circle is centered within the dilated pupil (B). Pulling the illuminating housing slightly out (C) decenters the illumination donut (D), decreasing the amount of light used to focus. Since the position of the electronic flash tube has not changed, the film image will be correctly exposed.

Figure 16: "Instant lid lifts" fashioned with adhesive tape may help facilitate the photography of patients with blepharoptosis.

resolve fine macular detail than the narrow angle camera (30°). When two fundus cameras have optics of equal quality, the fundus camera with higher magnification will achieve better definition of fine fundus details.

Resolution and contrast decrease with the introduction of angle changing lens systems. Multiple angle cameras typically have one best setting (often the widest angle). An optical departure from this angle of view degrades image quality. However, greater magnification may yield details not perceived under low magnification (Fig. 17 a,b). Professional judgement determines the most appropriate angle of view for a specific fundus photograph.

Wide angle cameras suffer greater losses in resolution from local areas of potential unsharpness (eg. a cataract or a corneal scar) than do narrow angle cameras. This phenomenon is due to the larger bundle of returning image forming rays constituting the wide angle image. The thinner bundles of narrow angle

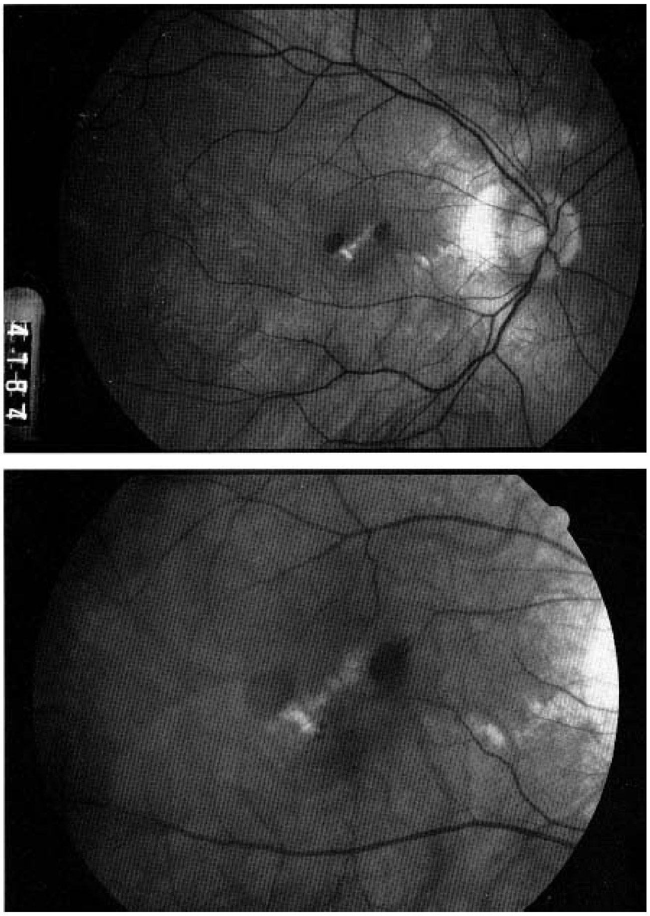


Figure 17: Changing the angle of view with a multiple angle camera decreases the sharpness and contrast of an image. Often extra optics are placed between the lens and film plane in order to magnify the image (bottom) from a wide angle camera (top). Although the resulting image is compromised, the increase in magnification may yield useful visual information. The magnified image in this pair of photographs of a patient with myopic degeneration shows the location and shape of the retinal hemorrhages in greater detail than the sharper wide angle view.

camera optics are more likely to fit into small pockets of clear media.

The cost of a fundus camera is not directly proportional to the sharpness of it's optics. Lens performance, cost, and ease of use must each be considered separately. While a low price and ergonomic design are important items to consider when purchasing a new fundus camera, actual lens performance is of critical concern.

It is here suggested that standardized procedures for laboratory and clinical testing of fundus camera optics be developed in the future. Only the publication of unbiased data detailing the actual performance of many fundus cameras will allow fair comparisons to be made. Until such tests are designed and implemented, the opinions of other ophthalmic photographers and personal experience must guide us.[12] The evaluation of a specific fundus camera's image quality is beyond the scope of this paper.

DIFFERENTIAL FOCUSING DURING STEREO FUNDUS PHOTOGRAPHY

Stereo fundus photography is a technique by which two retinal photographs, each taken from slightly different viewpoints, are fused by the viewer to form a single image. 13

Many factors affect the perception of sharpness in the final stereo fundus photograph. For clinical ophthalmic photography, it is especially important to note that the sharpness of the final stereo image is determined by the sharper of the two images, while depth perception is determined by the stereo base between the images.

As mentioned earlier, two images with unequal qualities may be combined to form an effective stereo pair. When the area of intended sharpness extends beyond the depth of field of the fundus camera, combining two images which have different planes of focus may help create the illusion of greater sharpness. When performing differential focusing, two (or more) stereo pairs are exposed, and each is focused to a different level (figure 18). After editing and matching pairs focused on the same level, alternate pairings may be pursued. For example, the left half of a pair in which the retina is in focus may be combined with the right half of a pair in which an elevated tumor is in focus. The observer will fuse the pair and perceive a clear image which appears to have a depth of field extending from the retina blood vessels to the top of the tumor. While changing the focus within the stereo pair is an option, preparing multiple pairs creates numerous alternatives during editing. This differential focusing technique is helpful when documenting both elevated tumors and papilledema.

