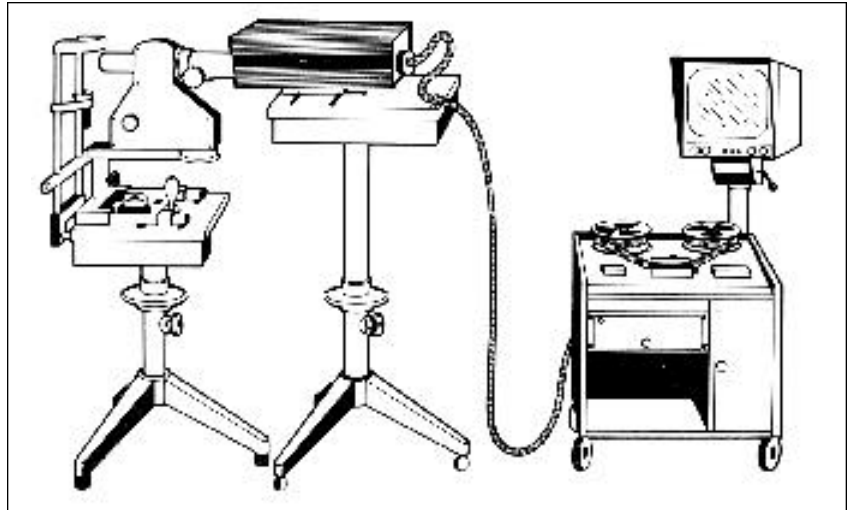**A**

FIGURE 7-2
Early video fluorescein angiography system. A. Television monitor image of selected lines in monochrome illumination. B. Perspective drawing of a television ophthalmoscope. (From RLDallow. *Television Ophthalmoscopy: Instrumentation and Medical Applications.* Springfield, IL: Charles C Thomas, 1970.)

B

minating beam splitter. This increased the intensity of the viewing lamp at the patient's eye. They stated: "The positive public-relations aspects of this fast service are not without reward," and mentioned that recording a fluorescein angiogram as a kinetic event was of potential importance.[7]

I have always marveled at the feeling I get when seeing the true dynamic nature of a fluorescein angiogram on a continuous medium such as videotape. Even when you take a film fluorescein angiogram, there is usually a mirror that blanks out the view of the fluorescein image each time you expose an image. A technological change to include continuous imaging would provide for analysis of the choroidal and early arterial angiographic phases.

In the 1980s, Vidicon video camera tube(s) were replaced with silicone chips. The imaging chip technology used is a charged coupled device (CCD).

Video Camera with Computer Digitizer

As computers became less expensive, smaller, and more powerful, the next generation of imaging systems began with the introduction of video frame grabbers. Apersonal computer–based video frame grabber permits an analog video signal to be digitized.

In 1980, at the University of Pittsburgh, Paul Rehkopf and Joseph Warnicki, with Stuart Brown, M.D. (Chairman of the Department of Ophthalmology), began developing an ophthalmic video digitizing system. In late 1982, they worked with James Cambier at PAR Microsystems to develop the first marketable electronic ophthalmic imaging system. This system was a Unix-based computer running a Motorola 68000

FIGURE 7-5
Integrating video or digital images. Electronic angiography systems use either a video or a digital camera. A video camera produces an analog signal, which can be recorded in analog on videotape or translated into 0s and 1s by a digitizing board in a computer. A digital camera provides a digital image directly to the computer.
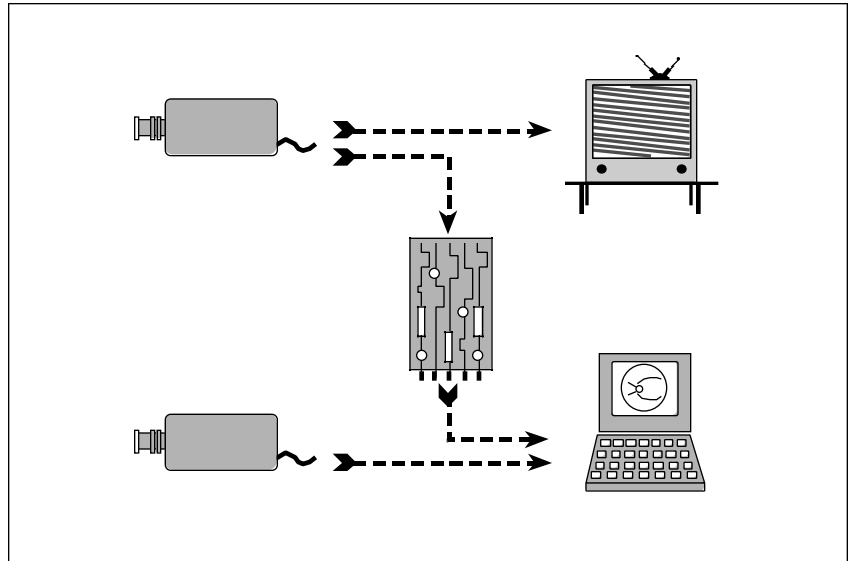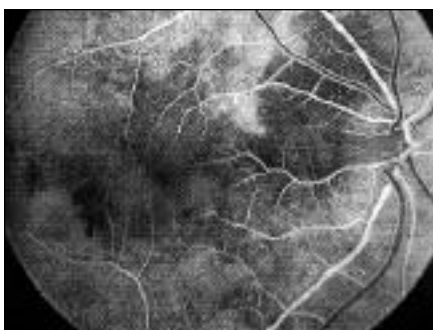

