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Assessment of Corneal Contour

In the early days of hard lens fitting, a lack of understanding of the nature of corneal contour was one of the single biggest limiting factors in comfortable contact lens wear. Now our understanding of the nature of corneal topography has advanced. At the same time, our knowledge of the interaction between the contact lens posterior surface and corneal anterior surface has also improved, leading to advances in contact lens design.

Modern rigid gas-permeable lenses are designed with ease of fit in mind, while the fit of modern soft lenses are largely independent of corneal curvature. These factors do not mean assessment of corneal curvature is no longer necessary in contact lens practice. Assessment of the corneal contour is important not only in the preliminary stages of contact lens fitting, but also in the on-going monitoring of the effects of contact lenses on the eye. Recording accurate corneal curvatures (K-readings) before a lens is placed on the eye is a critical baseline measure in contact lens practice. Subtle changes in corneal contour induced by contact lenses or pathology may be leading edge indicators of problems to come. It is important to record not only the actual measurements, but to assess the quality of the corneal surface at the same time. Table 1 shows the range of K-readings of normal populations.[1,2]

The most common method of measurement in contact lens practice remains keratometry, although in recent years there has been increasing usage of more sophisticated corneal analysers and corneal mapping systems, the full use of which are outside the scope of this article. Practitioners should be aware that keratometry measurements provide only limited information about corneal contour and additional measurements and observations should supplement this. Corneal size is easily estimated using a millimetre rule or a slit-lamp graticule. Judging the fluorescein patterns under a large spherical RGP lens of known specification can also make a crude assessment of the overall corneal shape.

It must be remembered that the cornea is the principal refractive surface of an eye, responsible for two thirds of the total dioptric power. Visual acuity and/or refractive correction can be significantly changed due to only relatively small changes to the corneal topography, hence the importance of using a sensitive and accurate method of measurement.
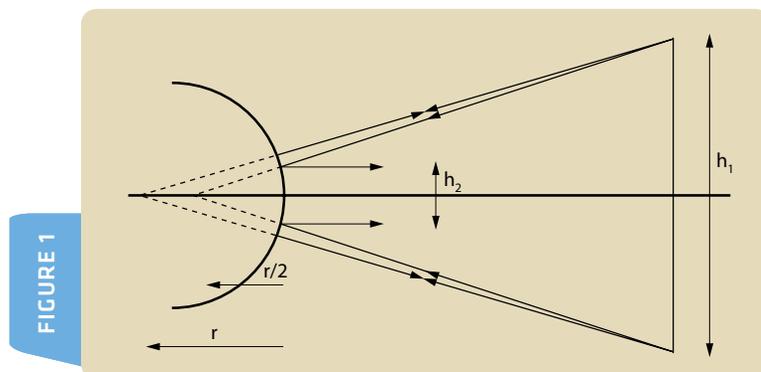

FIGURE 1 Optical principle of keratometry: h_1 = distance between mires, h_2 = image height (measured using doubling), r = corneal radius

This article describes the assessment of corneal contour in routine contact lens practice.
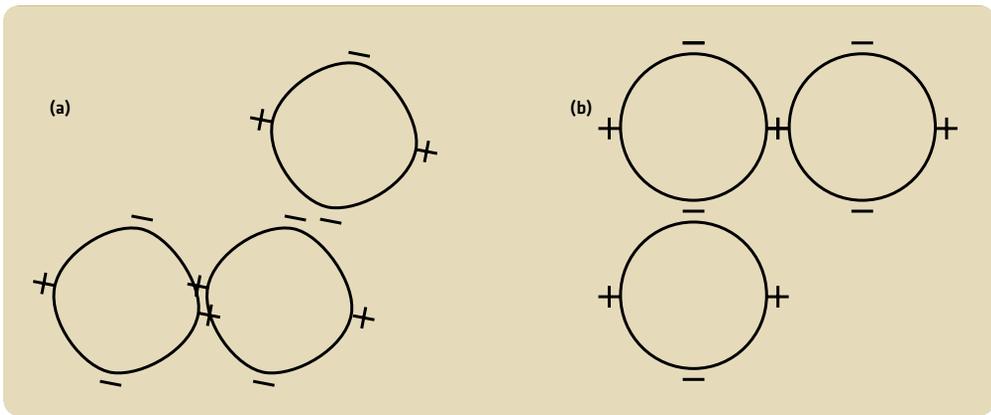

