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A New Contact Glass for Slit-lamp Examination of the Cornea, Especially in Specular Reflection

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Abstract: A new contact glass of 2.2× magnification for the examination of the cornea is described. With it, all three types of illumination provided by the slit lamp can be used to advantage: specular reflection, optical section, and indirect light. A precorneal chamber filled with liquid abolishes the surface reflex of the tear film, and a built-in orange filter suppresses most of the light scattered by the corneal stroma. In specular examination the necessity for a large angle between the illumination and observation beams no longer exists, so that quite small angles can be used. Since at the same time such a glass considerably widens the usable field, epi- and endothelioscopy are greatly facilitated. Handling of the glass is as easy as in routine biomicroscopy. It is shown that a contact glass of power M increases the resolution in depth by a factor of M^2. Image distortion introduced by the glass is measured and found to be tolerable within the area of photographic records usable for cell density determinations. Some modifications made on the Nikon FS-2 photo slit lamp in order to improve its suitability for endotheliography are described. Clinical application of the method is documented by several examples. [Key words: contact glass, cornea, distortion, resolution in depth, slit lamp, wide-field endothelioscopy.] Ophthalmology 92(S):72–83, 1985

When H. Goldmann introduced his diagnostic contact glasses (fundus glass, gonioscopy and three-mirror contact glass), the purpose was the optical neutralization of those parts of the eye which are in front of the structures to be observed.[1] The goal was to obtain an isometric image of the interior of the eye, that is, measurements in all three dimensions being to scale.

In this context there is in principle no need to use a contact glass for the examination of the cornea since the latter is seen directly without interference by the optical media.

In some instances, however, an intentional deviation from the condition of isometry may be advantageous in order to obtain a better view of specific anatomical structures; eg. exaggeration of distances in depth may be helpful for detecting otherwise unrecognizable structures.

This paper describes a contact glass designed for improving the examination of the cornea. Originally developed for specular microscopy of the endothelium,[2,3] it has shown its usefulness also in improving the evaluation of depth and the examination in indirect light. It can be used in conjunction with routine slit lamp equipment for simple biomicroscopical observation as well as for photographic documentation (Fig 1).

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PRINCIPLES OF CONSTRUCTION

The surface between air and medium of high refractive index, which usually is the surface of the tear film, is dis-

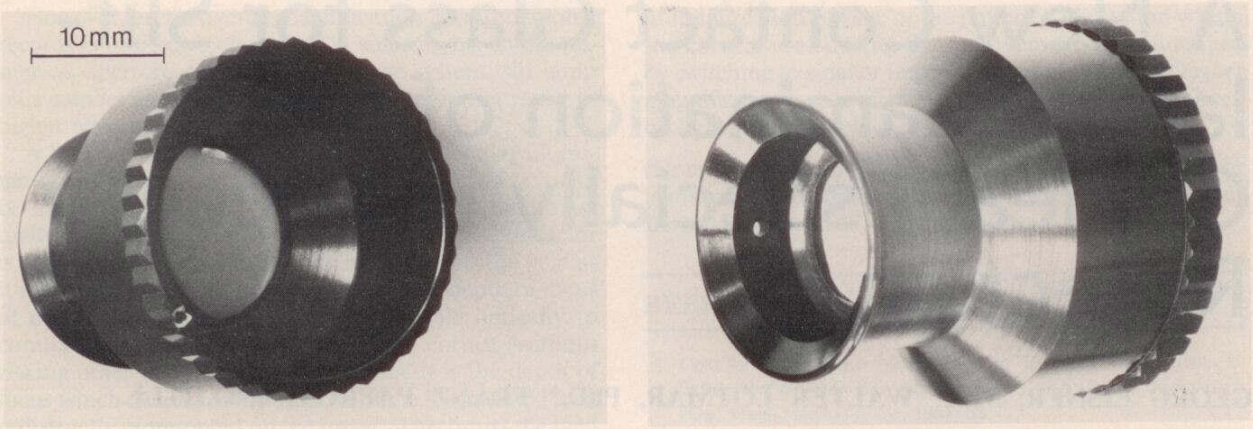

Fig 1. The new contact glass. *Left,* front view. *Right,* rear view. The large hollow space (precorneal chamber) is filled with fluid and then applied to the cornea.

placed anteriorly to the front surface of the contact glass. The bright reflex of the tear film which blurs the specular endothelial and epithelial reflexes is thus abolished. The newly formed reflex at the contact glass front surface, however, is not picked up by the objective lens of the microscope, and therefore presents no obstacle (Fig 2). To reduce light losses the front surface is antireflection-coated. The interspace between contact glass and cornea is filled with a transparent lubricant.

The optical data of the glass were chosen so that an aplanatic lens[4,5] of 2.2× paraxial magnification for the endothelium resulted; for the front radius (R) and thickness (t) of the cornea the values of Gullstrand's eye model were used (R = 7.7 mm, t = 0.5 mm). For differing values of t the magnification M is obtained by

$$M = 2.21 + 0.26\ \Delta t$$

where Δt is the difference from the normal value. For the epithelium ($\Delta t = -0.5$ mm), for example, we obtain M = 2.08×.

By such a magnifying lens in front of the binocular microscope the numerical aperture of the system is increased, resulting in better resolution of image details and higher resolution in depth. Perception of cells and structures in depth with routine slit lamp magnification is thus improved.

SPECULAR MICROSCOPY OF THE ENDOTHELIUM AND EPITHELIUM

Specular microscopy of the corneal endothelium was first described by Vogt in 1919.[6] In the last decade clinical interest in it has become widespread in connection with the development of more and more sophisticated anterior segment surgery.

Contact and non-contact specular photography, as well as simple slit lamp endothelioscopy, possess the great disadvantage of having a very small field. Scanning of large surfaces becomes cumbersome both for the patient and the investigator. In addition, current wide-field equipment is rather expensive.[7] Our contact glass offers a wide field of specular illumination but is simple with regard to equipment and practical use. The following properties are relevant to specular microscopy:

The field of specular illumination is increased to the full diameter of the slit beam owing to the high collecting power of the front surface and its considerable distance from the cornea. As the beam diameter, which for most slit lamps is 8 mm, is reduced by the contact glass to 3.6 mm at the corneal surface, the maximum surface of specular illumination is about 10 mm^2 (Figs 4, 5).

The images obtained from a cornea of normal form are remarkably flat, provided both the glass and the microscope are optimally centered. Cell density determinations can be made on photographic records over an area of typically 1 × 2.5 mm, containing roughly 6000 cells.