FIGURE 7-6
Analog film density versus digital camera output. The digital camera creates discrete values for each level of illumination and produces values that represent the linear nature of the imaging devices.
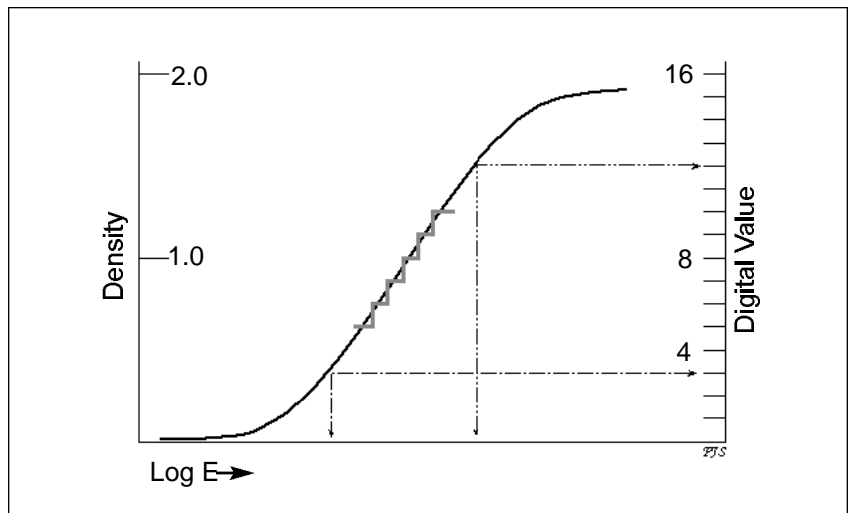
IMAGE DEPTH

A digital camera receives light onto its CCD, where the light on each pixel generates a number that represents the brightness of the light. Eight-bit cameras generate a number between 0 and 255 ($2^8 = 256$) and 12-bit cameras, 0 to 4095 (2^{12}). This number approximates the amount of light that falls on that specific pixel. Some cameras use a 10- or 12-bit dynamic range for image capture but save the image as an 8-bit image. There are also 16-bit cameras, and these store 65,536 gray-level values (2^{16}).

