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Stereo Fundus Photography: Principles and Technique

Marshall E. Tyler, CRA, FOPS

Editor's note: The following is an excerpt from a chapter in the forthcoming book by Patrick J. Same, M.Ed., CRA, FOPS, and Marshall E. Tyler, CRA, FOPS, *Ophthalmic Photography, A Textbook of Retinal Photography, Angiography, and Electronic Imaging,* Boston: Butterworth-Heinemann, 1997 (available October 1996). This up-to-date comprehensive manual covers the classic topics of fundus photographic principles, as well as thoroughly describes electronic imaging and the recent advances in Indocyanine Green Angiography . As evidenced by the two case reports included in this issue of *The Journal,* and the strong showing of 3-D imagery at the annual competition, stereo photography is a unique and important topic to ophthalmic photographers.

Introduction

A driving force in the advancement of ophthalmic photography is the desire to create the most accurate representation of a patient's condition. The ability of the ophthalmic photographer to record three-dimensional images is one of the most exciting capabilities in our profession. Stereo fundus photography permits clinical examination of the patient's pathology beyond the ordinary two-dimensional view of a conventional photograph. It is fascinating to be able to study a three-dimensional view of an optic nerve, tumor, or retinal detachment, or a fluorescein angiographic image of a subretinal neovascular complex, all without patient movement.

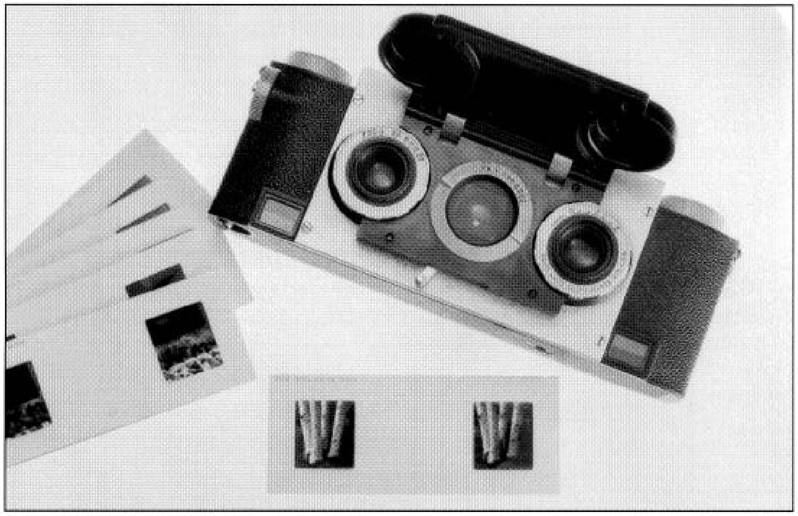
In stereo fundus photography, two Images are created photographically and, when viewed, become fused in the brain. [1] When you view the images, your left eye views the left image, your right eye views the right image, and your brain then recreates the depth relationships that were observed at the time of photography. If you have created the stereo photographs by a reproducible technique, they may also permit additional diagnostic interpretation on a follow-up visit.

Many ophthalmic photographers routinely expose all fundus images in stereo. Two exposures are available in case an image is not perfect, and the exposures also provide extra information if the images are a good stereo pair. Accept the challenge: Photograph every fundus in stereo and you will find—literally—a new dimension in fundus photography.

Instrumentation

Basic Stereo Photographic Techniques

Stereo photography creates two images of the same subject taken from two positions—that of the photographer's left eye and that of the photographer's right eye. After being processed, the images are then presented to the appropriate eye for viewing and the viewer's brain recreates the three-dimensional view. The goal of this process is to recreate the image as if the viewer were at the site of the photography. There are both desirable techniques to use and undesirable traps to avoid.



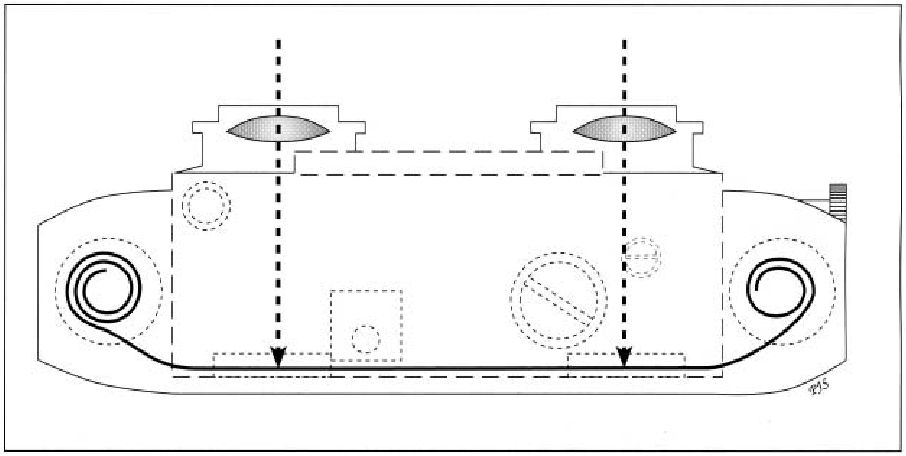


Figure 1: Nonophthalmic stereo camera
(A) - Left/ Realist stereo camera
(B) - Below/ Optical System of Realist stereo

In stereo photographs, the optical systems are kept parallel to each other and perpendicular to the plane of the subject. This introduces the least amount of distortion in the film Image (Fig. 1), and for the same reason, images should be viewed parallel to the visual plane. The distance between the two optical systems is called the stereo base.

Stereo Fundus Photography

Most modern mydriatic fundus cameras are capable of producing sequential stereo images—that is, taking one image of a stereo pair after the other. Precise techniques are used to create clinical Image pairs of the highest quality with the least stress to the patient.

The requirements for camera positioning are evaluated from the perspective of the optical systems that are in front of the subject—that is, cornea, lens, and retina. Understanding the optical systems makes it easier for the photographer to achieve consistent stereo images. Light rays traced from a single point on the human fundus are imaged by the eye's optical components at a distant point, perhaps even at infinity (Fig. 2). It is this phenomenon that permits cornea-induced stereo photography to work.

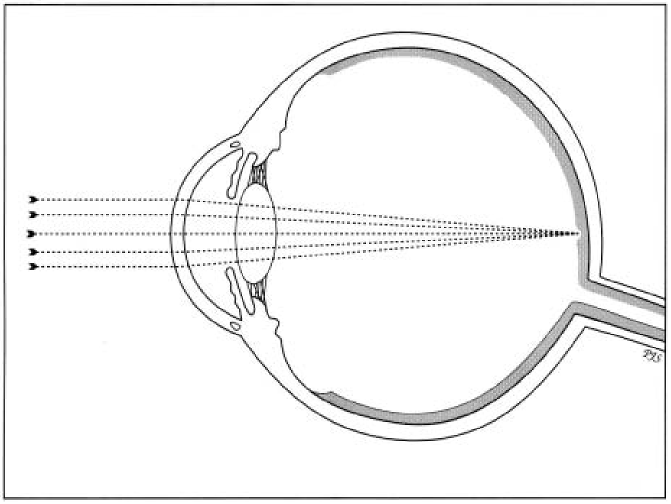
Convergence (rotation of the camera viewpoint) around the subject occurs inside the patient's eye, since the optics of the eye are being used when taking the fundus photographs. Convergence is permitted in photomacrography (typical magnification of lx to 25x) with a subject of a limited depth, such as the eye.