FIGURE 2 Bausch & Lomb keratometer mires: (a) mire misalignment and off axis (b) mire alignment

Keratometry – instrumentation

Keratometry works on the principle of recording the image size reflected from a known-sized object. Given the object size and distance from image to object, the radius of curvature of the cornea can be calculated. In keratometry, the object, which may be two separate mires or two points at distinct distances on a mire, reflects off a 3.2 mm central zone on the cornea (the exact distance depends on the instrument and corneal size).

The calculation of corneal radius assumes the cornea to be a sphere with a refractive index of 1.3375. Figure 1 shows the optical principle of keratometry. The measurement of corneal radius is made using an optical doubling system where the observer has to align the images of the mires reflected from the cornea. The doubling may be fixed, as in the case of the Javal-Schiotz instrument, or variable, as in Bausch & Lomb-type instruments.

In the fixed doubling instrument the distance between the mires (h_1 in Figure 1) is varied mechanically. When these are lined up, the reading is taken from a scale. With fixed doubling instruments K-readings are taken along each meridian in two stages.

In a variable doubling instrument the object size remains constant. This is achieved using prisms in the optics of the instrument. The prisms may be arranged simultaneously to produce doubling across the two principle meridians with readings from both taken once the instrument is lined up. Figure 2 shows examples of the mire images in this type of keratometer. The advantage of mires in the variable doubling

instrument is that they enable break-up of the tear film (from which the image is actually reflected) to be visualised more easily than the two-position instrument. It could be argued that the mires used in the variable doubling instrument make visualisation of the principle meridians easier and offer ergonomic advantages over the two-position instrument.

When choosing an instrument, the way in which the values are displayed should be considered. In some the K-values are displayed via the eyepiece so they may be read without removing the eye from the instrument. In others the values are on the outside of the instrument around the drums used to move the mire images. The axis can be read from either internal or external markings.

In these keratometers the observer has to align the mires manually. However, electronic keratometers are available. These are usually two-position instruments, which use servomotors to drive the doubling device until alignment can be assessed optically using light-emitting and detecting diodes. The recorded measurements are printed out by the machine, which will usually give a mean of three measurements and may also provide an estimate of the corneal shape by measuring corneal radius peripherally as well as centrally. Some instruments combine this facility within an autorefractor.

If the practitioner is choosing a new keratometer, consideration should given to the instrument table and slit-lamp. It is possible to adapt many keratometers so they can be used with the same chin rest as the biomicroscope with the two moved into position using a sliding table. A system of this kind has practical advantages in the consulting room.

TABLE 1

Range of K-readings in the human population[1,2]

RACE	AUTHORS	EYES	HORIZONTAL			VERTICAL		
			MEAN	SD	RANGE	MEAN	SD	RANGE
Caucasian	Kiely *et al* 1984	196	7.79	0.26	7.10 to 8.75	7.69	0.28	7.06 to 8.66
	Guillon *et al* 1986	220	7.87	0.25	7.14 to 8.54	7.7	0.27	7.03 to 8.46
	Lam & Loran 1991	63	7.98	0.21	7.10 to 8.36	8.03	0.20	7.29 to 8.43
Oriental	Lam & Loran 1991	64	7.74	0.24	7.21 to 8.31	7.9	0.23	7.46 to 8.48

Technique

Patient management

As with all objective assessments of the eye, the patient must be fully informed about the procedure. In keratometry, they should be assured that nothing will touch the eye and they will be in no discomfort. This is particularly important as any tendency to squeeze the lids may alter corneal contour. They should be sitting comfortably so fixation can be maintained with the chin in the chin rest and the forehead firmly against the headrest. The eyes must be in the straight-ahead position as any down gaze may also change contour. The practitioner must focus the mires in the eyepiece against a plain white background before the measurement can take place. If the instrument is not in focus the results will not be accurate.

