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The SLO, yet again

In recent years there have been a number of papers demonstrating the versatility of the scanning laser ophthalmoscope (SLO), including its use for fluorescein angiography,^{1,2} quantification of retinal blood flow,³ static fundus controlled perimetry,⁴ and the measurement of optic disc variables.^{5,6} To add to this list we now have the imaging of fundus autofluorescence, described in this issue in the paper by von Rückmann and colleagues (p 407). They take advantage of two of the major features of the confocal SLO, the ability to image using monochromatic light and the production of an image of a relatively thin slice of tissue. Clearly, the SLO is an extremely versatile instrument; to what extent does it offer the 'ultimate' imaging experience for ophthalmologists?

The concept of using lasers to image the retina was first proposed by Webb and colleagues in 1980⁷; the instrument was known initially as the flying spot TV ophthalmoscope, the term 'scanning laser ophthalmoscope' being introduced the following year. The conventional fundus camera illuminates a majority of the fundus simultaneously and so requires a large entrance aperture which, in turn, limits the size of the exit aperture through which the reflected beam can pass. The result is that the illuminating beam needs to be of high intensity. In contrast the SLO uses serial imaging; a narrow beam of laser light is scanned in a raster fashion across the fundus with an image of only one small point on the fundus being made at any one time. This means that a very small input beam of laser light can be used, freeing the rest of the pupil area for the reflected light to exit through. The immediate advantage of the system is that it allows imaging to be carried out at low light levels, some 200 times lower than with the fundus camera.⁸

The image is intrinsically a digitised one, although commercial instruments usually record it as a video signal. The main disadvantage of the instrument is its limited spatial resolution; the optics of the eye restricting the size of the laser spot on the retina to some 15 μm in diameter. Thus the SLO will lose some of the fine low contrast detail of the fundus camera. It should be noted, however, that providing the feature to be detected has sufficient contrast then it will be visible, albeit blurred, even though its actual size is much smaller than the spot size.

Apart from the convenience of being able to use low intensity light, the SLO offers a number of interesting features, several of whose potential has not yet been explored fully. The contrast of retinal features can be varied by changing the thickness of section over which

reflected light is received, the amount of scattered light detected, and the wavelength of the illuminating beam. The development of the confocal version of the SLO by Webb in 1987⁹ has led to tomographic imaging and a reduction in the amount of scattered light in the image. Unfortunately, imaging at depth will always depend upon the amount of light penetrating through the overlying layers of tissue and so it is inevitable that the quality of images of the deeper fundal layers will be limited. Also the thinner the section is, the lower will be the amount of light available and, hence, the poorer the quality of the image. There are two ways of addressing this problem; to increase either the strength of the illuminating beam or the exposure time. While the difference between the exposure from the SLO and fundus camera might suggest that the power of the irradiating laser, some 50 μW , may be safely increased there is, in fact, little information on the effect on retinal tissue of exposure to monochromatic laser light at this level. This is an area in which more work on safe working exposure levels is required.

The solution proposed in von Rückmann *et al*'s paper was to increase the effective exposure time, by summing multiple images. However, this introduces the problem of correcting for eye movement. Unfortunately, the registration of images requires not simply corrections for shift but also image warping, and manual alignment of the images is often not sufficient for this. Much effort has been expended upon algorithms for movement correction of retinal images,¹⁰ these are sophisticated but, as a result, often very time consuming even on modern workstations. This may prove to be the factor that limits the value of this technique.

A further problem is that there is little information as to the size of tomographic sections produced by the SLO. Although some workers have produced results measuring slice thickness,¹¹⁻¹³ the manufacturers of commercial instruments often only identify the confocal aperture by a number and do not provide information about slice thickness. In practice, the slice thickness needed to produce an image of reasonable quality appears to be about 2500 μm ,¹³ thinner slices being too noisy. This must surely raise questions as to the value of the instrument for measuring retinal topography. While there have been published results showing the technique to be reproducible,¹⁴ measurements made on humans have had certain inconsistencies in the values produced⁶ which have not been convincingly explained.

Perhaps the most interesting feature of the instrument is

the ability to image at different wavelengths. At present the most convenient source of laser light is the diode laser, which is compact, simple to operate, and cheap to purchase. Unfortunately, the range of wavelengths available is limited and for wavelengths shorter than 660 nm it is necessary to use a gas or dye laser. Given a range of wavelengths, it may be possible to study variables such as tissue blood flow, volume, and oxygenation; work that has already been successfully carried out in a non-imaging mode on cerebral tissue.^{15 16}

In their paper, von Rückmann and colleagues capture the SLO images on a video recorder and then digitise the video image, which will inevitably lead to a loss of image quality. The SLO is ideal for direct digital imaging as the serial nature of the image process effectively produces a digital image. The addition of a relatively cheap PC with an image grabber card permits rapid acquisition of sequential SLO images, such as would be required in fluorescein angiography. The value of making quantitative measurements of pathology from digitised fundus camera images has been demonstrated¹⁷⁻¹⁹ as such measurements can provide new information about the clinical status of the fundus. But digital imaging may be a mixed blessing. For example, while it avoids the need to develop film an angiographic sequence may require substantial storage requirements that challenges even that available from optical disks. In addition, the provision of an adequate numbers of suitable image viewing terminals needs to be taken into account. It may be that at the present time the adoption of digital imaging technology for other than very specialised tasks should be made only after very careful evaluation.

Whatever the problems, the confocal SLO undoubtedly offers a very versatile instrument for retinal imaging. However, much work is still required to realise its full potential. The study of autofluorescence is yet another exciting application, and an assessment of its clinical value is eagerly awaited.

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