Sequential Stereo Fundus Photography

In 1964, Lee Allen[2] described the technique that most ophthalmic photographers now use for achieving sequential stereo fundus photographs. Positioning of the camera for stereo fundus photography starts in the same manner as for monocular fundus photography. The camera is shifted slightly to the left and then to the right of the central position (Fig. 3), the stereo pair being thus exposed at each position.

There are additional locations where the fundus camera's doughnut of light can be positioned for stereo fundus photography. Factors influencing the choice of positioning include pupillary dilation, the desired stereo base, and media opacities.

Photographers with Zeiss 30-degree cameras have found that another view of the fundus can be seen after going beyond (side-to-side) the area where iris reflections form a crescent-shaped artifact. By sliding the camera further, you can see the bright crescent reflex followed by another clear image. Since the latter image



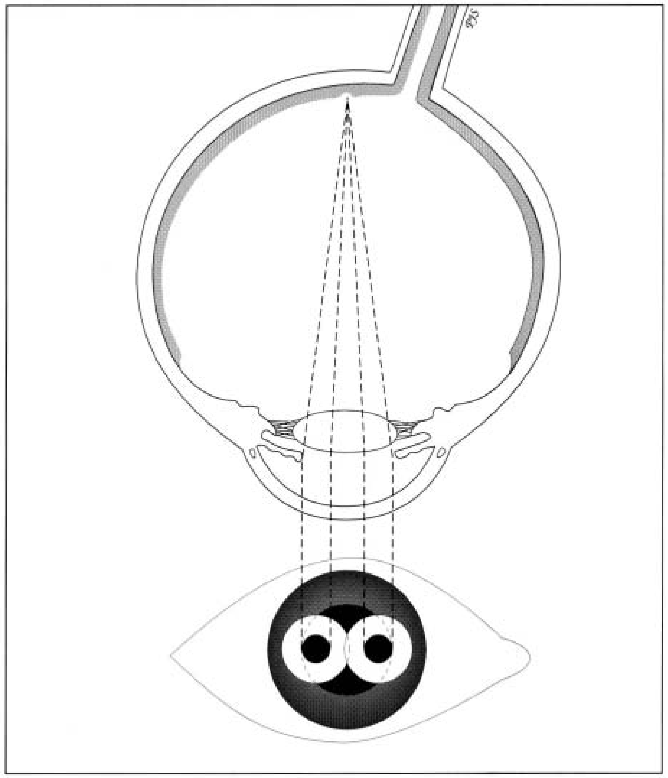


Figure 2: (above) The eye in cross section showing parallel light (infinity) converging on a single point on the fundus. Imaging rays coming from the patient's fundus will also produce similar parallel rays of light. A fundus camera pointed at any portion of the pupil will record an image of the same part of the fundus. Sliding the camera will simply record the fundus from a different vantage point.

Figure 3: (right) Stereo fundus imaging. Two fundus photographs are required to make a stereo pair. The diagram shows the pupillary positioning of the two image areas (small dark circles) and the fundus camera's doughnut of illuminating light for stereo fundus photography.

is taken through the peripheral cornea, its quality (sharpness and evenness of illumination) may not be as good as that of the images obtained centrally, but it will permit you to greatly increase the stereo base of your photographs. The peripheral cornea may introduce some astigmatism into the optical system, but this can be compensated for with astigmatic correction.[3] Illumination may also be decreased since part of the illuminating doughnut of light does not enter the pupil (Fig. 4).

Media opacities in the peripheral lens may limit your stereo base. A stereo pair with minimal stereo may still be better than one good monocular image.

If your images are exposed in a consistent order for each patient, then editing will be easier. For a glaucoma patient, a routine photographic sequence might be: Right eye: disc-left image, disc-right image, disc-left image, disc-right image, macula-left image, macula-right image; left eye: repeat for left disc and macula. This provides a backup set of stereo disc images in case of a patient blink.

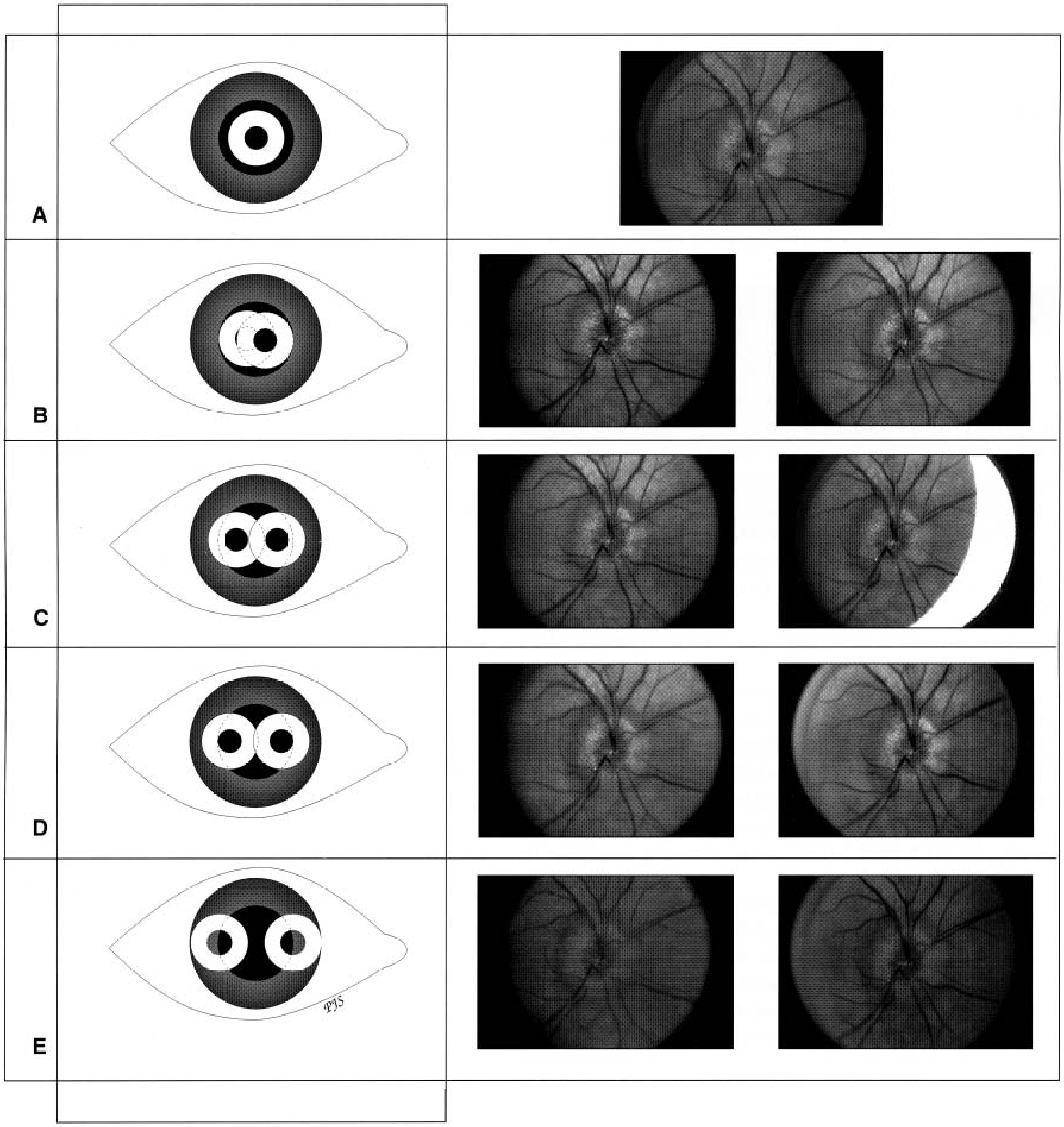
Diagnostic Interpretation: Limitations with Sequential Stereo Photography