Once instrument and patient are set up the patient should be asked to look at the centre of the object. If the instrument has a mirror the patients should be asked to look at their own eye. It is important to regularly check the instrument is calibrated correctly. This can be achieved using steel ball bearings, which have an accuracy of ±0.001mm. Five readings of each ball should be taken and a minimum of three balls of different size should be used so a calibration line can be plotted.

If radii which are steeper or flatter than those for which the machine is calibrated are to be measured, a + or -1.25D lens will be necessary. A +1.25D lens is for measuring a steeper cornea, as is often required when measuring keratoconic cornea, and a -1.25D is required for a flatter cornea. When using a supplementary lens, the keratometer must be calibrated using steel balls and a graph plotted of actual versus recorded-scale reading plotted. This is rarely required in routine general practice.

Measurement technique

The first stage in taking the measurement is to align the instrument along the principle meridians. The corneal radius can then be measured by adjusting the mires as shown in Figure 2. With the two-position instrument, the body of the equipment will need rotating before taking each measurement. Ideally, the reading should be taken three times and the median result used. As well as recording the keratometry readings, the practitioner should assess the clarity of the mires and record any distortion (Figure 3), as suggested in Table 2. At this stage the keratometer may be used to measure the non-invasive tear break-up time.

Automatic keratometry

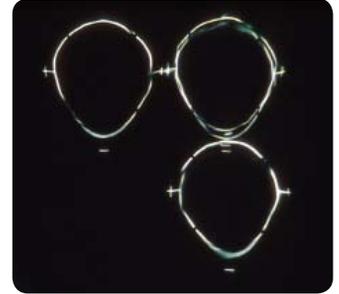When using an automatic keratometer the patient should

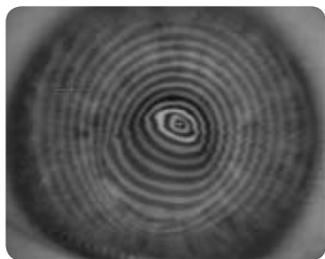**FIGURE 3** Mire distortion, showing corneal warpage due to contact lens wear

FIGURE 4 Placido rings projected onto cornea during photokeratoscopy

again be made to feel comfortable and relaxed. The instrument usually provides a light-emitting diode for the patient to fixate. The practitioner should look at the patient's eye during the measurement process to assess fixation. Most instruments take three measurements of each eye, but it is important to look at each measurement as well as the average to check for rogue readings due to eye movements.

Peripheral K-readings

Many automatic keratometers take and record peripheral K-readings. A normal manual instrument may also be adapted to take these readings by placing four fixation lights around the object and asking the patient to view each in turn. The accuracy of this technique is limited due to the aspheric nature of the corneal surface and indeed, to anatomical and fixation variation between patients and subsequent readings.

Keratoscopy – instrumentation

As already mentioned, the keratometer only provides an estimation of corneal curvature based on an approximate 3.2mm cord of its surface. The keratometer assumes the cornea to be spherical, which it is not. The corneal shape is often likened to an prolate ellipse, which flattens gradually towards its periphery.

