

Corneal Topography

Corneoscope

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• We present an introduction to a clinical quantitative corneoscope for measurement of corneal topography in detail. This instrument provides contour keratometry in all corneal meridians. We review the normal myopic and hyperopic eye contours, keratoconus, pellucid marginal degeneration, and wound gape and compression related to cataract surgery. We present a modified Placido disk for office use that incorporates the unique incident light image of the corneoscope for rapid review of irregular corneal contours. Corneal topography irregularities frequently contribute to devastating refractive states of the eye and should be examined carefully when keratorefractive surgery is considered.

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Topographic analysis of the normal and diseased cornea has become increasingly important with the development of keratorefractive surgical techniques. The clinical keratometer measures essentially the central 3 mm of the corneal surface area. However, analysis beyond the keratometer benefits the clinician. We have observed that a quantitative analysis of the peripheral cornea is necessary to

assess various proposed techniques of altering corneal dioptric power. In addition, early or progressive keratoconus in a patient who has worn contact lenses may be distinguished from lens-induced irregular corneal curvature when the peripheral cornea is examined. Difficult contact lens fittings are facilitated by an appreciation of peripheral corneal base curves.

We present herein the topographic corneoscope analysis of keratoconus and its progression in 827 patients observed by one of us (A.E.R.) for an average of eight years. Included for comparison is a topographic analysis of 200 emmetropic eyes, 100 hyperopic eyes, 100 myopic eyes, 50 eyes with "with-the-rule" astigmatism, and 50 eyes with "against-the-rule" astigmatism. To familiarize the clinician with the value of total corneal analysis in keratorefractive surgery, we also discuss the corneal topography after cataract extraction, wound gape, and wound compression phenomena.

MATERIALS AND METHODS

All normal eyes were evaluated using Bitanti's corneopter and the corneoscope.¹ The normal eyes had less than 0.5 diopter of hyperopia, no myopic correction, and less than 0.25 D of cylinder. The hyperopic and myopic eyes were defined as having more than 0.5 D of correction. Eyes having with-the-rule astigmatism or against-the-rule astigmatism exhibited more than 0.5 D of cylinder within 15° of 90° and 180°, respectively. Keratoconus was diagnosed by a combination of criteria, includ-

ing a cone on retinoscopy or over a red fundus reflex, apical corneal thinning, central corneal subepithelial fibrosis and scarring, Fleischer's ring, Descemet's striae, and Munson's sign.

The corneoscope (Fig 1) produces a color or black-and-white Polaroid photograph at 4.8X magnification (Fig 2A). Dioptric power (Fig 2B) is read from the photograph by using a comparator, which magnifies the picture 4.1× to 6.3× to match it to a standard set of rings on the comparator screen. The amount of magnification required to match photographed rings to the corresponding standard comparator rings determines the radius of curvature of the cornea at that point.

The corneoscope photograph is similar to a conventional contour map. The steeper the cornea, the closer together are the rings; the flatter the cornea, the farther apart the rings. Subtle variations between the normal cornea, pseudocone, true keratoconus, and suture-induced astigmatism can be recognized and delineated easily.

A corneoscope picture of a perfect sphere has concentric and equally spaced rings. In this respect the picture differs from a contour map, because the increments of elevation (sagittal depth) are not constant. The area of the cornea that can be examined is inversely related to the corneal power. A 40-D cornea at the ninth ring has a cord length of 8.3 mm, for example, whereas a 50-D cornea at the ninth ring has a cord length of 6.7 mm.

RESULTS

Corneopter measurements made of the 200 eyes from the corneal apex to the limbus demonstrated a sagittal depth for the cornea of from 1.8 to 2.6 mm, with a mean of 2.5 mm. Diameters measured from limbus to limbus

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Figure 1.

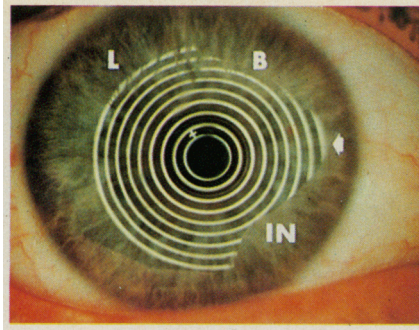


Figure 2A.