By applying part of the optical magnifying system, namely the contact glass, directly to the patient we obtain, at least in part, the advantage of the microscopical "contact method". In our case this means that focusing is no more sensitive than usual to manoevering the slit lamp in spite of higher overall magnification, since we focus on a virtual image lying at a *fixed distance* from the patient's cornea. On the other hand of course, we have traded off overall depth of focus against higher numerical aperture, that is, increased resolution. For the conditions prevailing when the Haag-Streit slit lamp is used, the resolution is theoretically of the order of 2 μm (500 lines/mm).[4]

An orange filter (Schott 570) is incorporated into the contact glass. It removes the shorter wavelengths mainly responsible for light-scattering in the corneal stroma. Scattered light creates a veil across the specular image when a wide beam is used, and prevents the utilisation of the maximum area of specular reflection obtainable with the contact glass. Efficient suppression of the veil is a precondition for obtaining sufficient contrast in wide-field endothelioscopy (Fig 6). It permits the choice of small angles between slit lamp and microscope, and therefore

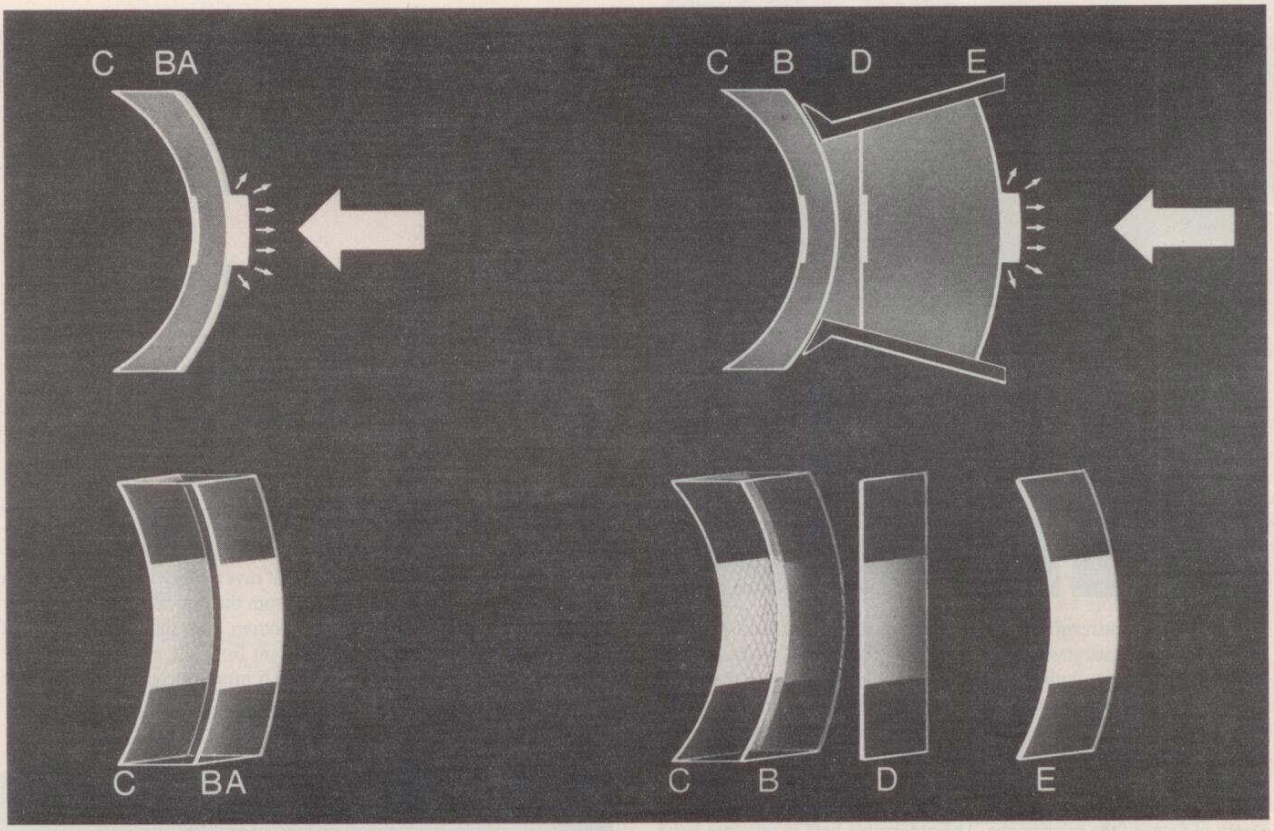

Fig 2. Examination of the specular reflexes from the cornea. *Upper row,* schematical section through the cornea and contact glass. *Lower row,* semi-perspective representation of the reflecting surfaces. *Left,* without the contact glass the specular reflex of the tear film (A) is very strong and blurs the underlying weaker reflexes from the epithelium (B) and endothelium (C). *Right,* with the contact glass the reflex between air and medium of high index of refraction forms at the front surface of the contact glass and hence is displaced far away from the focus of the microscope (E). The posterior surface of the glass is flat and its reflex (D) can be removed by merely tilting the glass. Between the cornea and the glass a precorneal chamber is created. This is filled with liquid (e.g. methyl cellulose) and thus the reflex of the tear film is abolished. The weaker reflexes of the epithelium (B) and endothelium (C) become distinctly visible.

facilitates visual observation as well as photography. In addition, with small angles the simultaneous observation of phenomena in regredient light becomes possible (Fig 5). The light scattered by methyl cellulose solution is also much reduced so that more transparent (and expensive) lubricants are not mandatory.

Choice of filter OG 570 is a compromise between cut-off wavelength and maintenance of sufficient brightness. It is usually sufficient for the normal clear cornea. However, in cases of increased corneal haziness, scattered light may remain, permitting the observation of smaller areas only and demanding large angles between slit and microscope. For special purposes, other filters of smaller bandwidth may be added either to the contact glass or to the illumination beam of the slit lamp.

The posterior surface of the contact glass is flat (Fig 2). Consequently, the posterior reflex can easily be removed from the visual field of the observer by slightly tilting the glass.

Since the posterior surface of the contact glass does not actually touch the cornea, there is an empty space in front of the cornea which is filled with saline or with a viscous lubricant. Deformation of the cornea, which might deteriorate the specular image, is thus avoided. The danger of corneal lesions is also decreased. A small orifice in the fluid chamber wall of the contact glass prevents overfilling or air inclusions.

To a certain extent, the contact glass steadies the patient's eye. However, changes in the direction of gaze are still easily possible without hindrance, so that all parts of the cornea can be inspected with the positions of the slit lamp and the microscope left unchanged.

ASSESSMENT OF IMAGE DISTORTION

Since the image-forming light bundles issuing from the outer parts of the field strike the front surface of the contact glass at relatively large angles of incidence, the question of image distortion in these parts and its possible influence on cell density determination has to be considered.

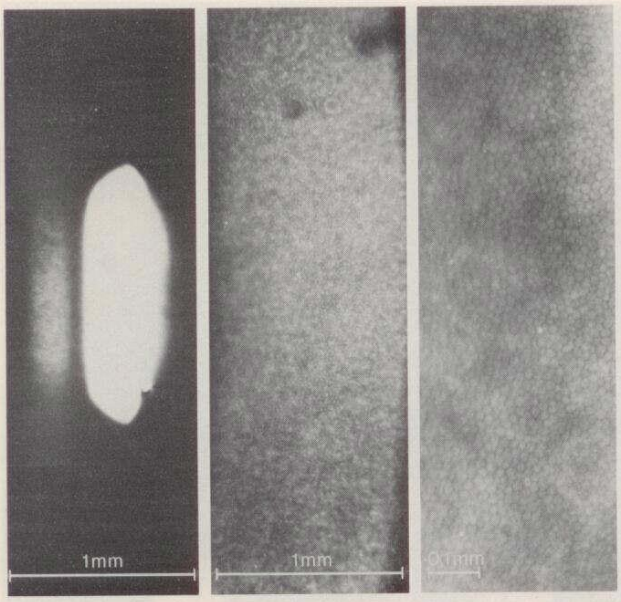

Fig 3. Photographic records of specular endothelial reflexes without (*left*) and with the contact glass (*center and right*). *Left,* without the contact glass the area of the endothelial reflex is small; the fine endothelial pattern is difficult to evaluate because the dazzling tear film reflex blinds the observer. *Center,* view of the reflex area with the contact glass. The size and the angle of the slit beam as well as the overall magnification are the same as at *left.* Note the increase of the illuminated field and the flattening of the corneal curvature, which brings a large area within the depth of focus of the microscope. The observable field in this case is 3.8 mm^2, 20 times that of *left. Right,* a record from another (normal) cornea at higher magnification.

