
A method is described which enables the fundus camera to be focused objectively. This method eliminates the focus errors arising from the subjective focusing method currently used and permits the consistent attainment of high resolution fundus photographs. The objective focusing method has been evaluated on test targets and anesthetized animals and is applicable for use on unanesthetized human subjects.

In current practice, sharp fundus photographs having the highest obtainable resolution using the fundus camera are seldom obtained. To obtain such photographs the fundus camera must be properly aligned and focused. Although with practice the ophthalmic photographer can become skilled at aligning the fundus camera properly, proper focusing of the camera remains a continuing problem for many people and results in a frustrating percentage of out-of-focus pictures. One reason for this is the difficulty for many people of avoiding accommodation error which results when the retinal image is focused somewhere other than the plane of the crosshairs seen in the viewing eyepiece. A second reason for this is that the eye is a relatively poor judge of image sharpness for low magnification and low-contrast images such as the human retinal image. This report describes an objective method for focusing a fundus camera which eliminates focus error and enables high resolution fundus photographs to be consistently taken.

In general terms, the resolution of a fundus camera can be considered to be the minimum separation of two self-luminous objects (such as two adjacent fluorescein-filled capillaries) which are perceived as being separate objects (or vessels). If the resolution is poor the images of the two objects merge into one, sharp contrast boundaries of the object become fuzzy boundaries on the photographic image, and the photographic image becomes generally unsharp and "out-of-focus." Using the optical properties of the Zeiss Fundus camera and the normal emmetropic human eye, Vaughan and Laing have calculated the theoretical resolution of this system to be 7.5 μm on the retina for green light. This number has been verified by experiments performed in our and in other laboratories which have measured resolutions of 7 to 8 μm when photographing high contrast targets located at the "retina" of a model eye. When viewing high contrast targets under high illumination conditions one can visually resolve objects whose separation is somewhat less than the theoretical resolution limit. This too has been verified by experiments in our and other laboratories which have shown that with a Zeiss Fundus camera one can visibly resolve lines on a test chart located at the "retina" of a model eye whose spacing is as little as 4 to 6 μm. The fundus camera is thus capable of resolving the smallest retinal capillaries if it can be accurately focused.

Using the theory of Fourier optics, it can be shown that the effect of defocusing an image is to reduce the contrast of all the spatial fre-
Fig. 2. Electrical signal from the focus detector vs. position of focus knob on the Zeiss Fundus camera for an artificial fundus and a cat fundus. CCW = counter clockwise rotation of focusing knob turned by right hand as looking at this knob; CW = clockwise rotation of this knob. BVF refers to the best visual focus as noted by the photographer. BAF refers to the value determined objectively from the microdensitometer scans.

Fig. 3. Representative microdensitometer traces of film image of a black line on a grey background (artificial fundus) located at the fundus of a model eye, showing the effect of turning the focusing knob of the Zeiss Fundus camera. BVF is that noted by the photographer. Traces have been translated vertically so as to superimpose peaks of the curves. (CCW = counter clockwise, CW = clockwise)

Fig. 4. Representative microdensitometer traces of film image of retinal artery in a cat showing the effect of turning the focusing knob of the Zeiss Fundus camera. BVF is that noted by the photographer at the time the fundus photographs were taken. BAF is that determined from the microdensitometer scans of the developed films. Traces have been translated vertically so as to superimpose peaks of the curves. (CCW = counter clockwise, CW = clockwise)

The objective focusing method discussed was applied to a Zeiss Fundus camera although it is applicable to any of the large fundus cameras sold by other manufacturers. An optical diagram of the Zeiss Fundus camera is shown in Fig. 1. The proper operation of this fundus camera is described in the operating instructions for this unit. For the present purpose, we need only note that when the focus knob of the Zeiss Fundus
camera is rotated the eye-piece head/camera back assembly moves closer to or further from the fixed telescope lens assembly shown. The fundus camera is constructed such that the film plane and the plane of the crosshairs are the same distance from the telescope lens assembly. These two planes are said to be optically conjugate to one another. If the retinal image is focused sharply in the plane of the crosshairs (with the hinged mirror in the “up” position shown) then it will also be sharply focused on the film plane (with the hinged mirror in the “down” position and the camera shutter open).