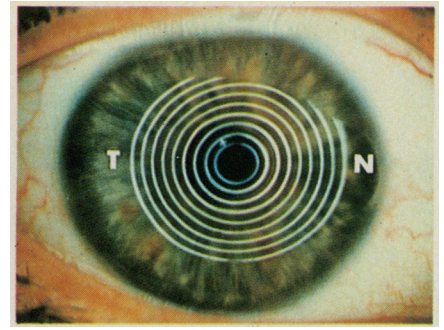


Figure 3A.



Figure 4A.

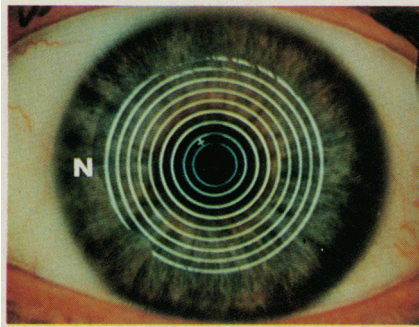


Figure 5A.

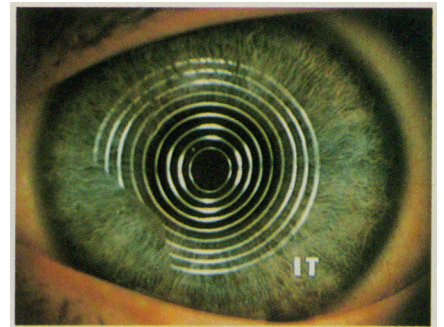


Figure 6A.

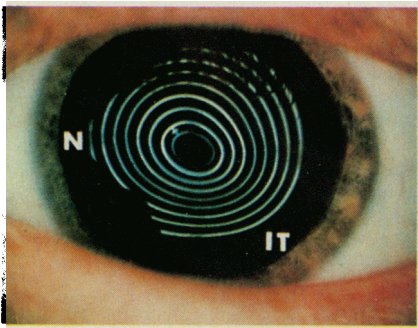


Figure 7A.

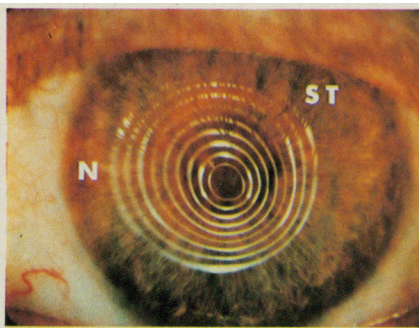


Figure 8A.

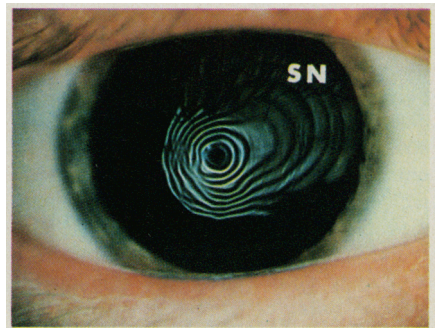


Figure 9A.

Fig 1.—Patient sits in front of corneoscope, which projects lighted Placido disk-like target onto cornea. Observer focuses on mires at high magnification and takes Polaroid photograph of patient's eye. **Fig 2A.**—Right eye of patient with visual acuity of 20/15 uncorrected. Visual axis is slightly nasal to optical axis (angle kappa), and one appreciates more of corneal topography nasally than temporally. Flattening of cornea nasally near limbus may be discerned from larger ring spacing at 3-o'clock position (arrow). Shadows from lashes (L) and brow (B) superiorly, and from nose inferonasally (IN). Plus sign at patient's upper right is used for precise focusing near corneal apex. **Fig 3A.**—With-the-rule astigmatism in eye with 2.50 diopters of cylinder at 90°. Greater refractive power in vertical meridian produces shorter chord lengths for rings vertically than horizontally and gives oval ring pattern. More of cornea is delineated nasally (N) than temporally (T). **Fig 4A.**—Against-the-rule astigmatism in eye with 2.50 D of cylinder at 180°. Ring pattern is oval, as in Fig 3A, but short axis associated with plus power here is horizontal. N indicates nasal. **Fig 5A.**—Simple myopia, -4.25 D, OS. (Note nose shadow.) N indicates nasal. **Fig 6A.**—Corneoscope picture of patient with early keratoconus shows characteristically egg-shaped central ring. Steepening appears first in inferotemporal quadrant (IT). **Fig 7A.**—Progressing keratoconus in another patient. Pear or egg shape of central rings is now easily appreciated on inspection pointing to inferotemporal quadrant (IT). Nasal cornea (N) is now involved. **Fig 8A.**—More advanced keratoconus. Cone progression moves into superotemporal ring (ST). N indicates nasal. **Fig 9A.**—Severe keratoconus. Superior nasal (SN) cornea is only quadrant not involved at this stage.