It may be impossible to acquire two correctly focused images when exposing stereo fundus photographs. Conditions which can locally disturb image sharpness have been discussed. Determining whether sharpness in both images is more significant than a large stereo base is a matter of professional judgement. The photographer should consult the referring physician when choosing the emphasis of the stereo fundus photograph.

Summary

A sharp fundus photograph accurately documents the precise layer of the retina which has been requested by the physician. The ophthalmic photographer must be aware of the layered anatomy of the posterior pole and its relationship to the disease process in order to create a sharp fundus photograph. Accurate adjustment of the fundus camera eyepiece and a stepwise procedure for focusing the fundus camera has been delineated. The photographer, patient, and camera are mutually responsible for the sharpness of the final photograph. Several strategies have been suggested to simplify clinically difficult focusing situations. Differential focusing and creative editing of stereo pairs may enhance perceived sharpness in stereo fundus photography.

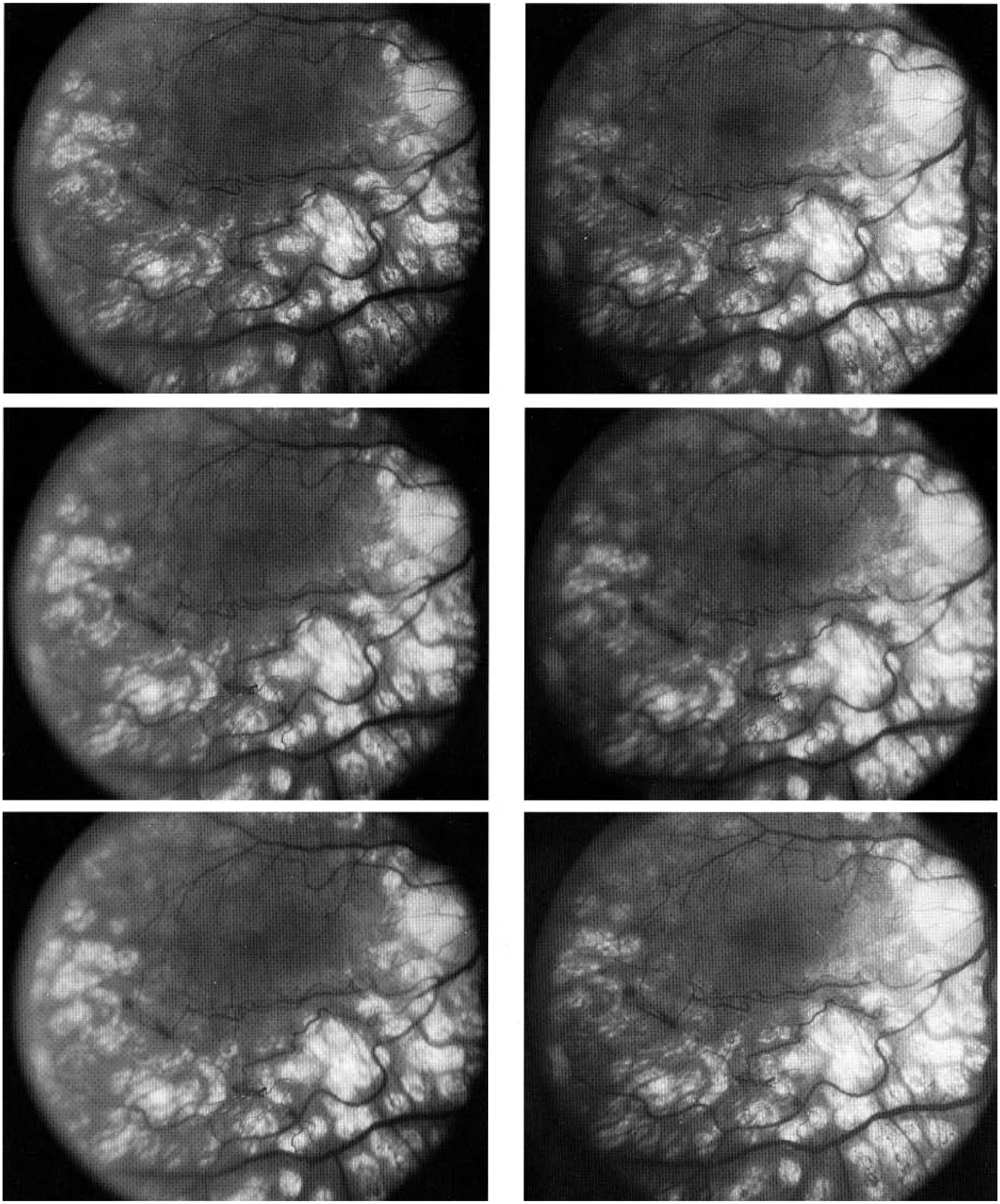


Figure 18: The results of using the differential focusing technique for stereo imaging are shown. The top pair of photographs were focused on the central portion of the retina. Blood vessels are evident, but not in sharp focus, near the 6 o'clock area of this photograph. These same blood vessels were focused on in the center pair. When each of these stereo images are viewed individually, only one (of five possible) level is in focus. In the bottom pair, the left and right halves of the top and center pairs are combined to form a single stereo image in which multiple levels of the retina are perceived in focus.

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