There are also two other planes which are conjugate to the retina. One is just to the right of the aspheric objective lens and the other is at the location shown as the position of the oscillating needle which has been installed as part of the objective focusing system. The exact position of these two latter conjugate planes varies slightly with the correction of the subject.

For the objective focusing method a 250 μm diameter needle was inserted into the illumination path of the Zeiss Fundus camera at the plane optically conjugate to the fundus at the oscillating needle position shown in Fig. 1. The needle was attached to a pen drive unit from an Eden Oscillographic recorder. The needle could be oscillated within the conjugate retinal plane by energizing the pen drive unit with a sinusoidal signal from an Exact Function generator. The image of this oscillating needle reflected from the fundus and the reflected light was collected by a small, sensitive United Detector Technology PIN-3D photodiode located at the film plane. This detector could also have been placed at the plane of the crosshairs. Signals from this detector were amplified and filtered using a specially made Lock-In Amplifier tuned to 100 Hz, which selectively amplified the signal component at the same frequency as the needle oscillation frequency. This frequency component was chosen because it could be observed with the greatest stability with the equipment which was available; this frequency component is not necessarily the best observation frequency.

To evaluate this system, measurements were made on the fundus of an anesthetized cat and
Fig. 6. Photographs of cat fundus taken with Zeiss Fundus camera for different settings of focus knob. Upper left: BVF as determined by photographer (but, in this case, not BAF, see text), upper right; CCW ¼ turn, lower left: CCW ½ turn, lower right: CW ¼ turn (BAF, see text).

also on an artificial fundus consisting of black lines drawn on a photographic grey card which was located at the fundus of a model eye. Fig. 2 shows the amplifier output at the oscillation frequency of the needle for different settings of the focus knob. The caption “Best Visual Focus” refers to the focus knob position for best visual focus as determined by the operator of the fundus camera. Black and white fundus photographs were taken on Tri-X film of both the cat fundus and the artificial fundus at the same settings of the focus knob used to obtain the data shown in Fig. 2. After development, these films were scanned with an Olympus MMSP Scanning Microdensitometer System. Figs. 3 and 4 show several of the microdensitometer traces from the films of the artificial fundus and the cat fundus, respectively, Figs. 5 and 6 show prints subsequently made from the films of the artificial fundus and the cat fundus which were scanned. The highest resolution photographs and, by definition, those in Best Actual Focus (BAF) are those for which the microdensitometer traces have the steepest sides. Although only CCW traces from BAF are shown in these figures, all of the traces exhibit a symmetry about the BAF position of the focusing knob. That is, in all cases from \( n = \frac{1}{4} \) turn up to \( n = 1 \) turn the microdensitometric scan for BAF + n turns was essentially identical with that for BAF - n turns. For both the artificial fundus and the cat fundus the BAF, as determined from the microdensitometer traces, was identical with the maximum signal from the lock-in amplifier. BAF can, therefore, be objectively determined by turning the focusing knob of the fundus camera until the signal from the lock-in amplifier is at maximum.

It is interesting to note that although for the artificial fundus the position of the focusing knob for Best Visual Focus (BVF) coincided with that for BAF, this was not the case for the cat fundus. In this case the operator, although a well-trained fundus photographer with as much time to focus the fundus camera as he wanted, was in error by \( \frac{1}{4} \) turn of the focusing knob. We have shown that \( \frac{1}{4} \) turn from BAF reduces the resolution by a factor of 3, from 7.5 \( \mu \)m to 23 \( \mu \)m. The value of the above (or other) objective focusing methods
for the fundus camera are apparent and such
methods are capable of providing a significant
improvement in the quality of fundus photographs.

From the Ophthalmic Biomedical Engineering
Section, Department of Ophthalmology, Boston
University School of Medicine, Boston, Mass.
02118. Submitted for publication Nov. 21, 1974.
Reprint requests: Dr. R. A. Laing.

Key words: fundus camera, focus, objective focusing, resolution, microdensitometer.

REFERENCES
Applications of Lasers in Medicine and Biology, Wolbarschat, M., editor. New York,
2. Flower, R. W., and Hochheimer, B. F.: A clinical technique and apparatus for simulta-
aneous angiography of the separate retinal and choroidal circulations, Invest. Ophthal-
ch. 6.
4. Carl Zeiss, Inc., Fundus Camera on Instrument Table, Specification of Equipment, Pub-