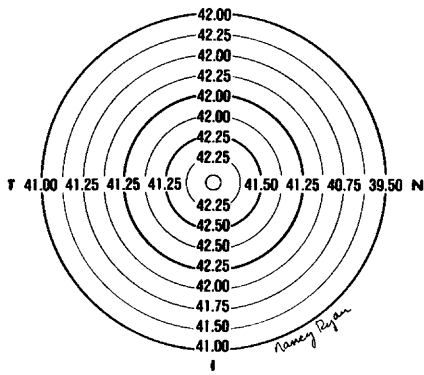


Figure 2B.

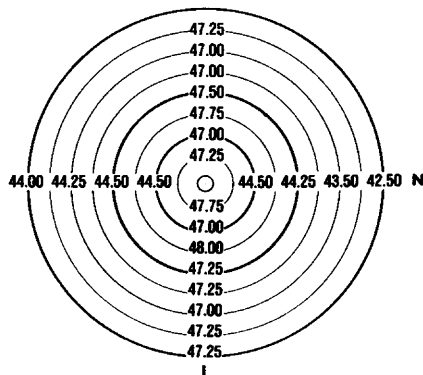


Figure 3B.

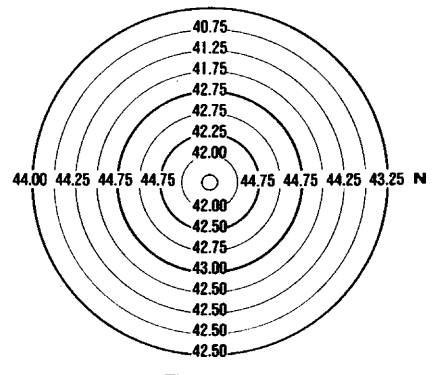


Figure 4B.

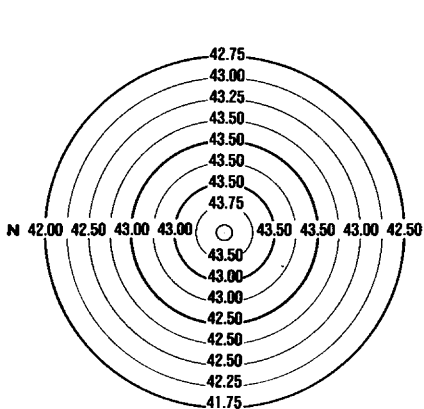


Figure 5B.

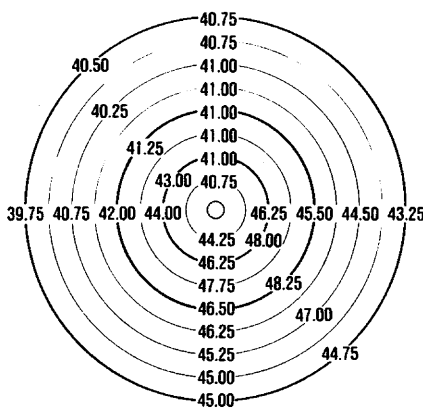


Figure 6B.

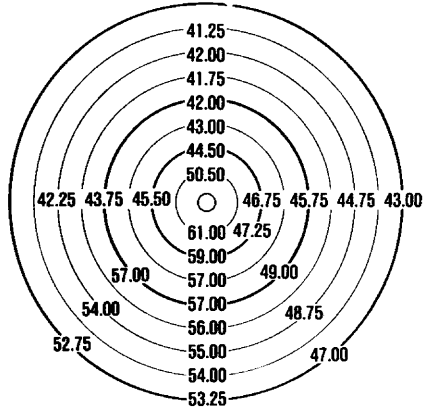


Figure 7B.

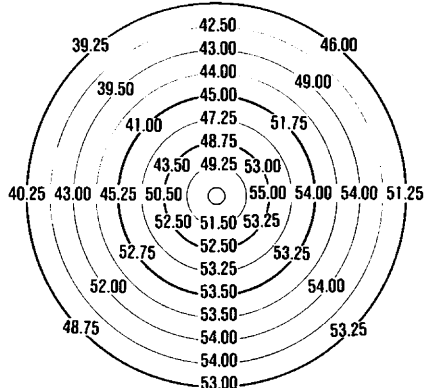


Figure 8B.