Pixels may be numbered starting in the upper left-hand corner of the image sensor. This location is 0,0 for the row-column location. The next pixel in the first row would be number 0,1. Since the pixels are read off in order, there is little reason to note the actual location of the pixel once the total array dimension (in pixels) of the CCD is known. Just the brightness (luminance) values are noted as discrete values—for example, 0, 127, 255. These values represent black, medium gray, and white.
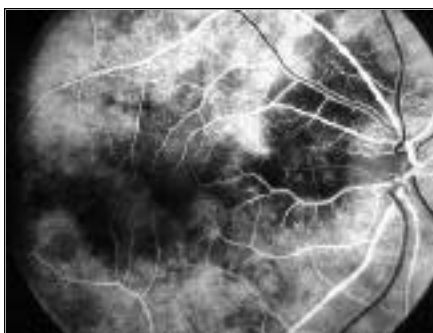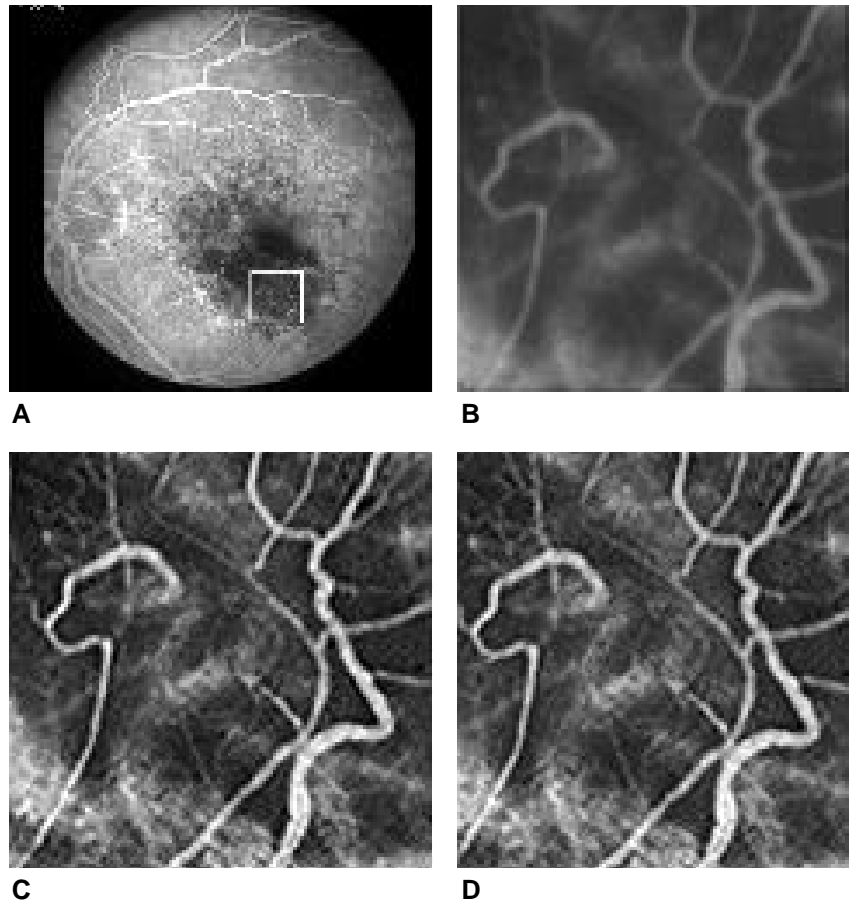
FIGURE 7-10
Magnified views of sample prints from different printing technologies. A. Laser print 300-dpi Hewlett-Packard LaserJet III. B. Laser print with photorealistic software on 600-dpi Hewlett-Packard LaserJet 5 printer. C. Dye sublimation print, Kodak XL-7700, black and white media ribbon. E. Photographic quality laser, Fuji Pictographic 3000 laser printer.

A

B

C

D

FIGURE 7-22
Sharpening versus enhancement order. A. Original.
B. Enlargement of original. C. Image enhanced, then
sharpened. Note the accentuated highlights on the larger
vessels and a decrease in shadow detail.
D. Image sharpened, then enhanced. Note the increased
shadow detail.

change to the detail of the image (Figure 7-22). Finally, never sharpen a destructively compressed image (see the discussion of compression later in this chapter).

Other Imaging Software Tools

ZOOMING

Image enlargement by zooming the image on the monitor provides visualization of important details that might otherwise be difficult to see. A larger image will not provide more information (unless your monitor shows you less resolution and detail than your image contains), but the image is easier to see. This may be particularly helpful in the laser treatment area where the monitor may be placed more than a few feet from the physician. You should be able to position a zoomed image on the monitor so that the area of interest is centered. Printing the zoomed image is particularly useful if you print with a lower-resolution laser printer.