The stereo base (the separation between the center of the lenses) of sequential stereo frames, and therefore the three-dimensional effect, may be inconsistent between photographic pairs taken at the same session, as well as at different patient visits. When interpreting visit-to-visit photographs, the physician should judge only relative changes in position of various anatomic structures and should not attempt to determine any absolute depth perception information between stereo images. Measurements are also invalid because of potential variability of stereo bases.

Fluorescein Angiograms in Stereo Shooting Order

The same techniques to align the camera in color fundus photography are used in stereo fluorescein angiography (FA). The film in most fundus cameras travels from left to right (photographer's point of view). Film FA studies are usually cut into strips of five or six frames to be placed into negative sleeves. Since the first image will be at the upper right corner of the contact sheet so that the images are right side up, then the first image will be to the right of the second image. You must therefore expose the right side of the stereo pair first: right side, left side, etc. If the order is not correct, then the pairs of images will produce stereo images in which the stereo depth information is reversed (depressions may seem to be elevations and retinal vessels will appear to lie beneath the choroid). Alternatively, if negatives are

Figure 4: Illumination positions through a dilated pupil. A monocular photograph results when you center the illuminating ring in the pupil (A). A small stereo separation **(B)** reproduces a minimal stereo effect (hypo-stereo) in the final photographs and with images will be evenly illuminated. Shifting each view slightly to each respective side **(C)** creates a crescent-shaped artifact. Further shifting to each side, past the crescent artifact, produces a wide-based stereo pair (D). Notice that the images are unevenly illuminated due to amputation of the illuminating ring. Further sideways camera movement reduces both the illuminating and imaging light rays, resulting in an underexposed image that cannot be used. **(E)**



sleeved with the first image in the upper left corner, the image will be upside down but the first image will be on the left. If the negatives are mounted in slide mounts, then the standard left/right stereo technique should be used.

Timing of Stereo Images in Angiography

The interval between the stereo pairs in angiography is important because the fluorescein sodium dye is moving during the study. Just as it is desirable to have little patient movement between stereo pairs, it is also important to have little movement of dye between the two images that comprise the stereo image. Reducing the time between stereo fluorescein images will reduce the Image discrepancy within stereo pairs.[3] A typical sequence would be as follows: Take the right Image and pause for 0.8 seconds (the shortest time permitted by most flash power supplies); take the left image and pause for 2.2 seconds; then repeat. This timing uses the same amount of film as taking one image every 1.5 seconds but reduces the image disparity by almost one-half. The total time per pair of images remains three seconds.

Simultaneous Stereo Fundus Cameras

Alternatives to sequential stereo imaging are available by using simultaneous stereo cameras. These cameras have the distinct advantage of providing the physician with images guaranteed to be of constant stereo base. This technique allows both subjective and analytical analysis to be made with a greater degree of repeatability between stereo photographs taken with the same image magnification and stereo base.

Photographing stereo images simultaneously offers other additional advantages: Patient cooperation is not needed between two sequential photographs, and only one flash is needed for one stereo pair of images! The disadvantage is the difficulty of simultaneously finding two clear, sharp, and evenly illuminated images through the same potentially small pupil.

The starting point for alignment of simultaneous stereo fundus photography is the same as that for monocular photography; however, you must have two images aligned simultaneously. Aligning these cameras properly requires a modified technique because you are recording two images with a single exposure. Take care to check each Image by alternately closing each eye. While all fundus cameras have external fixation devices, some stereo cameras have an internal fixation light that, when the patient fixates, attempts to center the optic nerve in the Image frame. Keep in mind that these split frame stereo images are vertical, with an Image area of 18 mm wide and 24 mm high.

While the magnification, and usually the stereo base, of these cameras are fixed, the position of the camera at successive visits may not be identical for each image. Obviously the centering of the subject—the optic nerve, for example—must be achieved with consistency to permit optimal analysis. The optical position of the camera in the pupillary aperture should also be precisely located to achieve greater consistency in visit-to-visit repeatability. If this is not done, the photograph may not be taken from the same viewpoint and therefore image comparison becomes less useful. Fortunately, because the pupil can only be so large, the maximal potential amount of change in the vantage point is about nine degrees. Use good photographic technique and align the camera on the corneal reflex to reduce this variability. Rotation of the eye is another variable that can compromise stereo consistency. Camera enhancements to improve the ease with which the photographer can maintain optical alignment will make these cameras an even more uniform diagnostic tool.

Modifying the stereo base is often not possible with simultaneous stereo fundus cameras. This may be a limitation if a wider stereo base is required to avoid central lens opacities (e.g., cataracts) or if there is limited dilation (as might be encountered with a patient taking glaucoma medications). Advanced techniques, such as high-low focusing and up-down 90-degree stereo techniques, have not been incorporated into these cameras. Astigmatic adjustments are also unavailable. It also is difficult for the photographer who does not have stereopsis to take full advantage of this technology.

Advanced Techniques
Stereo Base Limitations

The stereo base, the distance to the subject, and the relative depth of the subject are all important factors when photographing in stereo. To produce realistic stereo, the stereo base should be about one-thirtieth of the distance from the lens to the near-point of the subject. This rule is founded on the assumption that the photograph has a far point at infinity. This is not applicable to fundus photography, since the far point in a fundus photograph is only about 25 mm away. Thus, for example, patients with high elevations of neovascular complexes that ex-