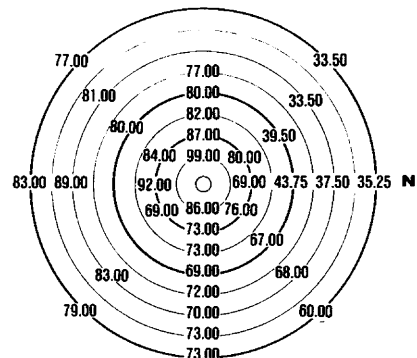


Figure 9B.

Fig 2B.—Comparator measurements for eye seen in Fig 2A, with ring power given in diopters. Despite 20/15 vision, eye is not emmetropic. Corneal power decreases nasally (N) as limbus is approached but remains nearly constant temporally (T) within measured area. Third corneascope ring corresponds to region measured by clinical keratometer. **Fig 3B.**—Comparator measurements for eye seen in Fig 3A. At third ring, 47 D of corneal power are measured vertically and 44.50 D horizontally, producing 2.50 D of plus power at 90°. There is greater disparity, fully 4.75 D, of refractive power between peripheral cornea nasally (N) and inferiorly (I). **Fig 4B.**—In eye seen in Fig 4A, comparator measurements at third ring indicate 2.50 D of cylinder at 180°. Cornea steepens superiorly to 42.75 D before flattening in periphery to 40.75 D, and steepens inferiorly to 43.00 D before flattening in periphery to 42.50 D. N indicates nasal. **Fig 5B.**—Comparator readings from eye in Fig 5A show central corneal power of 43.50 D. There is gradual flattening of cornea peripherally in all four

quadrants. N indicates nasal. **Fig 6B.**—Inferotemporal cornea steepens from 45.00 D at second ring to 48.25 D at fifth ring before flattening to 44.75 D at ninth ring. Cornea also steepens inferiorly before flattening toward periphery, but more normal pattern of gradual peripheral flattening is evident nasally, temporally, and superiorly. Cornea is flattest and least affected superiorly and nasally. **Fig 7B.**—Steepening is most pronounced inferiorly and extends nasally as well as temporally. Note inferior cornea is on average 13 D steeper than superior cornea. **Fig 8B.**—Comparator reading of patient in Fig 8A. Steepening is greatest in inferotemporal quadrant but now extends from inferior nasal to superotemporal regions, as measurements show. **Fig 9B.**—Comparator reading of patient in Fig 9A. Steepening centrally is not circumferential. Nasally (N) and superonasally, cornea remains relatively unaffected, or perhaps even flatter than normal in periphery. Extremely high dioptric powers (greater than 90) that may result from keratoconus are manifest.

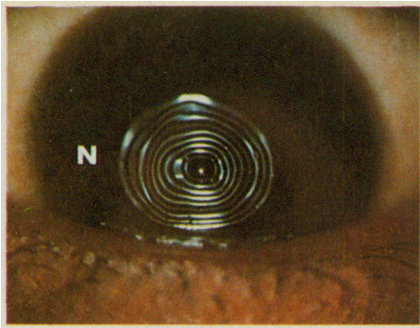


Figure 10A.

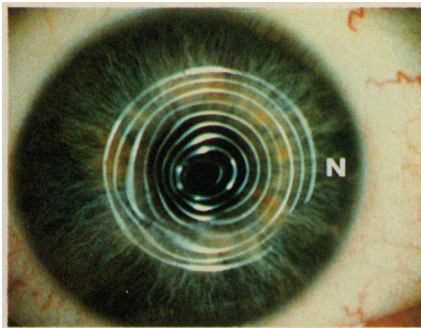


Figure 11A.

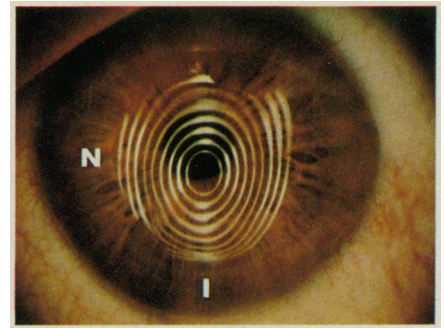


Figure 12A.