IMAGE OVERLAYS

Computers can do things that are impossible (or, for practical reasons, nearly impossible) in the darkroom. These programs allow a lesion to be outlined on one image and the outline to be overlayed from that image onto another image can provide feedback to the physician about the relative position and size of the lesion and the treatment (Figure 7-23). To make sure that the overlayed information is placed correctly on the image, there must be a mechanism to ensure that the fundus on the two images
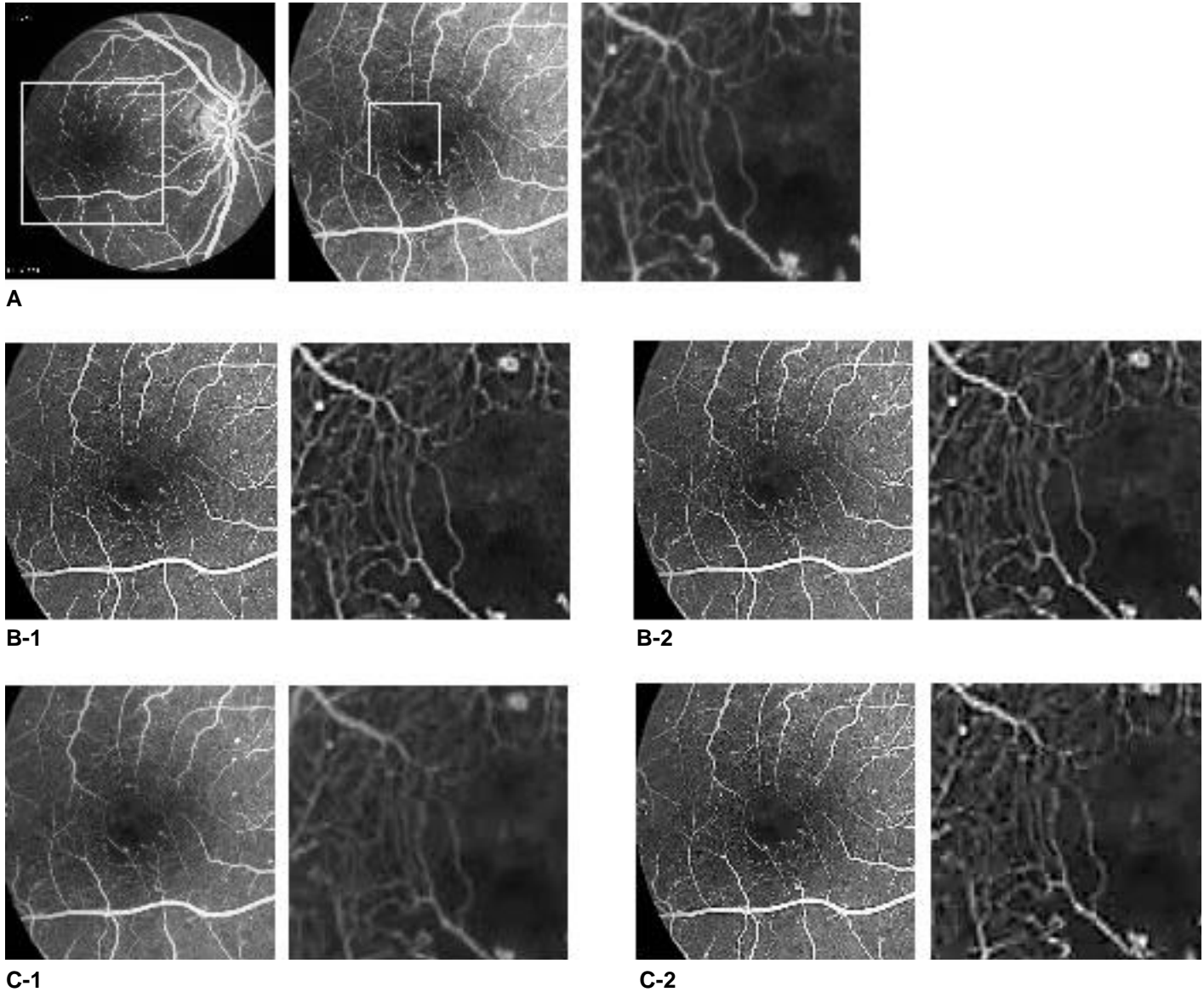
FIGURE 7-28
Image compression (destructive) with sharpening. The order may be important. Compressed images may not tolerate simple image enhancement techniques. A. Original with close-up. B-1. Image sharpened. B-2. Image compressed and decompressed. C-1. Image compressed and decompressed, and then sharpened (C-2). Notice how detail of the fine perifoveal vascularization does not tolerate image enhancement after an image has been compressed.

**Table 7-9. Image Review Systems Based on Size of Retinal Practice**

Size of Practice	Acquisition	Laser Room
Small	Acquire and review	Monitor only
Medium	Acquire and review	Simple computer review
Large	Acquire	Full review computer with network
Very large	Acquire	Network feed to laser and physicians' offices

puter may be sufficient. However, if the retinologist wants to enhance these images or to create his or her own image overlays, the review station should be a full-function system.

Images may be moved either by physically moving them with a floppy or an optical disk of images (the "sneaker-net"—running the disk down the hall) or with a cabled computer network. If the needs are simple, a sin-

FIGURE 7-33
Red filter photograph (A) and ICG photograph (B) of same eye showing nevus and hypofluorescence.

