Clinical assessment of retinal elevations: a review of methods and a novel clinical technique*

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SUMMARY A new clinical test for the detection of retinal elevation is described. The test, based on alterations of retinal surface light reflexes during indirect ophthalmoscopy, is extremely sensitive to very shallow detachments. The optics, the degree of sensitivity, and the limitations of the new clinical technique are examined and other clinical methods are reviewed.

The assessment of retinal disease is largely based on ophthalmoscopic signs and on auxiliary tests of retinal function, such as tests of visual field, colour discrimination, or retinal electrophysiology, and of anatomical and functional relationships—for example, fluorescein angiography, ultrasonography, and computerised x-ray tomography. Whereas extremely shallow retinal elevation (beyond the resolution of binocular indirect ophthalmoscopy) can often be inferred from other clinical signs—for example, the presence of subretinal haemorrhage or turbid fluid—in some instances it is necessary to assess the degree of elevation by clear subretinal fluids. It is with respect to the latter group that this paper is particularly addressed.

Systematic review of the clinical techniques available for assessing retinal elevation

The direct ophthalmoscope was introduced in 1851 by von Helmholtz,¹ although the principles of the technique, as detailed by Purkinje,² predate the advent of this instrument by several years. Indirect ophthalmoscopy was described by Reute in 1852³ and a binocular instrument was soon to follow in 1861.⁴ Binocular indirect ophthalmoscopy did not, however, gain widespread use until the introduction of the head mounted ophthalmoscope by Schepens in 1947.⁵ Slit-lamp biomicroscopic examination of the fundus was possible (in all except eyes with extreme myopia) only after the introduction of the corneal contact lens, the high power concave lens (Hruby lens), or the high power biconvex lenses of good

optical quality (namely the +60 dioptre and, more recently, the +90 dioptre).

Irrespective of the method of examination used, the techniques of optical assessment of retinal elevations can be considered in two groups. The first group of methods assess the degree of separation of retinal features from the normally adjacent retinal pigment epithelium and choroid. The less used second group depend on alterations of surface contour that occur with elevations of the sensory retina.

METHODS DEPENDENT ON SEPARATION OF IMAGES

The central displacement of the retinal structures or associated lesions—for example, retinal haemorrhages or holes—with respect to the underlying choroid and retinal pigment epithelium provides an optically assessable measure of retinal elevation. There are several methods of examining this displacement:

Monocular methods. (1) Disparity of dioptric correction required to focus the retinal and the choroidal details during direct ophthalmoscopy; (2) variable and increasingly hypermetropic objective refraction (indirectly related to (1)); (3) parallactic movement of retinal features over the choroidal background pattern; (4) position of shadows, cast by retinal structures, on the underlying choroid; (5) examination of 'optical sections' created with the slit-lamp biomicroscope.

Binocular methods. (1) Stereoscopic binocular indirect ophthalmoscopy and its adaptation to slit-lamp biomicroscopy (with the +60 dioptre El Bayadi lens or the +90 dioptre condenser lens); (2) stereoscopic binocular slit-lamp biomicroscopy, with a contact lens or –56 dioptre Hruby lens to create

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upright virtual images; (3) stereoscopic pairs of fundus photographs.

In practice the direct ophthalmoscope has the advantage of permitting viewing of the fundus through a small pupil, but with the limitation of this being only a monocular view. The approximation of 3 dioptres of hypermetropia for every 1 mm of retinal elevation (2 dioptres in the aphakic eye) is well known to most ophthalmologists. With normal retinal apposition structures such as retinal vessels do not cast visible shadows on the underlying retinal pigment epithelium and choroid; to see such shadows implies an elevation of the retina. The presence of parallax movements of retinal features with respect to the choroidal pattern is demonstrable only when the patient's pupil is dilated; uninterrupted visualisation of the retina during the side-to-side movement of the ophthalmoscope (this movement generating the parallax) is not possible with an undilated pupil.

Parallax movement can readily be demonstrated with the binocular indirect ophthalmoscope. One method involves closure of alternate eyes of the observer (thereby mimicking monocular indirect ophthalmoscopy with an observer movement equivalent to the reduced interpupillary distance of the instrument) and the second method involves the side-to-side displacement of the observer and the condenser lens (with the option of monocular or binocular viewing). The presence and displacement of shadows cast by retinal structures is often appreciated with the indirect ophthalmoscope, both because of the strong illumination and also because of the offset between the axes of illumination and observation.