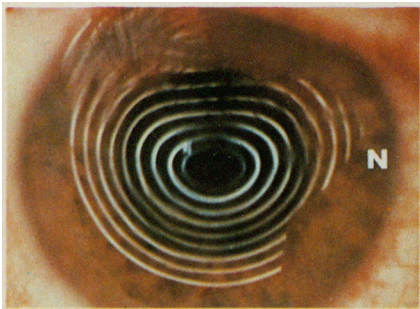


Figure 13A.

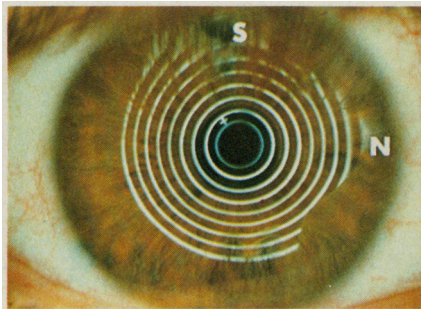


Figure 14A.

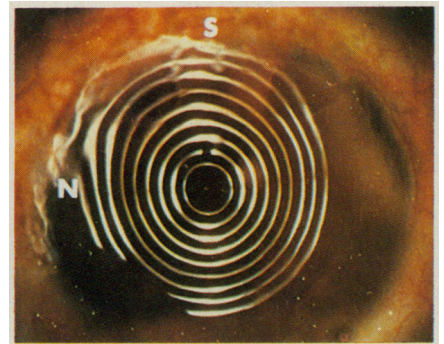


Figure 15A.

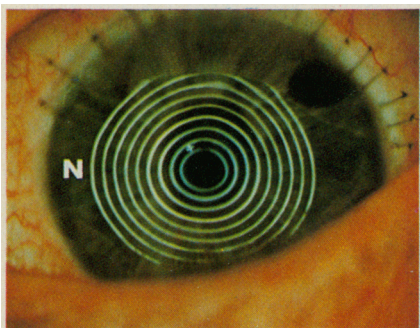


Figure 16A.

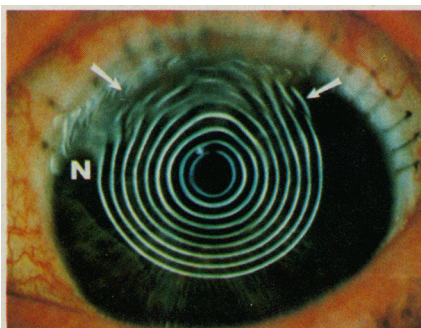


Figure 17A.



Figure 18.



Figure 19.

Fig 10A.—Final-stage keratoconus with 360° cone. If no apical scarring occurs, this patient may more readily be fit with contact lenses than in earlier stage. N indicates nasal. **Fig 11A.**—Midperipheral irregular corneal topography from contact lens-induced astigmatism. Sharp asymmetry of midperipheral rings is typical of poorly fit contact lens. This keratometer picture is not observed in any patient with keratoconus at any stage of progression. N indicates nasal. **Fig 12A.**—Pellucid marginal degeneration produces typical topographic appearance. Vertical axis of cornea is flatter than horizontal axis for first six rings of keratometer. N indicates nasal. Seventh, eighth, and ninth rings inferiorly (I), however, show by their close proximity a precipitous corneal drop-off. **Fig 13A.**—Single polyglactin (Vicryl) suture following phacoemulsification sharply indents cornea at 12-o'clock position, steepening vertical meridian and correspondingly flattening horizontal meridian. N indicates nasal. **Fig 14A.**—Four weeks postoperatively, superior cornea (S) flattens considerably as polyglactin (Vicryl) suture of patient shown in Fig 13A is absorbed. Release of single interrupted suture allows inferior cornea to flatten to 41.00 diopters. N indicates nasal. **Fig 15A.**—Superior (S) corneal dehiscence following cataract surgery. Notable asymmetry of this cornea, which is only flatter superiorly, precludes adequate contact lens fitting. N indicates nasal. **Fig 16A.**—Suture-induced corneal astigmatism in patient after cataract extraction. N indicates nasal. **Fig 17A.**—Patient from Fig 16 on downward gaze after removal of tight sutures at 12-o'clock position. Superior cornea has been flattened considerably, but inferior cornea has received little relief because tight sutures remain at 10- and 2-o'clock positions (arrows). N indicates nasal. **Fig 18.**—Placido disk currently available. "A condition which must be fulfilled while observing with any keratoscope is that the centre of the disc should be exactly on the common line of sight of the observer and the subject, and also that the plane of the disc, or the surface on which the zones are drawn, should be exactly perpendicular to this line."^{16, p 332} **Fig 19.**—Ophthalmologist using revised Placido disk. Reading light facing ophthalmologist is reflected from surface of disk onto patient's eye; this reflection is observed through central 20.00-D lens.