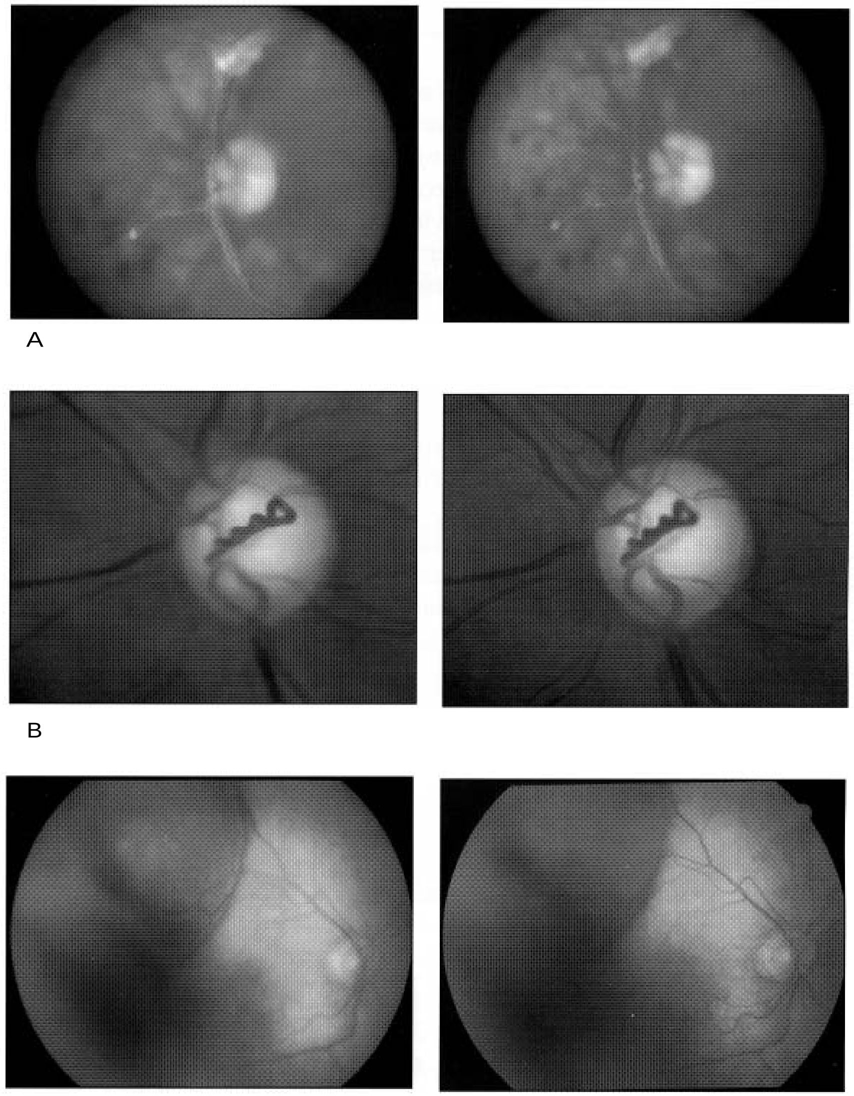


Figure 5: Differential focusing. Less visual information is conveyed when the focus is adjusted for a single plane **(A)** than when two different planes are in focus. (B). This technique is less effective when the focusing planes are far apart and without commonality. **(C)**

tend into the vitreous may produce Images with relatively distant far-points. Also, retinal detachments are often located anterior to the normal fundus location and therefore a decrease in the stereo base may be needed to create visually fusible stereo images.

Increasing Depth-of-Field

Ocular pathology may exceed the depth-of-field of fundus cameras. Sequential stereo photography can be used to increase the depth-of-field by combining two images that are focused at slightly different planes of focus4 (Fig. 5). This is called high-low focusing. When working with a subject that is concave, like the cupping of a deep optic nerve, select one view to be focused high and one view to be focused low. Decide whether the right or left image will have the best "view" of the bottom of the optic nerve. That image should be focused deep. The other image should be focused at the rim of the cup. An elevated subject (e.g., tumor) may have a better side to show with the lower focused image.

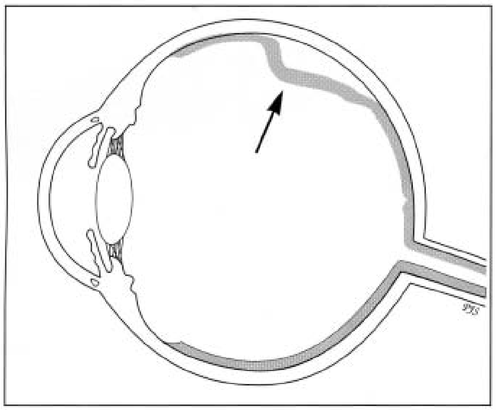
There is a limit to the amount of image blur that can be fused to create a clear stereo image. Stereo image pairs with an out-of-focus zone between the two images will be difficult to fuse. There must be enough clear common points-of-image information for image fusion to take place.

Once the film is processed and returned, it is very important that you review your work. Unfortunately, during alignment and photography, the brain does a marvelous job of registering even a marginal stereo image, and you may be astonished to find, on occasion, that one-half of your image pair is of low quality. Constantly check your work and refine your technique.

Stereo Orientation

The shape of the pathology is important when determining the appropriate stereo orientation for the photograph. If all of the elevation is in the vertical cross section (Fig. 6A), little stereo information will be gained if the images are taken with the conventional left/right stereo orientation. For the best stereo view through an indirect ophthalmoscope, you would need to tilt your head 90 degrees in either direction. This same stereo view can be photographed by modifying your stereo technique.

Rather than shifting the camera laterally, shift it in the up-down direction using the camera elevation control. The resultant photographs can then be rotated 90 degrees and viewed as if you had rotated your head when examining the patient (Fig. 6B). Slides should be labeled to reflect the photographic method used.



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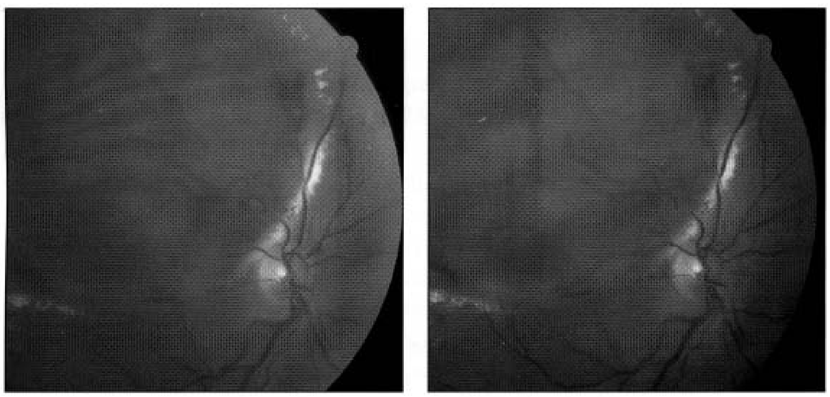

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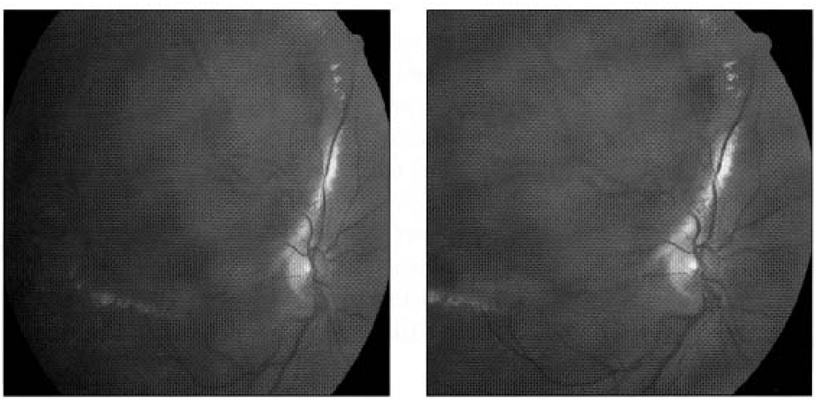

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Figure 6: Shifting the fundus camera vertically may produce better stereo imaging of ocular structures with greater depth information than when the viewpoint is shifted laterally.