Although the slit-lamp biomicroscope is generally regarded as a binocular instrument, the oblique 'optical section' may be assessed monocularly; the viewing of an oblique optical section requires a well dilated pupil. Although mydriasis is needed for binocular indirect ophthalmoscopy, it is not necessary for the slit-lamp biomicroscope arrangement using a +90 dioptre condenser lens. In contrast, the virtual images created by the Hruby lens or contact lens during fundal examination at the slit-lamp biomicroscope can be examined stereoscopically only with good mydriasis. The fundus camera is based on the principle of indirect ophthalmoscopy and, for good quality stereo pairs or photographs, needs a well dilated pupil.

METHODS DEPENDENT ON ALTERED RETINAL SURFACE TOPOGRAPHY

Of the methods dependent on the separation of images (*vs*), only the examination of the optical section created on the slit-lamp biomicroscope draws

further information from the alteration of retinal surface topography. Thus, when examining an elevation of the retina there is a deviation from the normal parallel concavities (of the retina and the choroid) as created by the oblique optical section. Depending on the degree of detachment, the retinal contour may be planar (instead of concave) or even convex with respect to the incident slit-beam illumination.

FURTHER THEORETICAL METHODS FOR ASSESSING ALTERED RETINAL SURFACE TOPOGRAPHY

The examination techniques reviewed form a powerful armamentarium for the detection of retinal elevations. They fail, however, to utilise the full potential of the changes in surface contour that occur with retinal elevation.

Although more complex in practice, the retinal surface can be considered to be a concave mirror over most of its area, and very small degrees of retinal

Fig. 1 Posterior retinal topography and the origin of the principal surface light reflexes. Reflex 'A' from the concavity of the foveal pit, macular reflex 'B' from the convexity caused by the area of maximum retinal thickness and reflex 'C' from the concavity of the extramacular retina. The Weiss reflex, 'D', arises from the concavity nasal to the optic disc.

Fig. 2 Alterations of the position of the three major light reflexes from the retinal surface with across-the-axis displacements of the condenser lens during indirect ophthalmoscopy; the light reflexes are represented by shading. The line XY represents the horizontal meridian at the midpoint of the eye under examination.

detachment will produce a marked increase in the radius of curvature of this concavity. As the retinal elevation increases, so the shape changes from concave to planar and finally becomes convex. The normal retinal surface reflexes that occur during indirect ophthalmoscopy (both binocular and monocular) are predominantly those that occur at a concave mirror, retinal elevation disturbing these patterns and thereby becoming manifest on clinical examination.

The detection of aberrations from the correct concavity of a spherical or parabolic mirror is a well established technique in the construction of astronomical telescopes. The Foucault test⁶ used in the detection of these aberrations is not, however, applicable as a test of retinal concavity. In contrast, the *movements* of the light reflexes during indirect ophthalmoscopy, as detailed in this paper, provide a novel, quick, and sensitive technique for the detection of shallow elevations of the sensory retina.

Shifting retinal light reflexes—the new clinical technique

When the pupil is well dilated and the surface light reflexes are strong during indirect ophthalmoscopy, the technique may be modified by the movement of the condenser lens from side to side. This displacement (by only a few millimetres) of the condenser lens from the optical axis causes a marked alteration of the fundal surface light reflexes.

In the normal fundus, especially in young subjects,

the light reflexes will be seen to comprise three distinct reflexes, with additional reflexes in certain cases (Fig. 1). The most peripheral conforms to a section of an annular reflex, often extending out to beyond the major temporal vascular arcades; this

Fig. 3 (a) Optics of the illumination of the retina under examination during indirect ophthalmoscopy and (b) during displacement of the condenser lens across the original axis, XY, of the system; the new optical axis is represented by the broken line. Only the limiting rays are illustrated (not to scale). The optical system forms a real image of the source of illumination, this image lying approximately at the iris plane of the eye under examination.

section moves in the direction of displacement of the condenser lens ('with' movement—Fig. 2). The middle reflex is ring shaped and arises at the fringe of the macula where the retina reaches a maximum thickness and is convex towards the vitreous cavity.⁷ In contrast to the extramacular reflex, however, this macular reflex displays an 'against' movement with respect to the condenser lens. The foveal pit frequently generates a third reflex, this demonstrating a small 'with' movement during shift of the condenser lens. The direction of movement of these reflexes is determined by the concavity or the convexity of the reflecting surface (*vi*).