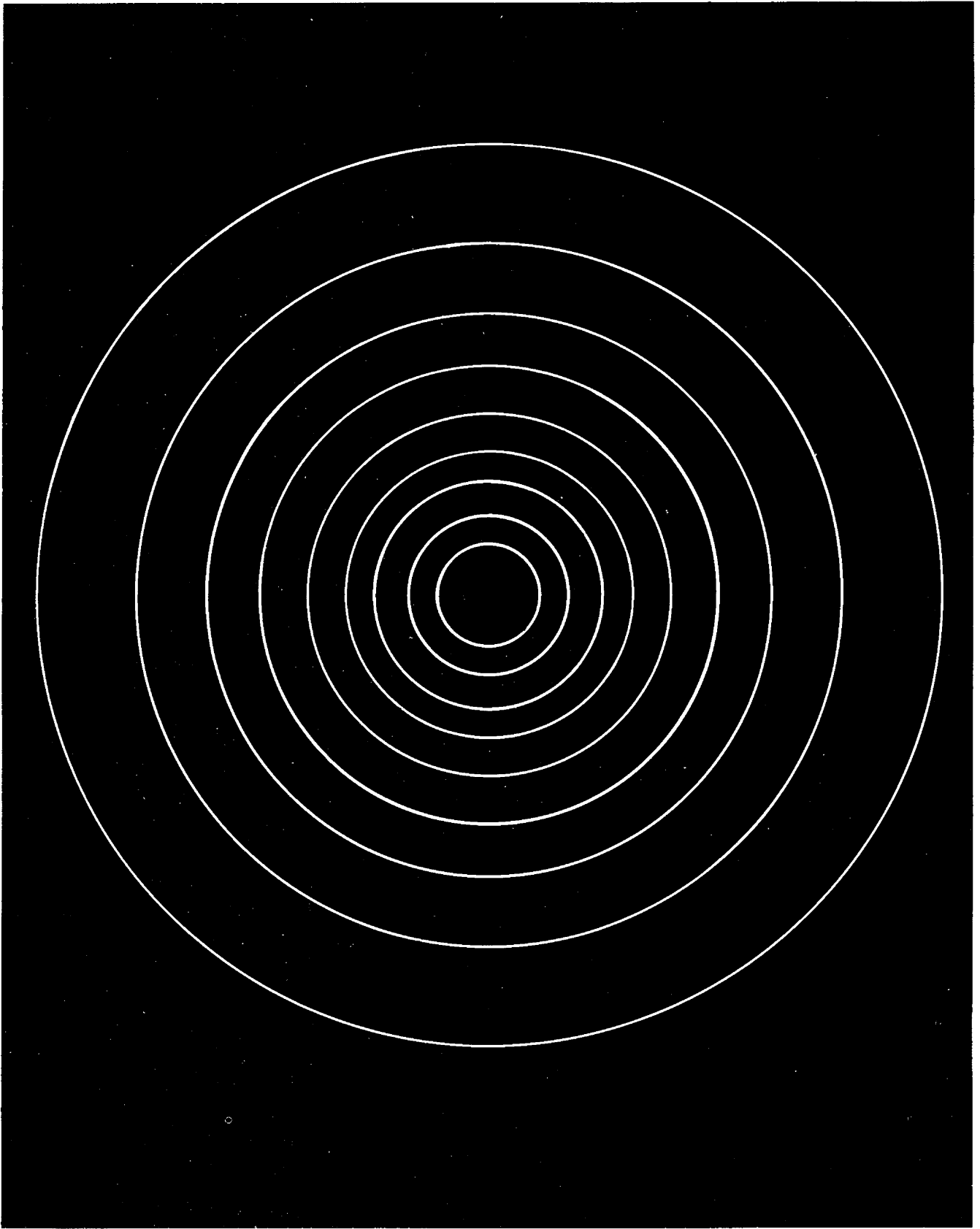


Fig 20.—Modified Placido disk using curvature of incident light from corneoscope onto flat plane. Increasing ring diameter allows for symmetrical ring appearance in normal peripheral cornea. Minute central and peripheral topographic alterations may be examined qualitatively with new disk design.

in the horizontal meridian varied from 11.6 to 12.4 mm, with a mean of 11.9 mm. Diameters in the vertical meridian varied from 11.2 to 12.0 mm, with a mean of 11.7 mm. Keratometry readings varied from 40 to 44 D, with a mean of 42.5 D.