A   B
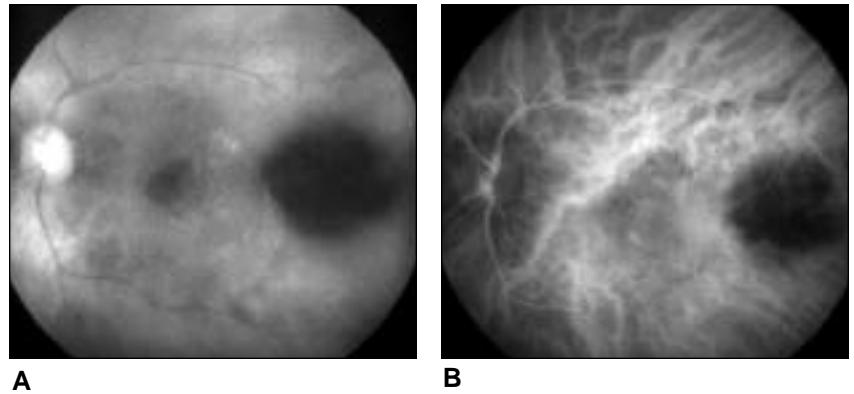
Focusing with Infrared Radiation

The range of electromagnetic radiation extends from gamma rays and x-rays through ultraviolet, visible, and infrared radiation to radiowaves and microwaves. Our eyes, our optical instruments, and our recording media are all optimized for that small band of the electromagnetic radiation that we call visible light.

We record infrared radiation (IR) during ICG angiography. While its longer wavelength allows visualization through some pigments and thin hemorrhages, IR does not focus in the same plane as visible light. An additional 0.25% of the focal length added to the lens-film distance is a standard correction.[27] The red index mark on 35-mm interchangeable camera lenses simplifies this process. After the lens is focused, the indicated distance is shifted to the red index mark. Both the standard calculation and the index mark options for correction are impractical for fundus photography.

Two different strategies have been used to ensure the sharp focus of IR wavelengths in ICG angiography. Real-time IR-sensitive video viewing (with or without a barrier filter) is available on some systems. An IR-sensitive video camera replaces the viewfinder and displays real-time images on a video-resolution monitor. Advantages include feedback from real-time focusing. Capital expense and lower viewing resolution are obvious disadvantages.

A technologically simpler strategy is to bias the focusing system manually by adding two positive diopters to your reticule setting. In this instance, you will see a blurry reticule when looking through the viewfinder. Focus on the choroid while keeping the blurred reticule as blurry as it looked when you first viewed it. The instant feedback of electronic imaging makes this method practical. Inexperienced angiographers may have some initial problems, but the experienced ophthalmic photographer will readily adapt. Although this solution is admirably inexpensive, it introduces the potential for photographer error.

Whichever focusing system is used, target the focus to the choroid by visually dissecting the retina as described in Chapter 2. Focus past the retinal blood vessels and the pigment in the retinal pigment epithelium to the larger choroidal vessels. Remember that even with the best possible focus, the spongy choroid will always seem less sharp than the retinal blood vessels you are accustomed to imaging.

most of the ICG becomes protein-bound and thus unavailable for exposure. As the test continues, less and less ICG is available for fluorescence, creating a need for increased flash and camera sensitivity.

Performing Indocyanine Green Angiography

ICG angiography uses the same basic fundus camera techniques used in fluorescein angiography. This section delineates a step-by-step procedure for ICG angiography, based on the following "prepare, position, expose, and follow up" format (also discussed in Chapter 2). The experienced angiographer who is proficient in the electronic imaging of fluorescein angiography can quickly become successful in ICG angiography.

Conduct a step-by-step review before or during the procedure to help establish your routine. Post a copy of the steps near your fundus camera for easy reference.

Prepare and Position

1. *Perform color fundus photography.* **Expose stereo photographs that document the status of the retina, including any hemorrhage and edema. After obtaining these photographs, switch from film to electronic image acquisition.**

2. *Expose monochromatic images.* **Capture green and red monochromatic images. The green images are establishing shots that provide landmarks for overlay and indicate the status of retinal blood vessels and hemorrhages. Use a low flash setting and normal camera sensitivity for the green photographs.**

   The red monochromatic photographs provide a view of the choroid without ICG dye (Figure 7-33) and document potential hypofluorescent areas (e.g., nevus, dense hemorrhage, or dense pigmentation). Exposure with a red filter can be problematic: You may need to abandon the flash and carry out the exposure using only the viewing light and perhaps some gain in camera sensitivity. Empirical testing will lead to a correct exposure.