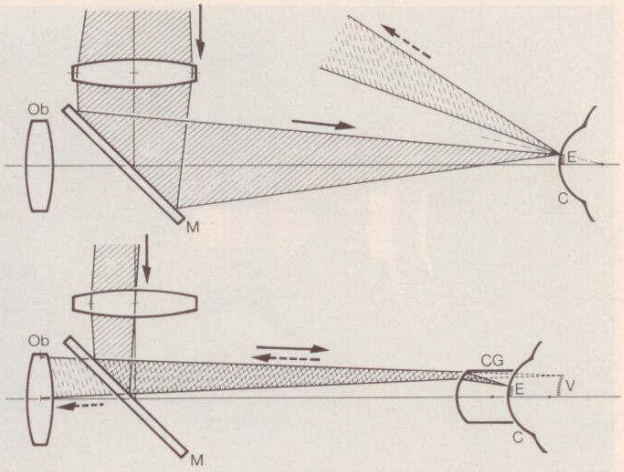

Fig 4. Course of rays without and with the contact glass. C = cornea; CG = contact glass; E = endothelium; V = virtual image of the endothelium; M = mirror of the slitlamp, Ob = objective lens of the microscope. *Top,* without the contact glass all rays reflected from points with an eccentricity of more than 0.4 mm from the optical axis cannot enter the objective lens of the microscope. *Bottom,* with the contact glass half of the beam reflected by a point 1.8 mm from the axis still enters the objective. Therefore, a zone of about 3.6 mm in height is made visible with the contact glass.

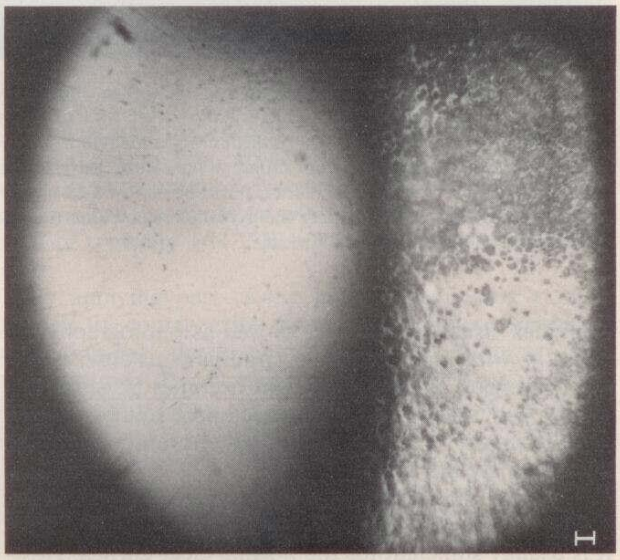

Fig 5. Female patient, age 74. Drusen of Descemet's membrane are seen in specular reflex and indirect illumination (×23).

Owing to the fact that in our case the object is not a plane but a spherical surface, the simple method used in photography of taking a picture of a plane two-dimensional equidistant grid is not applicable here because it is not possible to draw such a grid on a spherical surface. We resorted to engraving, on a sphere of 7.75 mm radius, small circles of equal diameter distributed over a field the size covered by the contact glass. The sphere was then photographed using a Nikon photo slit lamp FS-2 with and without application of the contact glass.

The sphere used was a steel ball whose surface was oxidized to a dark layer by 72 h immersion in a strong rock-salt solution at room temperature. Circles of 0.43 mm diameter were engraved on a lathe by a spring-loaded glass-cutting diamond tool that removed the oxide layer.

Figure 7 (*top*) shows a stereo picture of the field taken through the contact glass with the Nikon slit lamp. As can be seen, the vertex of the steel ball, and with it the optical axis of the contact glass, have purposely been slightly shifted upwards from the frame center, and so distortion (circles appearing as ellipses) has become evident in the lower part. Note however that in this area image definition is manifestly degraded and would not allow cell counting (of normal density) any more. On the other hand, Figure 7 (*bottom*) shows a picture of the same field taken without the contact glass. Practically no distortion is discernible.

Distortion in the case of cell density determination has to be defined as "apparent relative change in a given (small) area in the object as a function of its distance from the optical axis," in departure from its conventional definition in geometrical optics.[4] We obtain these factors by measuring the relative apparent surface areas covered by

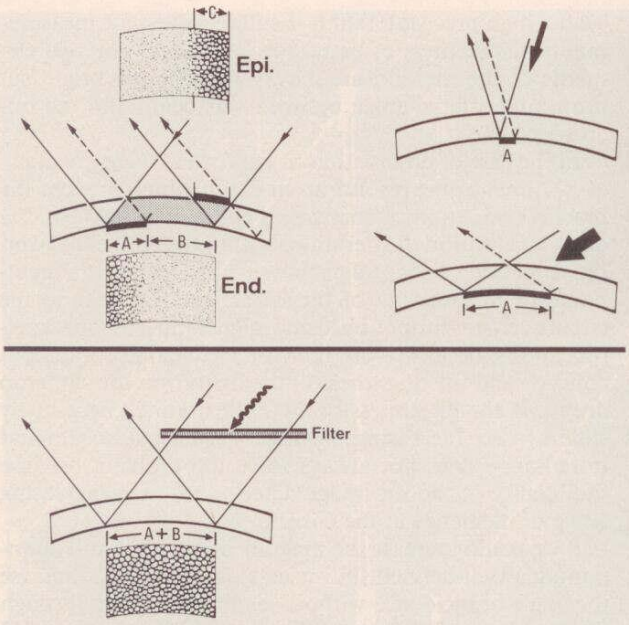

Fig 6. The rationale for using an orange filter to reduce light scattered by the corneal stroma. *Top,* without filter. *Left,* schematical section through the cornea and view onto the endothelium (End) and epithelium (Epi). *Right,* section through the cornea with different angles of the incident beam. The light incident from the right is scattered in the corneal stroma; hence the latter becomes opaque and prevents viewing the specular reflex of the endothelium. Only the light reflected from the margin opposite to the incident beam (on the figure: at left) arrives through transparent or partially transparent (ie. only partially or not illuminated) stroma to the observer. The width of the observable area (A) depends on the angle of incidence of the slit beam. The area is narrow with a small angle and can be increased by choosing a larger angle between slit-beam and microscope (*right*). End = specular reflex of the endothelium as seen by the observer. Only the cells at the left margin are visible (A), whereas the rest is more or less blurred by scattered light (B). Epi = epithelial reflex as seen by the observer. The portion of epithelium overlying the area of scattered light is seen indistinctly. For its examination the underlying stroma should be illuminated only partially or not at all by the slit beam. In contrast to the endothelium the epithelium is therefore best seen on the same side as the incident beam (C) *Bottom,* the use of an orange filter. *Upper part,* with an orange filter only the longer wavelengths, less likely to produce scatter, are transmitted to the cornea. Nearly all the light reflected from the endothelium (A + B) arrives undisturbed at the observer. *Lower part,* the specular reflex of the endothelium as seen by the examiner. All cells of the illuminated area are seen distinctly, the angle between illumination and observation being of little importance.