The 100 hyperopic eyes had a sagittal depth of from 1.8 to 2.6 mm, with a mean of 2.4 mm. The mean corneal horizontal diameter was 11.9 mm, and the mean vertical diameter, 11.7 mm. Keratometry readings varied from 39.50 to 44.50 D, with a mean of 43.00 D.

The 50 eyes having with-the-rule astigmatism had a sagittal depth of from 1.8 to 2.6 mm, with a mean of 2.4 mm. With-the-rule astigmatism is easily recognized from the corneoscope photograph (Fig 3A and 3B) by the oval ring pattern with the longer axis horizontal.

The 50 eyes with against-the-rule astigmatism exhibited a sagittal depth of from 1.8 mm to 2.5 mm, with a mean of 2.4 mm. Against-the-rule astigmatism (Fig 4A and 4B) presents an oval ring pattern in which the longer axis is vertical.

The 100 myopic eyes had a sagittal depth of from 2.2 to 2.7 mm, with a mean of 2.5 mm. The mean corneal horizontal diameter was 11.9 mm, the mean vertical diameter, 11.7 mm (Fig 5A and 5B).

Sagittal depth was measured in 127 of the patients with keratoconus. Three of these had sagittal depths of 2.8, 2.9, and 3.1 mm, respectively. For the rest, sagittal depth ranged from 2.1 to 2.7 mm, with a mean of 2.5 mm.

The corneoscope was able to delineate the earliest stages of keratoconus. The first topographical sign is a steepening on the inferotemporal side of the cornea, which produces a characteristic distortion of the central cornea (Fig 6A and 6B). As keratoconus progresses, this inferotemporal steepening advances to the periphery and spreads to the inferior nasal quadrant (Fig 7A and 7B), then to the superotemporal quadrant (Fig 8A and 8B). The superior nasal quadrant, which is the last and least affected, is first involved centrally (Fig 9A and 9B). Contact lens fitting by this stage has become very difficult due to four-quadrant irregular corneal astigmatism that cannot be matched with any combination of contact lens base curves. The mature cone (Figs 10A and 10B) is steep circumferentially, inducing a high myopia.

If the entire cornea is uniformly steep, contact lens fitting becomes

easier. When apical corneal scarring occurs, however, surface irregularities and subepithelial fibrosis preclude good vision with any contact lens. A more regular recipient edge is available for suturing a transplant, however, and may be associated with less graft astigmatism.

An attempt has been made to correlate the posterior corneal lines of Vogt, which are known to be stretch lines in Descemet's membrane with a point of steepening on the corneoscope. These stress lines are not scars at the level of Descemet's membrane, for they characteristically disappear with minimal elevation of intraocular pressure by massaging the globe while observing the stretch lines under slitlamp magnification. The stress lines appear to radiate along the axis of the area of greatest steepening of the cornea.

The most common causes of pseudocones are (1) contact lens-induced irregular astigmatism, (2) pellucid marginal degeneration, (3) and corneal or limbal trauma. These may be easily separated from true keratoconus by the configuration of the corneal topography. An improperly fit contact lens frequently rides high on the cornea. With blinking, the lower edge of this lens strikes the inferior intermediate area of the cornea, steepening this portion (Fig 11A and 11B). The central corneal ring is not pear shaped in this entity as in keratoconus; the central portion of the cornea is not pulled inferotemporally. The corneal rings of contact lens-induced astigmatism are irregularly steepened in various meridians inferiorly. The symmetry of the corneas thereby is lost inferiorly, and the gentle steepening typical of keratoconus is not observed. In severe contact lens irregular astigmatism on top of keratoconus, the corneoscope picture demonstrates irregularly irregular rings inferiorly, but the central ring demonstrates the pear shape of underlying keratoconus.

These irregular peripheral curves may be easily distinguished from pellucid marginal degeneration (Fig 12A and 12B) by the precipitous change in the peripheral corneal curvature within 2 mm of the limbus. We note that in pellucid marginal degeneration the pear-shaped appearance of the central corneal ring is not present and, therefore, keratoconus would not be confused on a topographic basis with this entity.