Alterations of the curvature with pathological retinal elevations cause either a shift of the retinal light reflexes (manifest as a readily evident 'jump' of the reflexes) or a reversal of the direction of movement at the site of the detachment (manifest as a contrasting counter movement of light reflexes with respect to those of the surrounding area). By moving the condenser lens sequentially in two or more meridians, the extent of the abnormal area of elevation can readily be defined.

Discussion

RETINAL SURFACE LIGHT REFLEXES

The glistening light reflexes arise through reflection at the interface between the vitreous, with its lower refractive index, and the internal limiting membrane of the retina.⁸ The surface reflexes are best seen at illuminating wavelengths of less than 540 nm (that is, red-free light) and become progressively more difficult to see with monochromatic light of longer wavelengths. Above 600 nm the reflexes are, for practical purposes, invisible.⁹ The reflexes are generally of greater intensity in the fundi of young or hypermetropic persons and in darkly pigmented fundi, whereas detachment of the posterior vitreous face generally reduces them.

Previous writers have concentrated on detailed descriptions of the morphology of the surface light reflexes, based often on painstaking and meticulous clinical observations; while frequently describing the reflexes as being 'highly mobile and elusive',¹⁰ possessing 'constant movement',⁸ or (erroneously) as 'shifting irregularly',¹¹ the observers would appear to have failed to record the value of the motions of these shifting reflexes. Thus, a fine 'granularity' of the extramacular reflex, called Gunn's dots,¹² has been attributed to the processes of Mueller's cells abutting on the internal limiting membrane, and the Weiss light reflex,¹³ parallel to the nasal border of the optic disc, has been ascribed to the convexity of the neural fibres as they turn posteriorly to enter the optic disc. In addition the normal fundal light reflexes some-

Fig. 4 Formation of the secondary image of the light source image (S) by the limiting rays AA' and BB' after specular reflection at the retinal surface of the eye under examination (not to scale). Cross-hatching represents the illuminating pencils of rays. The secondary image, represented by the unmarked dot, forms a real image in areas of concavity (a) and a virtual image in areas of convexity (b). During indirect ophthalmoscopy the secondary image in both cases will be perceived as an area of maximum retinal light reflex (M) on the retinal image (AMB).

times show striations along the direction of the retinal nerve fibre layer.

THE OPTICS OF SHIFTING RETINAL LIGHT REFLEXES

The condensing lens during indirect ophthalmoscopy produces an image of the light source positioned approximately at the iris plane of the eye under examination (Fig. 3a). Displacement of the lens across the optical axis of the system is accompanied by a relatively greater lateral displacement of this image in the direction of lens movement (Fig. 3b).

This image of the light source at the pupillary plane of the eye under examination may be regarded as a point source of light illuminating the retina. The

Fig. 5 The loci of the secondary image (small dots) during movement of the light source image (large dots) across the pupil of the eye undergoing indirect ophthalmoscopy. The curved surfaces represent the retina (not to scale). The locus in (a) represents that of the major light reflexes from the concave surfaces of the normal eye. In (b), a shallowing of the concavity is associated with an image 'jump' at the edges of the lesion. There is a reversal of image movement once the elevation becomes planar (c) or when it is convex (d). In addition, there is a transient reduplication of the secondary images in these two phases (see text).

specular reflections (arising from the mirror-like properties of the retinal surface) will produce a zone of bright reflex on the retina (AMB in Figs. 4a and 4b), this reflex being greatest where the incident ray and its reflected ray coincide (points M in Fig. 4). As illustrated in Fig. 4a, the concave surface produces reflex highlights on the side of the retina *opposite* to that of the displacement of the light source (or lens). In contrast, the convex surface will have highlights on the same half of the retinal surface as that of the lens displacement (Fig. 4b).

As the lens is moved across, so the light source image traverses the pupil and so the highlight moves across the *retina* 'against' the lens movement with a concave surface (Fig. 5a) and 'with' the lens movement for a convex surface (Fig. 5d). After allowance for the inversion of the retinal image (and hence the light reflexes) as formed by the condensing lens, the net result is a 'with' movement of the reflexes (in relation to the condenser lens) for a concave surface and an 'against' movement for a convex surface.

SENSITIVITY OF THE NEW CLINICAL TEST

If an assumption is made of uniform concavity for the

retinal surface, it is possible to describe a locus, during the movement of the condenser lens, of the point of maximal light intensity after reflection at the retinal surface. In clinical practice this image of the illumination forms a highlight on the retinal image. The apparent brightness of the light reflex is dependent on the proximity of the image of the light source and the retinal surface.