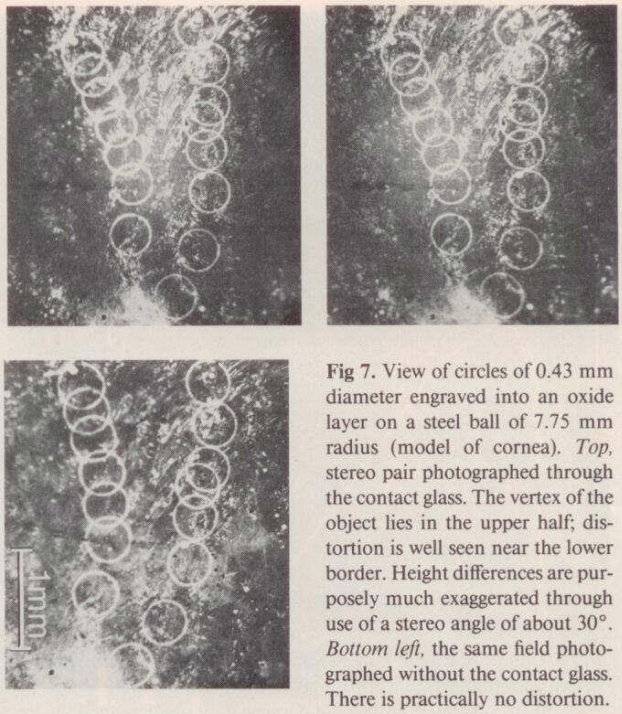

Fig 7. View of circles of 0.43 mm diameter engraved into an oxide layer on a steel ball of 7.75 mm radius (model of cornea). *Top,* stereo pair photographed through the contact glass. The vertex of the object lies in the upper half; distortion is well seen near the lower border. Height differences are purposely much exaggerated through use of a stereo angle of about 30°. *Bottom left,* the same field photographed without the contact glass. There is practically no distortion.

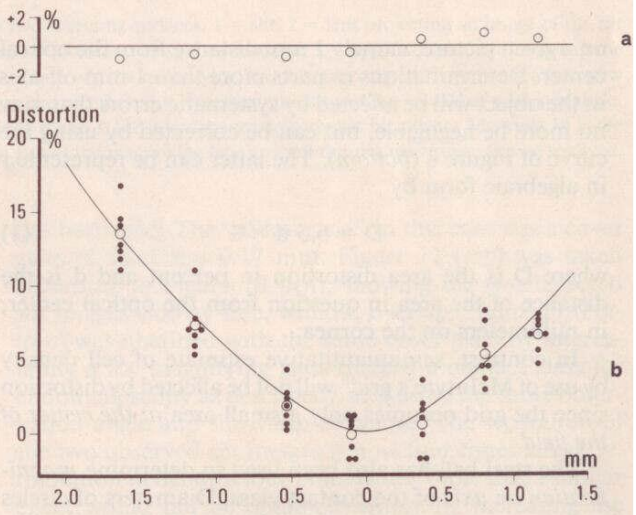

Fig 8. Apparent relative area distortion (%) of small circles on a spherical surface of 7.75 mm radius photographed with the Nikon FS-2 photo slit lamp, **a,** directly, and **b,** with intercalation of the contact glass. Abscissa is distance of circle centers from the vertex of the sphere. Full points are values of individual circles; hollow points are their mean values at a given eccentricity. The latter are approximated by curve D (see eq. [1]) when the contact glass is used.

our 0.4 mm circles on the film. Since the surface of an ellipse is πab, a and b being the half-axes, a measurement of the latter is all we need. This was performed on a measuring projector to an accuracy of about ±1%. Because it had to be anticipated that the amount of distortion might also depend on the angle between the illumination and photo-equipment axes, a total of seven pictures at different angles were taken. The results of measurement on seven circles per picture are shown in Figure 8. Individual values and means are given. It is seen that without the contact glass, the optics of the slit lamp produce a distortion-free image within the measurement error of our method. With the contact glass, the area distortion amounts to about 7% within the region usable for cell density determinations

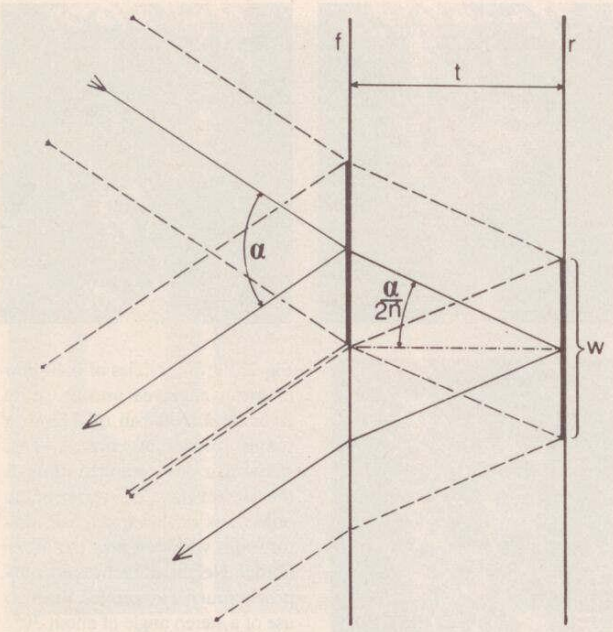

Fig 9. Course of rays at a membrane observed with the slit lamp. The drawing corresponds to a horizontal cross section of Figure 10 *left;* f and r are the front and rear surfaces of a transparent membrane of thickness t and refraction index n, on which two images of the slit are formed; w is their width and α is the angle between slit beam and microscope axis.

on a given picture, namely 1 mm distance from the optical center. Determinations in parts more than 1 mm off-axis in the object will be affected by systematic errors that may no more be negligible, but can be corrected by using the curve of Figure 8 (*bottom*). The latter can be represented in algebraic form by

$$D = 6.5\ d^{3/2}\% \qquad (1)$$

where D is the area distortion in percent and d is the distance of the area in question from the optical center, in millimeters on the cornea.

In contrast, semiquantitative estimate of cell density by use of McIntyre's grid[8] will not be affected by distortion since the grid occupies only a small area *at the center of the field.*

The steel ball has also been used to determine *magnification on axis* of the contact glass. Diameters of circles at the center of records taken with and without the glass were measured, using one and the same magnification factor of the photo slit lamp. A value of 2.07 ± 0.06 was found for the magnification of the glass, compared with a theoretically calculated one of 2.08 (see p. 73).