3. *Prepare the camera.* **After these monochromatic photographs are obtained, prepare the fundus camera and electronic imaging unit for ICG angiography. Double-check the exposure (we suggest a high flash intensity: 300 w/s), camera sensitivity (high), infrared exciter and barrier filter position (in), aperture setting (fully open), and focus (see the sidebar on focusing with infrared light). Remember that the exposure values are suggestions only: Empirical experimentation will yield the proper starting point for your particular instrument.**
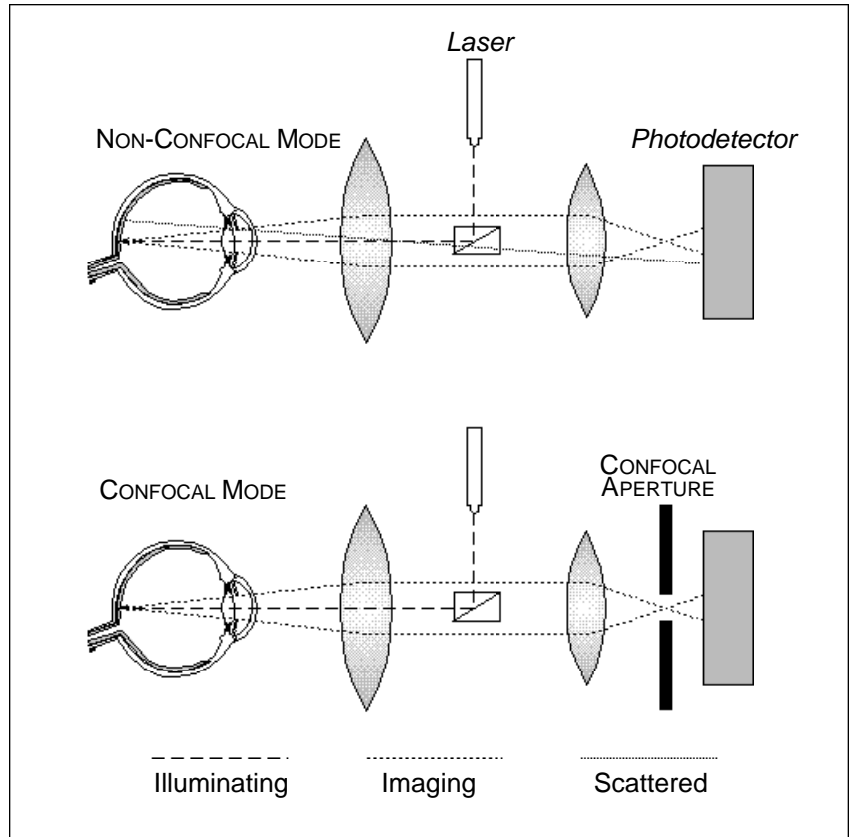
FIGURE 7-37
Scanning laser ophthalmoscope (SLO) schematic diagrams, including the aperture that is added to the confocal SLO.

patient—for example, the figure of a walking man, or words. At the same time the eye is receiving this image, the photoreceptor is measuring the reflective light from the retina and creating an image of the retinal vessels (minus the darker or lighter areas where the virtual image was presented to the patient). The resulting image permits you to examine the retina and the projected image simultaneously, which indicates the location of retinal functionality.[33]

Additional imaging capabilities are possible. In a confocal SLO (cSLO), an aperture is placed in front of the photo-detector to receive light only from the illuminated area of the subject. This increases contrast by reducing scattered light (Figure 7-37). cSLOs are used for fluorescein and ICG angiography (Figure 7-38). They can image these procedures with limited pupillary dilation. A disadvantage is the resolution limitation of these video-based systems.

The use of polarized light, with compensation for the polarizing properties of the cornea, has enhanced documentation of the nerve fiber layer (Figure 7-39).[34]

Retinal topography is achieved with yet another form of SLO. Since the depth of focus in the cSLO is small and precisely located, only the subject that is at the image plane of focus will be recorded. By acquiring a series of images that are sequentially "focused" from the anterior to the posterior levels in the retina (typically 32 images), a computer reconstruction of sharply demarcated retinal structures can be recreated in a three-dimensional computer map. Even though these systems use resolution images, it is the digital data that are being used for objective measurements. With this topographic information, different characteristics of the retina and optic nerve can be described (Figure 7-40). This is a quantitative process. Advantages to this technology are that a large pupil