A uniform concavity would be associated with a linear movement at the image plane (Fig. 5a). Small degrees of retinal elevation, reducing the concavity, cause an image 'jump' at the edges of the lesion (Fig. 5b); this 'jump', to an image plane remote from the retina, is associated with a reduced intensity of the reflexes in the area of elevation. When the concavity is raised to a planar configuration (Fig. 5c), the locus can become more complex, having a mixture of both a 'with' and an 'against' movement. The former image results from the concave portion of retina and the latter from the planar (elevated) portion. The image formed by the planar surface is, because of its relative remoteness from the retina, of lower intensity than that from the concave (normal) retina. Indeed the author considers it probable that this

Table 1 The central retinal elevation (μm) required to produce a 1° , a 5° , or a 10° 'jump' of the retinal surface light reflex at the edge of various diameters of retinal lesion. The derivation of these values is detailed in the appendix, as are the assumptions made during the calculations

Diameter of lesion (mm)	Elevation (μm) to cause an image jump of		
	1°	5°	10°
0.5	0.8	1.0	1.1
1.0	2.7	3.9	4.2
1.5	5.0	8.4	9.1
2.0	7.6	14.1	15.8
3.0	13.4	28.8	33.7
4.0	19.6	47.1	57.3

Table 2 The central retinal elevation (μm) required to cause convexity of various diameters of retinal lesion in an eye of average dimensions

Diameter of lesion (mm)	Minimum central elevation for convexity (μm)
0.5	2.6
1.0	10.4
1.5	23.5
2.0	41.7
3.0	94.1
4.0	167.8

reduced intensity of the light reflexes over areas of shallow retinal elevation contributes to the typical 'lustreless', reflex-free, clinical appearance of macular oedema. Convexity (Fig. 5d) is associated with a marked image 'jump' and also a reversal of image movement.

The new test proves to be extremely sensitive to small elevations of the retina (Appendix). A 1° 'jump' subtended at the observer pupil in the pupillary plane represents approximately 0.37 mm of movement at the retinal plane in an eye of average dimensions. Such an image 'jump', of 1° , occurs with extremely small elevations of the retina—for example, with less than $1 \mu\text{m}$ at the centre of a lesion 0.5 mm diameter and with $20 \mu\text{m}$ for a lesion 4 mm across (Table 1). Similarly, elevation to convexity (with concomitant reversal of the light reflex movements) occurs, again, with shallow subretinal fluid—namely, with greater than $2.6 \mu\text{m}$ central depth for a 0.5 mm lesion and approximately 0.17 mm for a lesion of 4 mm diameter (Table 2).

Appendix

The magnitude of 'jump' as the principal ray crosses the edge of an area of retinal elevation can be calculated. The case of the least degree of elevation is considered here, in which the elevation is very shallow and the raised area still concave. In practice, an elevation of such shape is infrequent, but such a calculation provides a useful guide as to the sensitivity of the new clinical test.

During indirect ophthalmoscopy the optics are equivalent to the entrance pupil of the observer lying at the iris plane of the patient. In addition the centre of the observer entrance pupil bears a very close and almost constant relationship to the light source image at this plane, even with lateral displacement of the condenser lens. Because of this constant relationship between the light source image (S in Fig. 7) and the optics of the observation system, the image 'jump' is defined in this work as the angle subtended at the source image in the iris plane (angle β in Fig. 7).

Fig. 6 Geometry associated with a central elevation, e of the retina, from its original radius of curvature, r , to a new concavity with radius r' (and centres of curvature C and C' respectively). The geometry is discussed in the Appendix.

With reference to Fig. 6:

In right-angled triangle CEG,

$$r^2 = (d/2)^2 + CG^2$$

$$\text{or, } CG = \sqrt{r^2 - d^2/4}.$$

$$\text{But, } p = r - CG$$

$$\text{or, } p = r - \sqrt{r^2 - d^2/4}.$$

$$\text{Also, } \theta = \arcsin(d/2r) \dots \dots \dots \text{Eq. 1}$$

In right-angled triangle EFG,

$$\alpha = \arctan(d/2s)$$

$$\text{or, } \alpha = \arctan[d/(2(p-e))] \dots \dots \dots \text{Eq. 2}$$

In isosceles triangle $C'EF$,

$$\delta = 180 - 2\alpha \dots \dots \dots \text{Eq. 3}$$

In right-angled triangle $C'EG$,

$$\sin \delta = d/2r'$$

$$\text{or, } r' = d/(2 \sin \delta) \dots \dots \dots \text{Eq. 4}$$

Fig. 7 Geometry associated with the calculation of the angular image 'jump', β , occurring at the edge of an area of concave retinal elevation. Point S represents the light source image at the pupillary plane, I the secondary image formed by specular reflection on the normal concavity of the retina, and V the secondary image formed by the elevated retina. Further detail is given in the Appendix.