RESOLUTION IN DEPTH

The essential aim in slit lamp examination is to generate an optical section of the transparent media of the eye by an extremely narrow and well-defined beam of light. This method allows the evaluation of depth differences with such a high precision that it is suitable even for measurements of thickness of tissues or interfaces. The two elements of the method are a very narrow and bright slit beam and a large angle between this beam and the microscope axis.

In the case of observation of the cornea there are, however, limits to the resolution in depth which prevent the precise evaluation of changes in epithelial thickness, the exact localisation of alterations within the epithelial layer, the detection of slight detachments of Descemet's membrane or of doubling of the latter, etc. This cannot be circumvented simply by using higher microscope magnifications, because, with increase in magnification, both contrast and the brightness of the light from the slit lamp drop and the "keenness of the optical knife" necessarily suffers. Also, increasing the angle between slit beam and microscope does not always solve the problem because the quality of the slit image deteriorates with increasing angle of incidence at the cornea.

If we could increase the magnification while still maintaining a well-defined slit image and if we could increase the angle of incidence without leading the beam through the periphery of the cornea the resolution in depth would be improved. This can be accomplished with the help of a magnifying contact glass. The improvement, as compared to observation without the glass under the same conditions, amounts to a factor of M^2, where M is the lateral magnification factor of the glass used. Note however that in doing so we deviate purposely from Goldmann's principle that the goal of a diagnostic contact glass consists in procuring an isometric image of the interior of the eye.

To explain the principle of the effect we use a simplified model consisting of a thin membrane as shown in Figures 9 and 10 (*left*) (thickness is much exaggerated in order to make matters clear). Evaluation of membrane thickness actually is the discrimination between the anterior and posterior surfaces. The interdistance can be perceived only if the slit images reflected from both surfaces do not overlap, ie. if they are sufficiently narrow and well-defined. With a given angle α between the directions of illumination and observation, the maximum admissible width of the slit image, w, without overlap, is given by

$$w = \frac{\alpha t}{n} \qquad (2)$$

where t is the thickness and n the refraction index of the membrane (we equate $\mathrm{tg}\frac{\alpha}{2}$ with $\frac{\alpha}{2}$ which for $\frac{\alpha}{2} = 20°$ corresponds to a difference of 4%).

Eq. (2) can also be written in the form

$$t = \frac{nw}{\alpha} \qquad (2a)$$

in words: t is the lowest membrane thickness that can be resolved at a given slit width w and angle α.

Now suppose we leave the slit width and the observation angle α unchanged, but use, in addition, a magnifying glass of magnification M, both for illumination and observation (Fig 10b). This glass reduces the width of the

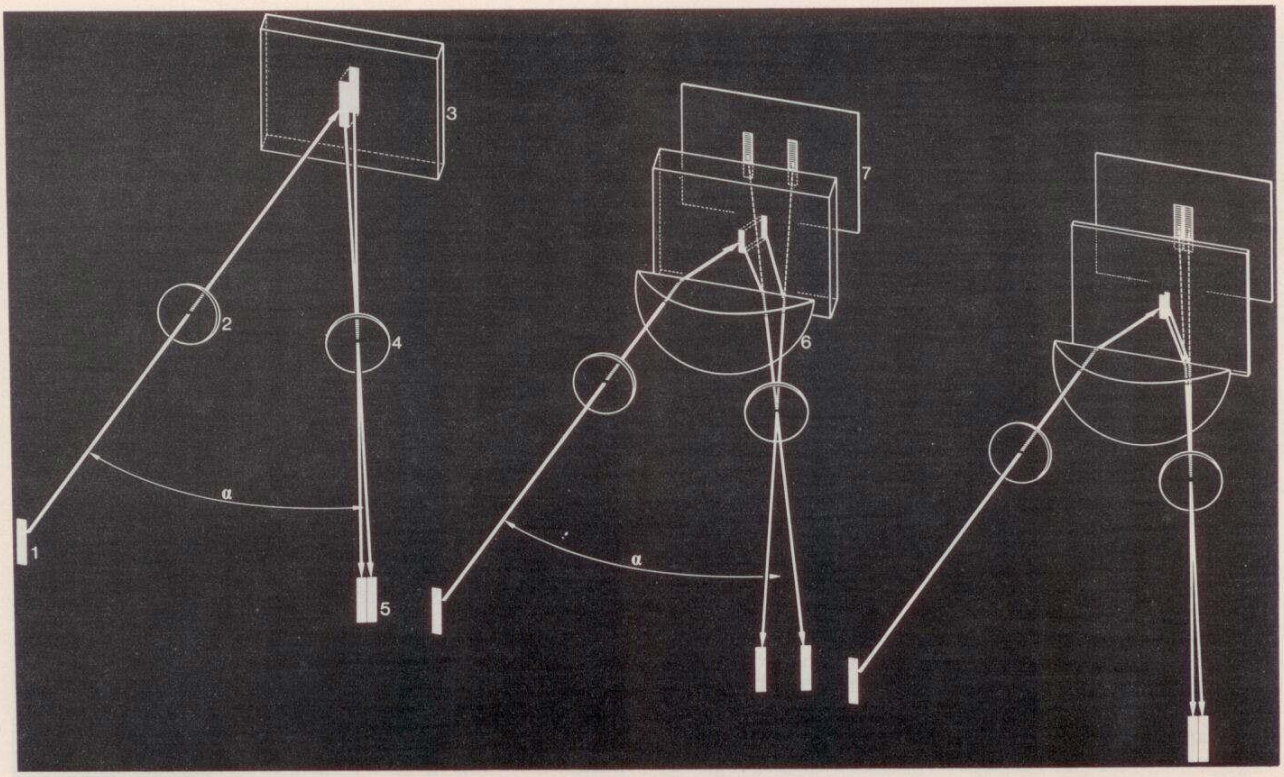

Fig 10. *Left,* standard slit lamp method of evaluating the distance between two reflecting surfaces. 1 = slit; 2 = lens projecting an image of the slit onto the object; 3 = reflecting membrane with slit images on both surfaces; 4 = objective lens of microscope; 5 = appearance of slit images in the focal plane of the eyepiece; the latter is not shown. *Center,* modified course of rays when a magnifying lens 6 is intercalated. To procure a free view of the situation behind lens 6 only its lower half is shown. The slit images on the membrane surfaces are smaller and are viewed at a steeper angle. Their virtual images generated by action of lens 6 on the reflected beams lie in plane 7, the interdistance being larger by a factor M^2 when M is the magnifying power of lens 6. *Right,* same optics as in *center,* showing that by use of the magnifying lens a much thinner membrane can be resolved.

slit image on the membrane to w/M and increases the observation angle *at the membrane* to αM. If we introduce these new values into eq. (2a) we obtain the membrane thickness t′ that can now be resolved:

$$t' = n\frac{W}{M}\cdot\frac{1}{\alpha M} = \frac{nw}{\alpha M^2} \qquad (3)$$

hence

$$\frac{t'}{t} = \frac{1}{M^2} \qquad (4)$$

In words: By intercalating the magnifying glass the resolvable membrane thickness is smaller by a factor M^2 than without the glass, as shown by Figure 10 (*right*). Note that the slit width you see in the microscope is *the same* as before since the reduction by the glass at the membrane is compensated again by its magnifying action upon the reflected beam. Conversely, of course, the visible illuminated *area* of the membrane is reduced by a factor $1/M^2$. Brightness and contrast of the slit images are, in principle, not affected apart from reflection losses and residual imagery aberrations of the contact glass, both of which are small. Figure 11 is an experimental illustration of what has been said. The "membrane" in this case was a cover glass of thickness 0.17 mm. Figure 11 (*top*) was taken according to Figure 10 (*left*), showing the two reflected slit images side by side, without overlap. Figure 11 (*bottom*) was obtained with the same cover glass by intercalating a 2× magnifying glass (indeed a contact glass for endothelioscopy as described), and using the same observation angle and slit width as before. The separation of the two observed slit images is now four times larger, ie. resolution in depth is four times better. Note that a similar effect would not be obtained simply by increasing the power of the microscope alone; it is a specific result of using a magnifying glass *both for the illumination and observation beams.* Application to clinical problems is described below (Fig 12).

