An advanced slit-image camera

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Precision slit-image photographs of the anterior segment of the eye are capable of giving information about the dimensions and densities (light-scattering properties) of the refractive structures of the eye, which is not obtainable by direct inspection, and of providing a record of progress. Slit-image pictures were first used for this purpose by Goldmann (1940).

For a slit-image photograph to be suitable for measurement it should be in perfectly sharp focus in all parts, the slit beam should cut exactly the same section of the eye on each occasion, and this section should be as nearly as possible along the optic axis of the eye. Valid comparisons can then be made between the same eye on different occasions and between different eyes.

For density measurements a standard density reference needs to be incorporated in each slit-image picture (Fig. 1).

FIG. 1 *Slit-image photograph of a normal eye*

SHARP FOCUS

A sharp image is obtained when the slit beam cuts a fine section of all structures from the cornea to the vitreous, and the camera is capable of forming a focused image of all parts of this slit beam at the film plane.

SLIT BEAM CHARACTERISTICS

The slit beam is formed by the focused image of a slit. It is therefore not a parallel-sided beam, but has a double wedge shape, which has been previously discussed (Duke-Elder, 1938; Brown, 1969).

Image sharpness improves greatly on narrowing the slit beam which is done by using a narrow slit width and an aperture on the slit projection lens. A 0.05 mm. slit width has been found to give the best results. Slit widths narrower than this produced no further improvement.

The aperture on the slit projection lens is rectangular with its long axis parallel to the slit. A slit aperture of 2 mm. has been found satisfactory. The actual shape of a narrow slit beam is shown in Fig. 2, in which it is seen that the wedge shape is nearly eliminated. The narrowest point is at the point of focus of the slit image which is upon the anterior lens capsule.

FIG. 2 Photograph of a narrow slit beam. Slit width 0.10 mm. Slit aperture, 3 mm.

FOCUS OF THE IMAGE AT THE FILM PLANE

The techniques for obtaining an all-in focus image of the slit beam depend upon the application of Scheimpflug's principles (Scheimpflug, 1906). Apparatus built on these principles has been described by Anjou and Krakau (1960), Viazovsky (1961), Drews (1964), and Niesel (1966).

An apparatus constructed on Scheimpflug's principles has either a tilted objective, a tilted film plane, or both in combination. The relative advantages of each method of construction were fully discussed by Brown (1969).

The new apparatus described here uses a tilted film plane. The angle of tilt of this film plane is critical and is now discussed. The camera has a fixed reproduction ratio of 1.75:1, which is found to make best use of the 35 mm. film format. The angle between the slit beam and camera axis is fixed at 45° . By the application of Scheimpflug's principle it is found that a film plane tilt of 60.5° would be required.

However, the slit beam is not viewed in air, but through the cornea, anterior chamber, and lens of the eye. The apparent depth position of the slit beam is displaced towards the camera, and it is upon the apparent slit beam that the camera needs to be focused. The apparent depth position of the slit beam for a viewing angle of 45° has been calculated using Tscherning's (1900) figures for distances, radii of curvature, and refractive indices (Fig. 3). A curve is produced, but a straight line can be drawn to cut this curve at the points of importance: cornea, anterior lens surface, and posterior lens surface. This line intersects the true slit beam at the cornea at an angle of 3° . The angle between the camera axis and the line of the apparent slit beam is therefore 48° ($45^\circ + 3^\circ$), and the angle of film plane tilt needs to be 57.5° (Fig. 4). The camera is constructed with this film plane tilt.

Experiments have confirmed that the above calculation is correct. When the distance between the camera and the slit beam is adjusted, it is found that the cornea and the anterior and posterior surfaces of the lens each appear in sharpest focus at the same point in the adjustment.

CAMERA OBJECTIVE

Since depth of field problems are eliminated by the tilted film plane, a large-aperture objective can be used on the camera. This has certain advantages: more light is obtained for exposure of the film. Objects which do not lie on the slit beam are well out of focus and therefore interfere less with the slit image. There is better visualization of the posterior parts of the lens of the eye since the out-of-focus iris interferes less with the image formation.

Macro objectives were first used and were found to be capable of producing sharp images but, with maximum apertures of F3.5, did not give adequate exposure. Normal high-speed objectives are designed for distance photography and perform poorly in macro-photography. A high-speed objective designed for 1.75:1 reproduction ratio has been specially made for the camera.* It is a 51 mm. F1.9. It is used at a little below full aperture at F2.7, which gives correct exposure of the narrow slit beam on normal-speed film (Kodak Tri. X. ASA.400).