(A) Pathology located in the vertical cross section (arrow).

(B) Stereo photograph taken with normal lateral shift technique does not reflect the depth of this tumor.

(C) Stereo photograph taken with a vertical camera shift and viewed with a 90-degree rotation.

Stereo with High Magnification and Wide-Field Fundus Cameras

High-magnification and wide-field fundus images can be taken in stereo, but the wide-field fundus images may show less depth effect, since the image is recorded at a lower subject-to-film magnification.

The green alignment dots on some Canon wide-field fundus cameras can simplify camera positioning for stereo photography. These dots are located at nine and three o'clock and are normally used for monocular camera alignment. The basic principle is that the green dots replace the crescent reflections that are seen on 30-degree cameras. First align the dots for a standard monocular fundus photograph with both dots showing. Move the camera left until the nine o'clock dot disappears and then shoot. Then shift right until you see both dots, continue until you just see the three o'clock dot, and shoot again. This will give the maximal stereo base while maintaining evenly illuminated fields.

Assessing Stereo Images Stereo Slide Formats

In the pictorial stereo photography world, there are many stereo slide formats. [5] Fortunately, only a few transparency (slide) formats are used in ophthalmology. Formats include two full 35mm frames (two 2 x 2 mounts), split-frame 35 mm (two half-frame images mounted into a single 2 x 2 mount), Realist formats, and Viewmaster disks. There are many other stereo slide formats, including those for 6 x 7-cm format cameras, but the two 35mm formats are most commonly used in ophthalmology.6

Except for photographic competition entries and specially designed stereo projection systems, we suggest using 2 x 2 mounts to store, view, and project your stereo slides. This choice permits the easy projection of a single monocular frame for conventional (non-stereo) projection. Realist mounts require labor-intensive mounting procedures, and there are no split-frame 35-mm stereo projectors currently being manufactured. Separate 2 x 2 slides are easy to reposition if alignment is not optimal.

The easiest filing solution is to use split-frame stereo pairs mounted in conventional 2 x2 slide mounts. These are ready-to-go stereo pairs. Make sure that the film processing laboratory understands that these are stereo images and that two similar images are to be mounted in one standard mount. Occasionally a lab will mount 36 stereo images as 72 half-frame 2 x 2 slide mounts. Send a correctly mounted sample slide or explanatory note with the unprocessed film.

Editing Stereo Images

Selecting only the best quality images of each view helps maintain a medical record of the highest quality. Selecting appropriate images is easier when stereo Images are photographed using a standard sequence, as noted previously. The slides can simply be placed in a standard slide page with the stereo images paired together. All processed stereo images should be checked by the photographer to ensure that the images are properly aligned and the stereo-depth relationships are correct—i.e., the retinal blood vessels are seen in front of the choroid and optic nerve cupping is seen as a depression (not as an elevation). It is important to be familiar with the normal and abnormal retinal pathology because it is relatively easy to trick an inexperienced viewer into perceiving a depression where there is in fact an elevation, or vice versa. Only the best pairs should be saved and labeled as stereo. Adequate monocular images may be kept, but not

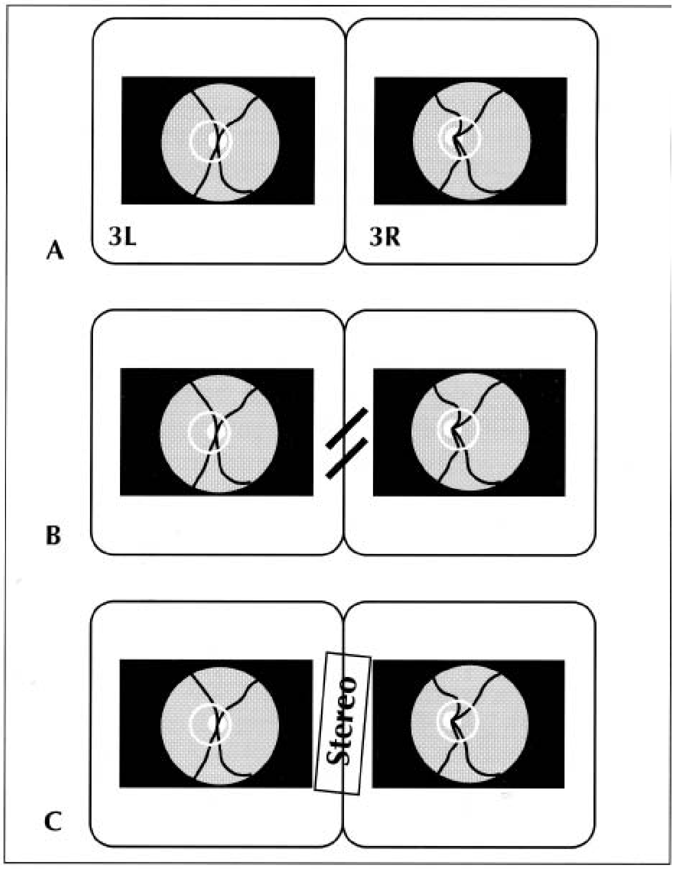


Figure 7: Labeling conventions for indication stereo on the pairs of 2 x 2 slides:
(A) Slide pairs labeled with sequential pair numbers and L & R.
(B) A simple set of lines
(C) A rubber stamp with the word stereo.
Avoid time-wasting mix-ups due to not marking your stereo pairs; pick a method and use it consistently.

marked as stereo. A photographer without stereo perception can take excellent stereo photographs with standard monocular cameras since stereo vision is not required to use a monocular camera.

Labeling of Stereo Slides

Stereo slides should be edited, marked, and placed into the chart so that they are easily identifiable. This is very helpful to the clinician.

Marking of the stereo pairs can be accomplished using a variety of methods. Pairs for a particular patient from each visit can be numbered sequentially and identified as to whether the individual image is the left or the right image (Fig. 7). If the slides are not to be removed from the plastic slide pages, then a simple line[7] or a pair of lines may be used to indicate stereo pairs. The word stereo can be written or rubber stamped between the two slides.