WORKING WITH THE EQUIPMENT

SLIT LAMP EXAMINATION

For normal examinations, methyl cellulose 2% is quite satisfactory as filling material for the precorneal chamber. It produces some light scattering, but this is of little con-

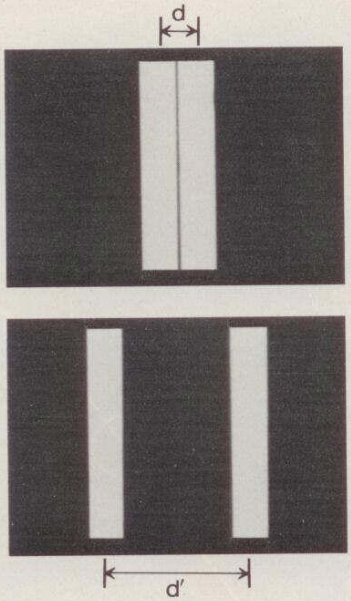

Fig 11. Results of an experiment performed with a photo slit lamp (Nikon FS-2). *Top* was obtained on a cover glass 0.17 mm thick with a set-up according to Figure 10 *left*. By intercalating a contact glass of magnifying power ×2 according to Figure 10 *center, bottom* was obtained. The slit width and the angle between illumination beam and microscope were the same for both pictures. Image separation d′ = 4d.

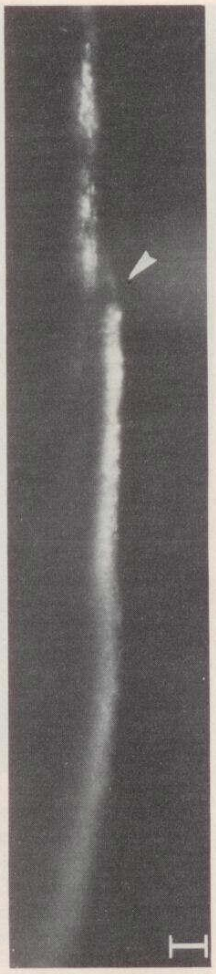

Fig 12. Male patient, age 64, with chronic neuroparalytic lesion. Border of corneal erosion in optical section. Note the distinct step between epithelium and bare stroma accentuated through the increased resolution in depth of the contact glass. The irregularities at the edge (arrow) are visible only with the contact glass because without it they are flattened by the surface tension between air and lacrimal film (×57). *Note: The white bars on Figs 5, 12–20 indicate a length of 0.1 mm*

sequence if an orange filter is used with the contact glass, as described. For special purposes, if a contact glass without an orange filter is used, the precorneal chamber may be filled with rejects of Healon, which is more transparent. In case of slight corneal edema glycerol is used not only on the cornea before the examination in order to reduce the epithelial edema but may also be instilled into the precorneal chamber in order to maintain the dehydration during the entire examination. For experimental purposes the precorneal chamber can be filled with drugs or solutions of various concentration in order to test their effects on the corneal epithelium.

The corneal contact glass then is applied to the eye in the usual manner. For observation of the cornea, the patient is asked to direct his gaze in the desired directions. Magnification is chosen low for beginning the examination and then increased according to the specific requirements. At the start of the examination the patient's gaze is directed straight ahead. For specular reflection examination, a small angle between the microscope and the slit beam is chosen (eg. 5–15°), and the desired corneal surface (epithelium or endothelium) is then brought into focus. Tilting the contact glass slightly in various directions will finally make the specular reflex apparent.

At this point, width and incidence angle of the slit beam can be adjusted. In a clear cornea, we use small angles and wide beams. In slightly hazy cornea it is necessary to increase the angle and to reduce the width of the slit because scattered light from the stroma veils the endothelium, or blurs the epithelial reflex, respectively.

For observation in optical section, the slit is made as narrow as possible at maximum intensity.

PHOTOGRAPHY

For photography we used a Nikon photo slit lamp type FS-2. However, some modifications were made as follows:

Photographic magnification was increased by a factor 2× through intercalation of a dispersing lens between the camera housing and the microscope support. It acts at the same time as a (partial) field flattener. At position "30×" of the slit lamp the magnification on the film then is 14× when a 2.2× contact glass is used. This allows for useful overall magnification of up to 200×.

The 12.5× eyepiece of the Nikon was replaced by a Haag-Streit 25× type, bringing the overall visual magnification to maximally 60×. This made correct focusing considerably easier.

The exposure release button on top of the steering handle was replaced by a foot switch. This increased the percentage of well-focused picture since it was found difficult to press the button while holding the handle exactly in focus position.

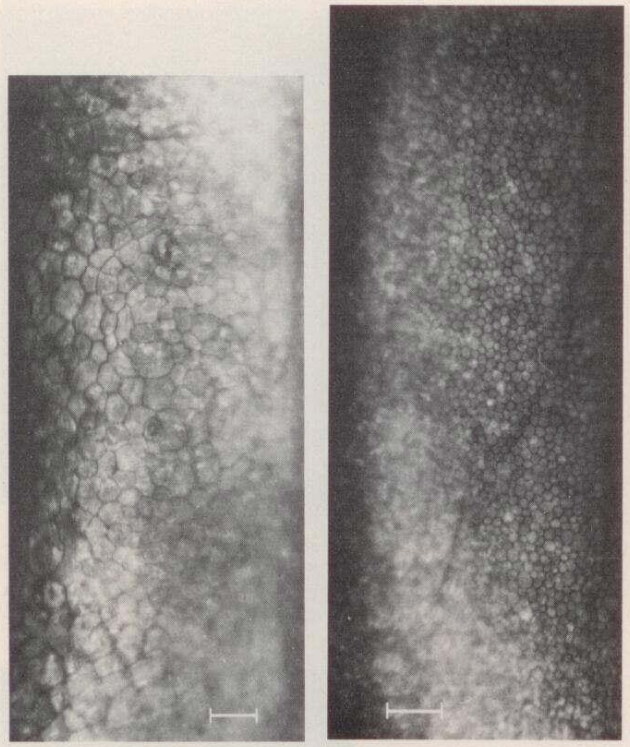

Fig 13. Male patient, age 63. *Left,* left eye four years after 4-loop implant; severe endothelial damage, cell density 620/mm^2. *Right,* right eye, not operated. Marked polymorphism, cell density 3310/mm^2.