ALIGNMENT

Alignment devices are incorporated to achieve antero-posterior, vertical, and horizontal alignments.

ANTERO-POSTERIOR ALIGNMENT

It is essential that the image of the lens should always occupy the same position on the film plane, since the magnification varies along the film plane. This is achieved by an aerial image reflex viewfinder with a vertical cross-hair. The camera is advanced towards the eye of the subject until the cross-hair appears to touch upon the anterior lens surface.

* Manufactured by J. H. Dallmeyer, London

FIG. 4 Slit-image camera optics

HORIZONTAL ALIGNMENT

This is obtained by a fixation device (Figs 5 and 6, overleaf) and the corneal reflex is used as an optical pointer.

The device has two pin-point fixation lights, one for each eye. Each light is displaced 6 mm. nasal to the centre line of the slit projector, which corresponds to an angle of 5° (the normal angle α) at the nodal point of the eye. The slit beam reflected from the cornea falls upon the white front surface of the fixation device as a vertical streak of light. While the subject fixes the pin-point light, the apparatus is traversed until the corneal reflex is seen to fall on the vertical centre line of the slit projector, which is marked on the fixation device. In this situation the visual axis is directed toward the fixation light, and the slit beam is sectioning the optic axis of the eye (given a normal angle α).

FIG. 5 *Fixation device* FIG. 6 *Photograph of apparatus, showing fixation device*

VERTICAL ALIGNMENT

The visual axis is vertically displaced from the optic axis of the eye, but figures for this angle have not been found in the literature. It has been found experimentally that a fixation point placed 4 mm. up from the horizontal centre line of the slit projector, corresponding to 3.5° at the nodal point of the eye, produces pictures with the optic axis directed horizontally in the majority of subjects. The fixation point used is therefore displaced 6 mm. nasal and 4 mm. up from the centre line of the slit projector.

To obtain the vertical alignment, the subject fixes the pin-point light and the slit is turned into the horizontal position. The apparatus is then raised or lowered to centre the reflex upon the horizontal centre line of the slit projector, which is marked on the face of the fixation device. The slit is then returned to its vertical position for the photograph.

DENSITY STANDARDIZATION

Film is unsuitable for density measurements unless a standard is provided. This needs to be recorded on each frame of the film at the instant of exposure. A standard density is incorporated in the apparatus having ten steps of 0.10 density gradations which appear

in each picture (Fig. 1). The holder for the standard also carries data about the subject. Light is conveyed to the standard density by a fibre optic bundle from the flash tube which illuminates the slit, and so will take into account any variation in flash intensity. The image of the standard density is formed on the film plane by a subsidiary objective and a mirror (Fig. 7). Density measuring instruments can make valid measurements of the densities in the lens of the eye by direct comparison with those in the standard.

FIG. 7 *Slit-image camera*

FIG. 8 *Complete apparatus*

Construction of the apparatus

SLIT PROJECTOR

The slit beam is provided by a production Zeiss photoflash slit projector intended for use with their Photo-Slit Lamp. It is modified by the insertion of the fibre optic bundle for the standard density device. The fixation device is fixed over the top prism and a corneal reflex eliminator is fitted in front (discussed by Brown, 1969) (Figs 6 and 8 see page 626/629).

CAMERA

The camera (Figs 6 and 7) is a standard single lens reflex (Exakta), which is itself unmodified, but is fitted with a tilted film plane and special viewfinder.

The film plane (Fig. 9) is tilted at an angle of 57.5° , and the film is transported over it by rollers (Fig. 10).

FIG. 9 Camera film plane

FIG. 10 Diagram of film transport

The viewfinder (Figs 6 and 11) has a clear screen with cross-hairs tilted at the same angle as the film plane and parafoveal with it. The screen is viewed through a lens system giving a clear erect view of the aerial image.

FIG. 11 Viewfinder assembly

In front of the camera is a box-shaped structure carrying the main objective and the subsidiary objective with its mirror. This is mounted on a fine focusing slide with geared drive and vernier, which is parallel with the camera axis, and gives final fine adjustment

to the plane of focus of the camera. This adjustment is used before exposure to give the best focus upon the apparent depth position of the slit beam, which varies slightly with anterior chamber depth, a range of travel of only 0.5 mm. being sufficient. For repeat photographs of the same eye the vernier is referred to.

The whole apparatus is mounted on a stand having vertical, horizontal, and antero-posterior geared adjustments (Fig. 8).

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