Viewing Stereo Images
Personal Viewing

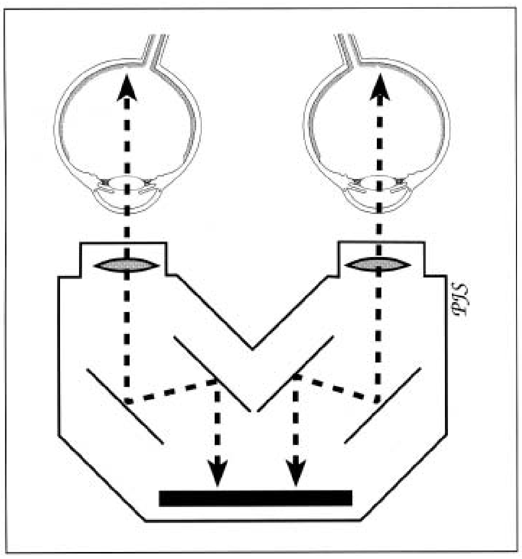
Personal viewing techniques fall into two categories, based on image size: images that are smaller and images that are larger than the average interpupillary distance (PD) of about 60 mm. Of the two techniques that allow you to view stereo images without viewing paraphernalia, one requires that you accommodate your focus but not to converge your eyes, called parallel viewing, and the other requires that you over converge your eyes (cross-eye) to achieve stereopsis. All other techniques require optical devices to assist you in seeing the stereo images.8

2 x 2 Stereo Slides

The most commonly used stereo viewing techniques in ophthalmology are for viewing two full-frame 35-mm stereo slides. The slide that was taken through the left side of the pupil is so positioned in the viewer that it can be viewed by your left eye, and the right image is so positioned that it can be viewed by your right eye. Most stereo slide viewers have a pair of +4 to +12 diopters lenses. This permits you to relax your accommodation and avoid convergence. A few viewers use compound lenses to reduce distortion and increase sharpness. Once the two images are seen as one, you can adjust the focus with either a focusing adjustment or by physically changing the distance between the slides and the lenses. For extensive viewing, you might consider having an optical shop make you some +10 glasses.

If you have a large amount of accommodation and/or are myopic, you may not need a viewer. Simply place the slides, side by side (or with a space between the slide mounts up to 10 mm) on a light table and orient your eyes exactly perpendicular to the center of the slides. Using a sloping light box may make it easier to position your head and eyes properly. Place your face very close to the slides and relax your convergence by imagining that you are looking far into space. Allow both images to overlap and become one image. Do not be concerned about image sharpness at this point. Rather, keep your eyes perpendicular to the two slides and slowly move your head away from the slides to a distance of 6-12 inches, while attempting to focus on the slides without losing the single image and having it become two images. If you see two separate images, you are moving back from the slides too quickly and your eyes are converging. Relax and try again. Viewing stereo slides cannot be practiced in a rush!

Figure 8: Split-frame 35-mm stereo slide. **(A) Left** Schematic drawing showing the optical paths. (B) **Below** Split-frame stereo slide. **(C) Right / adjacent page** Photograph of split frame stereo Viewer.



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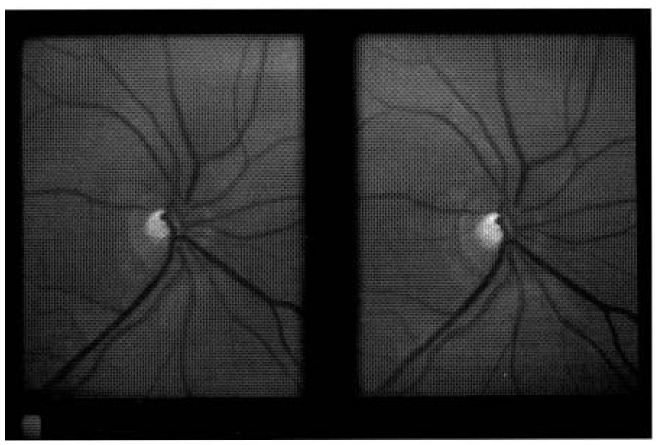

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With practice, you may be able to grab a slide page out of a chart, hold it up to a light source, and view the images in stereo. The key phrase is, *with practice.*

Split-Frame 35-mm Stereo Slides

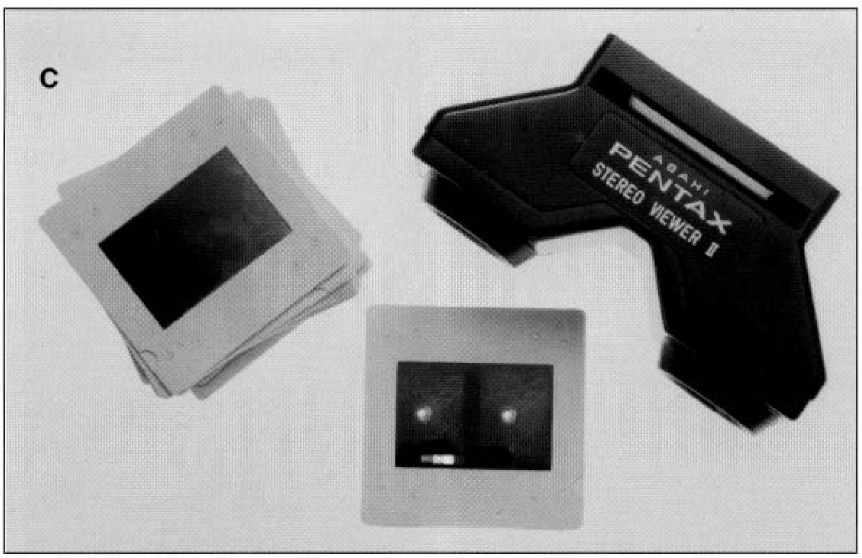
Split-frame (sometimes mistakenly called half-frame) stereo images have two vertical images displayed on a single 35-mm slide frame (Fig. 8). Most camera systems produce slides with the left image on the left, but a few systems produce slides with the image that is to be viewed with the left eye placed on the right side of the slide. Consequently, there are two types of split-frame stereo viewers. If you get a viewer with the wrong configuration of optics for the slides you are producing, you will get stereoscopically reversed images — e.g., disk cupping will be presented as an elevation.

Realist Stereo Slides

Realist stereo slide mounts can be viewed with a set of plus lenses, in a single stereo pair viewer, or a drum viewer that holds 18 stereo pairs. Currently, these drum viewers are no longer available except on the used market.

Viewmaster Reels

Viewmaster reels are often used to illustrate ophthalmic textbooks, usually with foldout viewers. However, purchasing a higher quality viewer is well worth the investment. Even a toy store viewer will outperform the folding viewers.



Computer Images

The dynamic range and color saturation are very good on computer screens. Stereo images can be displayed on the monitor or printed on paper (from the computer image file), the same as for the standard viewing systems as noted above. Side-by-side (small), side-by-side (over 60-mm), and red-blue images are useful viewing methods. Monitor resolution is a limitation, since it is less than one-tenth that of 35-mm slide pairs. Zooming the image on the monitor may help to overcome the limits of screen resolution.

Stereo viewing hoods can be used to cover the monitor and provide the appropriate optics to aid in seeing side-by-side images. Over-under image pairs are viewed with a different mirror configuration. Stereo images red and the other blue, display them on a color computer screen, and view them through red-blue glasses. The left image is typically colored red and is viewed through a red lens in front of your left eye. The right eye has a blue (and sometimes cyan or even green) filter, and since such a filter does not pass very much red light, your right eye will not see the left image (and vice versa). An advantage of the red-blue system is that your head position (rotation) is not critical. It is also an inexpensive way to view the images.

Color stereo images may be combined into a single color image that is viewed with red-blue glasses. Specialized computer programs (e.g., 3D Maker by Synthonics) make this task easier. While this software works well for angiograms and images that have a full spectrum of colors, the effect on the mostly red fundus images is not as good.

Software that both stores the aligned stereo images and allows printing on paper or onto slide film is useful.