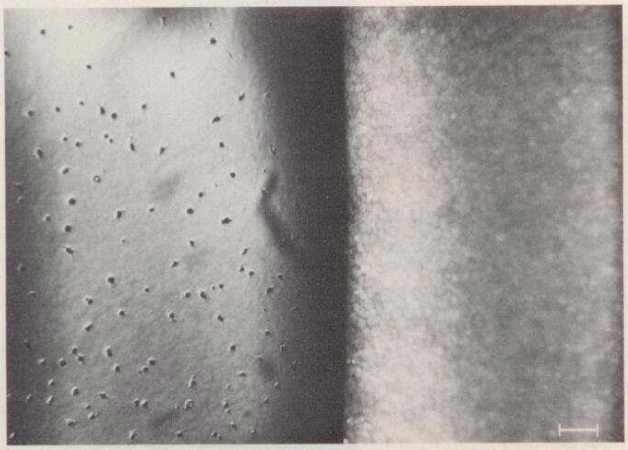

Fig 15. Female patient, age 70, four years after 4-loop implant. There are deposits of pigmented cells on posterior surface of cornea (white dots in specular reflex, dark dots in indirect illumination); but no interruption of normal endothelial pattern.

A fiber-optic cable was placed between the signal light of the flashlamp and a site on the microscope support easily visible to the operator when in observing position. This permits control of the flash without removing the head from the eyepiece and hence facilitates maintaining

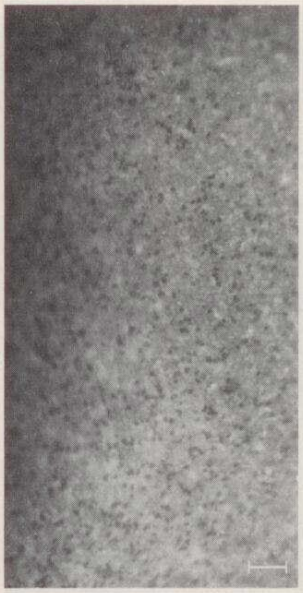

Fig 14. Female patient, age 17, with chronic iridocyclitis; deposits of inflammatory cells on endothelium interrupting normal endothelial pattern.

of the focus and the optimal angle for specular illumination during the whole procedure.

A swing-out dispersing lens in front of the microscope permitted photography of a 30 × 30 mm field. A swing-out card holder for the patient's data was fixed to the headrest support.

We used Kodak Technical Pan film Nr. 2415 because of its very fine grain, and developed in Kodak HC-110, solution D, requiring level 1 of the flash generator at magnification "10×", and levels 4 to 5 at "30×". For pictures taken with a very narrow slit (Fig. 12) we used solution B for nine minutes. Ninety-two percent of pictures showed correct focusing over at least part of the frame when a batch of 10 films (336 pictures) chosen at random from our material was analyzed.

RESULTS

Figures 5 and 12 to 20 are photographs of some cases of clinical interest. They show that the new corneal contact glass can be used universally for the examination of the cornea because it offers advantages in all types of illumination provided by the slit lamp: optical section, specular reflection and indirect light. A wide field greatly simplifies *endothelioscopy* because a few changes in the direction of gaze of the patient bring practically the entire endothelium into observation position. Similarly, for photographic records, the whole of the cornea may be covered by a few exposures.

McIntyre's grid is very useful but must be corrected for the magnification of the contact glass. The small angle between slit beam and microscope made possible by the new contact glass allows for phenomena produced by *indirect light* to be observed and photographed simultaneously. For example, drusen or cell deposits appear on the same photograph along with the specular reflex, thus

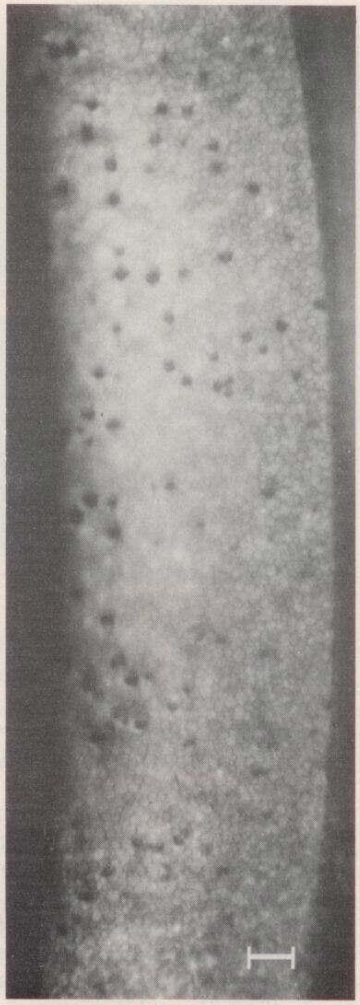

Fig 16. Female patient, age 70. Fifteen minutes after YAG laser iridectomy, the endothelium has multiple small ("single cell size") lesions.

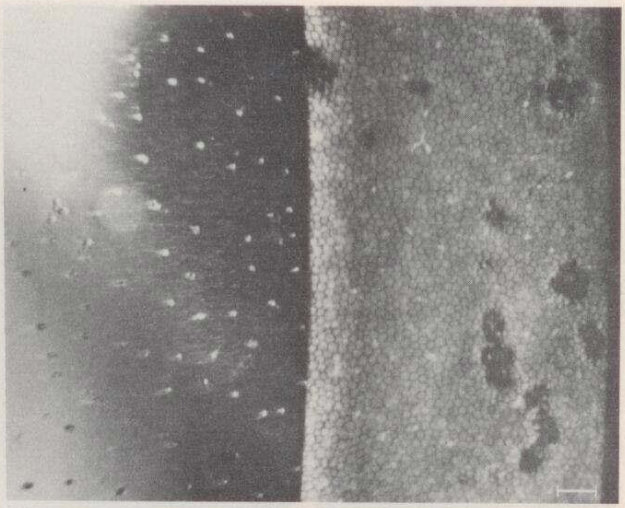

Fig 17. Male patient, age 68. Fifteen minutes after YAG-laser iridectomy, the endothelium has multiple large lesions. Note pigment particles (white dots) in center of lesions. Other pigment particles are seen in indirect illumination (at left).

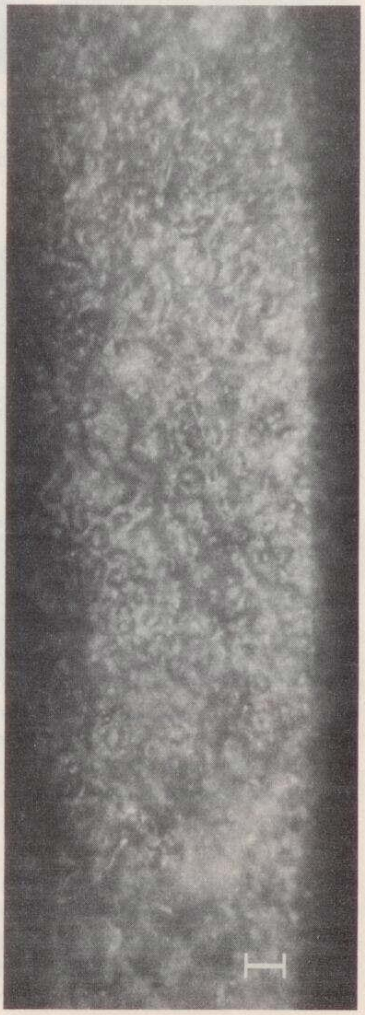

Fig 18. Female patient, age 68, with severe Fuchs dystrophy and irregularities of Descemet's membrane; no endothelial cells are visible.

permitting direct juxtaposition of both phenomena (Figs 5, 15, 17). A small angle also helps to avoid vignetting due to the distance (17 mm) between the virtual image and the limiting front surface of the glass.