With reference to Fig. 7:

By the rule of image formation in mirrors,

$$1/(v-e) = 2/r' - 1/(u-e)$$

$$\text{or, } v = [ur' + 2e(u-r')]/[2(u-e) - r'] \quad \text{Eq.5}$$

where 'e' is the central retinal elevation (Fig. 6).

In right-angled triangle C'I'X,

$$\tan \delta = h/(r' + e - v)$$

$$\text{or, } h = (r' + e - v) \tan \delta \quad \text{Eq.6}$$

In right-angled triangle CSY,

$$\tan \theta = a/(u-r)$$

$$\text{or, } a = (u-r) \tan \theta \quad \text{Eq.7}$$

In right-angled triangle SI'Z,

$$\tan \phi = (u-v)/(h+a)$$

$$\text{or, } \phi = \arctan[(u-v)/(h+a)] \quad \text{Eq.8}$$

Finally, in triangle CWS,

$$\angle I'WC = \beta + \theta$$

$$\text{or, } \beta = \angle I'WC - \theta$$

But, $\angle I'WC = 90 - \phi$ (Because $\angle I'WC = \angle I'WX$)

$$\text{Thus, } \beta = 90 - \phi - \theta \quad \text{Eq.9}$$

On the assumption that the typical eye has a radius (r) of 12 mm and that the pupillary plane lies approximately 3 mm central to the anterior pole of the eye (making 'u' approximately 21 mm), then the image 'jump', β , can be calculated in terms of two other factors—the diameter of the retinal elevation (d) and the degree of central elevation (e). The angular image 'jump', β , given by equation 9 is derived by sequentially solving equations 1 to 8.

References

- Helmholtz H von. Beschreibung eines Augen-Spiegels zur Untersuchung der Netzhaut im Lebenden Auge. Berlin: Forstner, 1851. Translation in *Arch Ophthalmol* 1951; **46**: 565-83.
- Albert DM, Miller WH. Jan Purkinje and the ophthalmoscope. *Am J Ophthalmol* 1973; **76**: 494-9.
- Reute CGT. Der Augenspiegel und das Optometer für praktische Aertze. Göttingen, Prussia: Dieterich, 1852.
- Giraud-Teulon MALF. Ophthalmoscopic binoculaire ou s'exerçant par le concours des yeux associés. *Ann Oculist (Paris)* 1861; **45**: 233-50.
- Schepens CL. A new ophthalmoscope demonstration. *Ophthalmology* 1947; **51**: 298-301.
- Howard NE. *Handbook for telescope making*. 2nd ed. London: Faber and Faber, 1975.
- Sigelman J, Ozanics V. Retina. In: Duane TD, Jaeger EA, eds. *Biomedical foundations of ophthalmology*. Philadelphia: Harper and Row 1982; **1**: Ch 19: 5.
- Goodside V. The anterior limiting membrane and the retinal light reflexes. *Am J Ophthalmol* 1956; **41**: 288-92.
- Delori FC, Gragoudas ES, Francisco R, Pruett RC. Monochromatic ophthalmoscopy and fundus photography. The normal fundus. *Arch Ophthalmol* 1977; **95**: 861-8.
- Ballantyne AJ, Michaelson IC. *Textbook of the fundus of the eye*. 2nd ed. Edinburgh and London: Churchill Livingstone, 1973: 61.
- Sautter H, Straub W, Turss R, Rossmann H. Translated by Blodi FC. *Atlas of the ocular fundus*. Baltimore and Munich: Urban and Schwarzenberg, 1984: 7.
- Gunn RM. Peculiar appearance in the retina in the vicinity of the optic disc occurring in several members of the same family. *Trans Ophthalmol Soc UK* 1883; **3**: 110-3.
- Weiss L. Ueber den an der Innenseite der Papille sichtbaren Reflex bogenstreif und seine Beziehung zur beginnenden Kurzsichtigkeit. *Graefes Arch Clin Exp Ophthalmol* 1885; **31** (III): 239-319.

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