Computers can use other viewing systems that are not possible with either prints or slides. These techniques require electronically controlled glasses. In one technique, the computer alternately displays the images comprising the stereo pair at a rate of at least 30 images per second, and the image is viewed on a single screen by a person wearing computer-controlled liquid crystal device (LCD) glasses. The stereo images are first processed to create two half-height images, one over the other. An electronic device is inserted between the computer and the monitor and displays the two images alternately. This control box sends out an infrared timing signal to the LCD glasses to control the opacity of the lenses. The LCDs have the ability to turn opacity on and off and therefore permit the two stereo images to be sequentially viewed through the appropriate eye.

Another system uses a polarized LCD panel placed over the computer monitor screen while the person viewing it wears standard polarized stereo glasses. With this system, the glasses must be horizontal to create maximal image extinction, the same as for stereo slide projection. The glasses are inexpensive, so this system may be useful if a large audience is involved.

Red-blue stereo glasses may bring back memories of comic books and grade-B movies, but in ophthalmic photography, they have some very good applications. Since our angiographic images are usually viewed as monochrome (gray-scale) images, it is possible to color one of the two.

Prints and Publications

While prints are not commonly used to view stereo images in a clinical setting, there are a variety of viewing methods that may be available to see the stereo images found in publications.[9] An understanding of these viewing methods will assist you in selecting the appropriate publishing method for stereo images and will allow you to tell the person reviewing your images how to look at them. It is important to be able to inform the publication's editor and printer of size requirements for easy viewing.

A commonly used stereo printing method involves two images printed just less than two inches in width with a small space between them. It is important to make sure that the distance between common points on the stereo images is not greater than the average PD of 60 mm. A good working rule is that each of the images should be no wider than 55 mm. If you have a narrow PD or the printer has made the prints too large for convenient viewing, then you can use base-out prisms, one for each eye to assist in viewing.

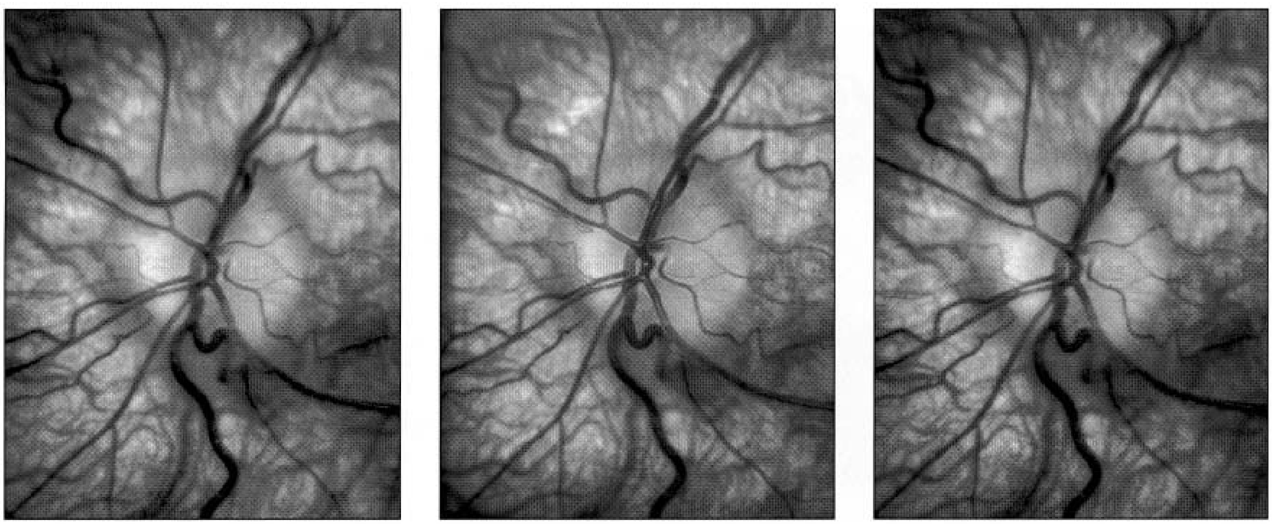
Some stereo magazines print larger images to increase image sharpness. To assist in viewing, they often include a set of +40, 80 baseout prism viewing glasses with each subscription. These glasses are also useful for viewing stereo images that are each 60- to 90-mm wide.

Usually the left image is on the left and the right on the right, but if the images have been printed in reverse, you must cross your eyes to see stereo with the proper depth relationships. The cross-eyed method prohibits the easy use of magnifying lenses and makes it difficult for some individuals to fuse the images. There also is some image distortion, since some parts of the image are farther away from the eye than the center of the image. If you cannot cross your eyes sufficiently for free viewing, try base-in prisms to Imitate cross-eyed viewing of large prints.

Larger prints may require an optical device to align your eyes with the images. Base-out prisms are useful only if the images are relatively small. If the images are larger, try a mirrored viewer.

An interesting approach is to provide three images: L, R, and L. The first two images are paired for "parallel" viewing and the second and third images are paired for cross-eyed viewing (Fig. 9).

Figure 9: Set of three images for stereo viewing. Images (A) and (B) may be viewed using the parallel technique: Image (B) and (C) may be viewed using the cross eye technique.



It is important that you purchase the proper equipment to view large-print stereo images (see manufacturers' list in Appendix C). I know of one experienced ophthalmic photographer who prided himself in being able to free-view large prints using the cross-eyed method. He did this for many years and later in life acquired double vision whenever he was tired.

Over-Under Prints

The over-under prints method allows you to perceive stereo with two stacked horizontal Images. The viewer contains multiple mirrors that are precisely set for a specific print size and a specific stereo separation. If you are interested in this format, obtain the viewer first and then create your images to fit it.

Figure 10: Vectographs are viewed using polarized glasses. A common vectograpgh is the Titmus fly test.

Single-Mirror Viewing

A unique printing technique requires just a single mirror to view the stereo image. As usual, the Image for the left eye is on the left and that for the right eye is on the right, but the right image is printed as a left-right reversed Image. Follow this viewing technique: The right image is reversed with a mirror that is placed vertically in front of your nose with the reflecting side toward the right. Look directly at the left image with your left eye and with your right eye also try to view the left image. If the mirror is aligned properly, you will view the reversed right Image through the mirror. Fusing these two views reveals a stereo image. The only catch is that either the right image must be printed slightly larger or you must lean your head to the right so that both image paths are the same length.

Vectographs

Single prints that can be viewed without lenses or mirrors make viewing easier for people who have difficulty fusing images that may not be optimally aligned. The Titmus stereo fly test is an example of the Vectograph viewing system, which uses two superimposed and polarized images viewed through polarized glasses (Fig. 10).

Lenticular Prints

Lenticular prints require no viewing aids: no mirrors, lenses, or glasses! The two stereo images are created in alternating thin vertical strips, which are cemented behind a series of lenses. The lenticular lens permits both of your eyes to see the many small vertical slices of an image. Your left eye sees the left image and your right eye sees the right image. The width of each individual lenticular lens determines the horizontal resolution of the image. The image resolution on the small lenticular prints is 180 lenses per inch. Each lens has an image pair behind it. A 4 x 3 inch print of an optic nerve will not provide as much information as a stereo pair of 35-mm slides, due to the resolution limitation of the number of lenses used to create the Image.