Examination of the specular reflex of the *epithelium*—made possible through the abolition of the tear film reflex—is more difficult. While the endothelium is a single layer of evenly shaped cells, the epithelium is multilayered; the superficial cells are of different thicknesses, orientation and surface characteristics. Therefore the image is not at all similar to that of the endothelium with its sharp cell boundaries around strongly reflecting flat cell surfaces. We observe rather ill-defined areas of varying reflectivity, and on some areas the interference colors of extremely thin layers (Newton's colors). The reflexes are rather weak and easily blurred by scattered light from the underlying corneal stroma. They are therefore best seen on that margin of the illuminated area which is at the incident slit beam side (just opposite the area of best visibility of the endothelium) (Figs 19, 20). The exact significance of the different phenomena we observe in specular illumination of the epithelium remains to be elucidated. Therefore,

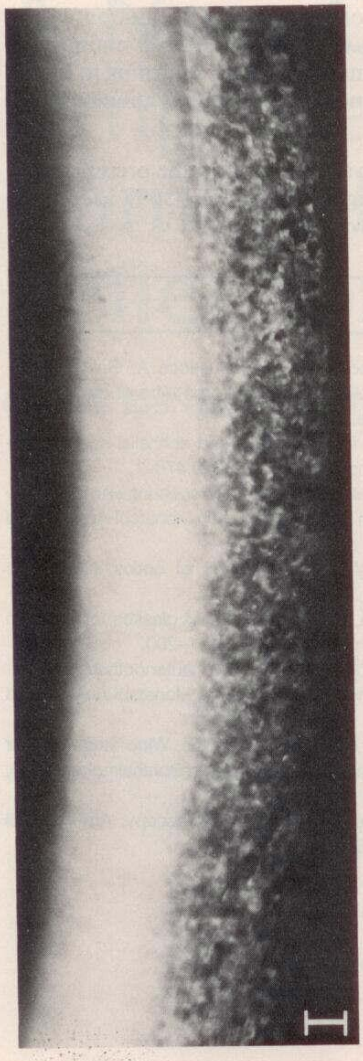

Fig 19. Male patient, age 35, with normal epithelium.

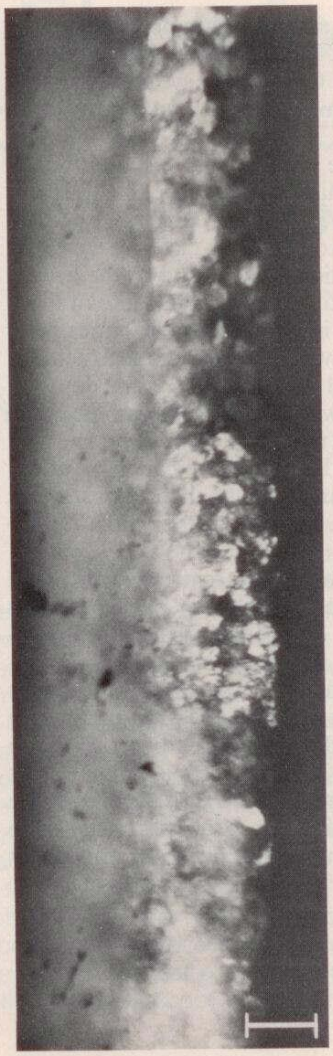

Fig 20. Female patient, age 66, with epithelium in dry eye syndrome.

while endothelioscopy is a well-established clinical method, examination of the epithelium needs further clinical research.

The evaluation of the phenomena observed in *optical section* with an extremely narrow slit beam is improved by the increase of resolution in depth. The thickness of the normal epithelium, the changes in its thickness, the exact position of alterations in the stroma, irregularities in or doubling of Descemet's membrane, etc, can be seen more distinctly because the distance between superposed layers is apparently increased.

In addition, the absence of contact between air and tear film abolishes the phenomena of *surface tension* and their flattening effects on the corneal surface. Irregularities, loose strands of epithelium, and deposits of mucus or foreign substances become more readily visible in the narrow slit beam as well as stereoscopically in diffuse illumination. However, photography of these phenomena is not easy, because it is difficult to obtain sufficient brightness of the slit beam and sufficient positional stability in the contact glass–patient system.

DISCUSSION

The main advantage of the contact glass is its versatility. It can be used with different types of slit lamps and photographic equipment, so that the optical apparatus suitable for a specific task can be selected. Should new and better equipment for observation and photography appear on the market, transformation into an endothelioscope, epithelioscope etc., simply by using the corneal contact glass, should present no problems.

Another advantage is the simplicity of manipulation. The new glass is used like every ordinary contact glass for the examination of the eye, and little practice is needed to obtain an image of the endothelium or epithelium. Since neither complicated mechanical nor electric machinery is involved, working with the apparatus is as easy as with the ordinary slit lamp. Change of magnification and field size is obtained by simply exchanging the microscope objectives or adjusting the zoom position, respectively.

However, useful overall magnification of photographic records is limited to about 200×, since owing to the numerical aperture of about 0.20 of the system, slit lamp plus contact glass, higher magnification will not result in higher resolution.

A third advantage is the wide field of specular illumination offered in endothelioscopy. Theoretically, it can be maximally 10 mm^2. Whether this large area can actually be exploited depends on different factors. One factor is obviously the magnification, which restricts the field as it increases. A second limiting factor is the depth of focus of the microscope. Since it is not possible optically to completely flatten the curvature of the cornea (without risking other major optical distortions) it is the depth of focus which decides on how much of the illuminated area is distinctly represented on the image. This limits the field in photography. In simple biomicroscopical observation, however, it is less important because slight adjustments of the focus will permit evaluation of the whole illuminated area.

Another interfering factor is the scattered light from the stroma which veils the endothelium underneath, as discussed above. When an orange filter is used few problems generally exist in the clear cornea of young individuals, and therefore large fields of specular illumination can be observed. With increasing haziness the useful area becomes narrower, the width now depending mainly on the angle between slit lamp and microscope. In these cases again, the simplicity of the contact glass facilitates the examination because scanning of large areas is still possible through slight displacements of the slit beam or changes in the direction of gaze of the patient. Orientation within the corneal area during these movements is maintained by switching to smaller magnifications, returning to higher magnifications once the new target of observation has been brought into the field.

(Note: The contact glass as described in the present paper is manufactured by Haag-Streit AG, CH-3097 Liebefeld/Bern, Hessstrasse 27, Switzerland.)

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