The cataract incision may be tied too tightly at the time of surgery, producing with-the-rule astigmatism,

or too loosely, producing wound gape and against-the-rule astigmatism. The corneoscope easily differentiates the localization of the suture defect in these two entities (Fig 13A and 13B and 14A and 14B) and eliminates the confusion produced by the keratometer, which measures only the central 3 mm of the cornea. Careful, repeated analysis of the limbal architecture's contribution to the central corneal astigmatism may be performed by the corneoscope.

In Fig 13A and 13B, a single polyglactin (Vicryl) suture has been used to close a phakoemulsification site at the limbus. The suture creates corneal asymmetry by limbal invagination. The normal relaxation of this suture during absorption is followed by a release of the corneal compression. Consequently, corneolimbus wound gaping is seen (Fig 14A and 14B).

Wound gape or dehiscence after cataract surgery causes flattening of the superior cornea and against-the-rule astigmatism (Fig 15A and 15B). This flattening is associated clinically with movement of a contact lens inferiorly. In severe instances the patient cannot receive adequate correction with glasses because of high corneal astigmatism and cannot wear a contact lens because of lens movement inferiorly. With the corneoscope, the dehiscence may be localized easily and the exact area of keratorefractive surgical repair determined.

Although physicians are well aware of the difficulty with tight sutures at the 12-o'clock position, simple removal of these sutures at the 12-o'clock position may not be associated with relief of the induced corneal astigmatism; in fact, the plus power at 90° may increase, both by keratometry measurements and refractively. In Fig 16A and 16B, after cataract surgery, a cornea with interrupted sutures is steeper in the vertical meridian, especially inferiorly, than in the horizontal.

Removal of sutures at the 11:30-, 12-, and 12:30-o'clock positions (Fig 17A and 17B) causes flattening superiorly. Inferiorly, the effect of traction from sutures at the 10- and 12-o'clock positions is persistent, slightly improved, steepness. Removal of all sutures from the 9- to 3-o'clock positions superiorly is indicated, therefore, to remove this astigmatic pattern.

COMMENT

The regular keratometer may be used as a topographic keratometer as the patient changes fixation pattern.²

The main advantage of the topogometer is a precise evaluation of the apical zone size.² The Placido disk allows the physician a greater appreciation of the peripheral corneal topography qualitatively, but has been a difficult instrument to convert to quantitative evaluation.

The Placido disk (Fig 18) was first invented by Henry Goode³ in 1847 and further developed by Antonio Placido.^{4,5} A valuable office instrument that is frequently overlooked as unsophisticated, it can be employed postoperatively to estimate corneal astigmatism and preoperatively to diagnose irregularly irregular, ie, contact lens-induced, astigmatism.

The photokeratoscope, invented by Antonio Placido,⁶ was subsequently popularized by Dr Gullstrand,⁶ who is universally incorrectly credited with the actual invention. The advantages of a photokeratoscope such as the corneoscope in determining astigmatic errors are numerous and significant: (1) it provides hard copy data that may be reexamined by several investigators; (2) it allows examination of the

apical cap of the cornea inside the normal keratometric 3-mm reflected ring; (3) it allows examination of the midperipheral cornea, wherein early astigmatic errors may occur; (4) it allows examination of approximately 55% of the total corneal curvature compared with 8% with the clinical keratometer; (5) it provides for estimation of subtle topographic shifts induced by trauma, by contact lenses, or in the normal history of corneal dystrophies; (6) it provides for determination of the peripheral corneal curves that assist in very difficult contact lens fitting situations; and (7) it allows quantitative evaluations of surgically induced astigmatism.^{7,8}

The disadvantages of a photokeratoscope include (1) aberrations induced by measurement around the visual axis rather than the corneal apical normal, and (2) requirements of some experience for good photography. Any defocusing of the reflected images produces an inaccurate chord length measurement, which is too large if the eye is too close to the camera and too small if the eye is too

far away.⁸

The corneoscope, developed by one of us (A.E.R.),¹ has enabled us to refine the Placido disk. If a 20-D lens is placed in the center of the Placido disk, the ophthalmologist may approach the eye to within 4 cm and examine the midperipheral and peripheral corneal curvature (Fig 19). Figure 20 incorporates the incident light of the hemispherical corneoscope target face into a flat Placido-like disk. As with the corneoscope, one sees equal ring separations with this modified disc when viewing a perfect sphere. Slight separations from perfect sphericity may be appreciated with the modified Placido disk, allowing the ophthalmologist not only to gauge the axis of astigmatism, but to localize areas of flattening and steepening, and differentiate the entities discussed in this article.

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