Lenticular prints and transparencies can be made into poster-size images. One lenticular print has been used on the cover of the Journal of Ophthalmic Photography.10 This image was created using a Nidek 3Dx simultaneous stereo camera, and the split-frame stereo image was reproduced by Lentec, Inc.

Red-Blue Glasses

Printing monochromatic stereo images as a single color image lets most viewers perceive stereo image with red-blue glasses (Fig. 11). The left image is printed in red and the right in blue. Red-blue stereo allows images to be printed large, presenting more information than small side-by-side images. Computer programs may also be used to create red-blue images (see previous discussion on computer images). This technique is not often used because of the expense of color printing.

Future of Stereo Imaging in Ophthalmology

The value of the two images that comprise a stereo pair is truly greater than the sum of the parts. The additional information provided by stereo imaging should not be underestimated. In the changing medical community, the ability of the clinician to obtain medical advice without consultants having to physically see the patient will play an important role in the future of ophthalmic photography. With computer network capabilities, the ability to access a stereo view of the fundus of a patient in a remote location may become an accepted practice.

Simultaneous stereo camera images taken with reproducible stereo techniques permit computer analysis of these images. Through optic nerve analysis, the diagnosis of glaucoma may become possible even before functional field loss is manifested. Thus, the ability to photograph stereo images is a crucial skill. The ophthalmic photographer must have complete understanding and control of the theories and practices of ophthalmic stereo photography in order to ensure the ultimate care for the patient.

About the author: Mr. Tyler was formally introduced to stereo visual phenomena while working at Bell Telephone Laboratories' research laboratory in Murray Hill, New Jersey from 1962-1966. His duties in the Neurophysiology Laboratory included working with the computer generated images by Bela Julesz, including Julesz's classic random dot stereograms. 1

In 1976, he applied for a US Patent for the method of stereo sequence timing[4]. In 1970, he came to Wake Forest University, Bowman Gray School of Medicine (Department of Ophthalmology), where he now holds the rank of instructor.

Mr. Tyler has taught workshops in stereo photography at the Ophthalmic Photographers' Society annual meetings. He continues his work in ophthalmic stereo imaging while integrating it with computer systems.

REFERENCES

1. Julesz B. *The Foundations of Cyclopean Perception.* Chicago: The University of Chicago Press, 1971.

2. Allen L. Ocular fundus photography. Am *J Ophthalmol* 1964;57:13.

3. Bussy BJ, Mittelman D. Use of the astigmatism correction device on the Zeiss fundus camera for peripheral retinal photography. *Int Ophthalmol Clin* 1976;16:2.

4. Tyler ME. Stereo sequence programmer for retinal fluorescein angiography. *J Biol Photographic Assoc* 1977;45:19.

5. Tyler ME. High-low focusing to increase depth of field. OPS annual meeting, 1977.

6. 3D-Web. 3D Frequently Asked Questions, 1996. HTTP://www.3 D-web. com/3 dfaq. htm

7. Walker BP. Photographic filing systems. *Int Ophthalmol Clin* 1976;16:2.

8. Merin L. Construction and use of stereo viewers. *J Ophthal Photog* 1981;4:39.

9. Ferwerda JG. *The World of 3-D, A Practical Guide to Stereo Photography.* Borger, The Netherlands: 3-D Book Productions, 1987.

10. Tyler M. Cover: lenticular print of optic disk edema. *J Ophthal Photog* 1993;15:1.

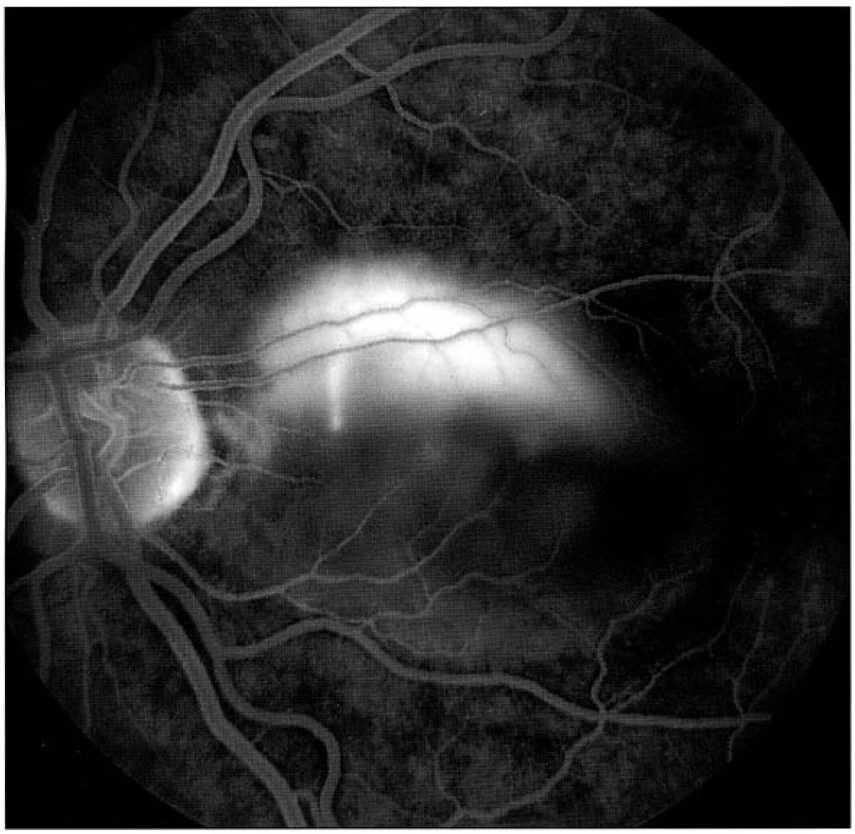


Figure 11: Bicolor stereo image viewing. A stereo fluorescein angiogram to be viewed with red-blue stereo glasses.

Resources: Stereo Supplies and Equipment Manufacturers

3-D Concept
Jon Golden
Roundwood Road Productions
16 Roundwood Road
Newton, MA 02164
617 332-5460
Email: JGoldenRRP@aol.com
Products: RBT stereo mounts (4, 5, 7, 8 perf. and full-frame mounts), RBT stereo cameras and projectors

3D-Magazin (German)
Oerter Puett 28
D-45621 Haltern, Germany
+49 (2364) 16107, FAX +49 (2364) 169273
Email: 3D-Magazin@stereo. s.bawue. de
Website: http: / /www.tisco.com/ 3d-web/3dmag/3dmag.htm
Products: Magazine about stereoscopic imaging. Includes test of stereo equipment (cameras, viewers), book reviews, etc.

Reel 3-D Enterprises, Inc.
PO Box 2368
Culver City, CA 90231
310-837-2368, FAX 310-558-1653
Products: 2- x 2-inch transparency viewers, 3-D slide viewers, side-by-side print viewers, precision 2- x 2-inch slide mounts, projector polarizers, polarized 3-D glasses, books

Stereo World
National Stereoscopic Association, Inc.
Box 14801
Columbus, Ohio 43214
Products: magazine and books