The variations in curvature across the surface of the cornea can be likened to a conic section and quantified by calculating the shape factor. This is achieved by calculating measurements of the cornea at different points across its surface. The shape factor varies between 0 and 1, where 1 is a perfect sphere. The corneal shape factor of the Caucasian eye has a mean value of 0.83+0.13 (range 0.21-1.20) for the flat meridians and 0.81+0.16 (range 0.11-1.16) for the steep meridians. The shape factor can also be described in terms of eccentricity (e), where shape factor = $1 - e$.[2]

Traditional keratometry does not provide a measurement of shape factor, so the change in contour across the whole cornea needs to be determined. The technique of keratoscopy allows the corneal contour to be assessed more comprehensively than could be done by traditional keratometry. Keratoscopy determines the anterior corneal contour by observation of a reflected image of an object.[3]

The first keratoscope was the placido disc and modern photokeratoscopy is based on this principle. The placido disc is a series of illuminated concentric rings. The rings are projected onto the cornea and the observer looks at their reflection, the first catoptric image. The assessment of corneal topography is made by judging the regularity of the image. While this method is a simple way to make a gross assessment of any
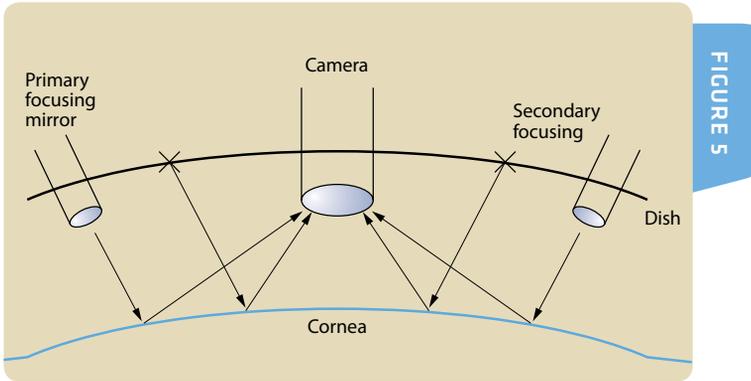
FIGURE 5

FIGURE 5 Focusing mechanism used in a photo-keratoscope

corneal irregularities (Figure 4), it cannot provide a detailed quantifiable assessment of the contour.

One of the earlier attempts at quantifying the corneal contour was made by Wesley-Jessen's photo electronic keratoscope (PEK). A Polaroid photograph was taken of a series of concentric rings and the diameter of each ring was then measured. From these the shape factor was calculated. Both the lack of immediacy of the measurement and problems in the reproducibility of rigid lenses ordered using the system restricted its capability.

Today, dramatic advances in computer-imaging technology have led to a resurgence in the analysis of corneal topography. Computerised corneal mapping systems have given the practitioner the means of looking at corneal contours with far more accuracy than had previously been possible.

Photokeratoscopy uses a computer-imaging system to calculate variations in contours from a series of rings projected on to the cornea. The image from the rings is collected by a camera, which sends the data for processing. The rings and camera are linked to a computer, which shows the results on screen or as a colour print. Computerised photokeratoscopes use between 16 and 25 rings projected onto the cornea and allow more than 6,000 data points across the corneal surface to be analysed.

Grading of mire distortion

Grade 0	Clear mire image
Grade 1	Slight distortion of mires
Grade 2	Mild distortion: reading possible with some difficulty
Grade 3	Moderate distortion: reading difficult to assess
Grade 4	Gross distortion: reading impossible

TABLE 2

FIGURE 6

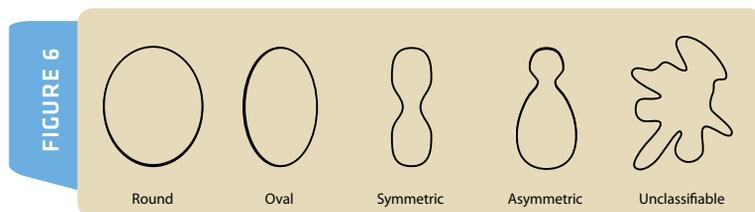Round   Oval   Symmetric   Asymmetric   Unclassifiable

FIGURE 6 Diagrammatic Patterns observed in colour-coded topographic maps of normal eyes as described by Brogan *et al* [5]

The first photokeratoscopes used a disc of 10-14 inches in diameter, which projected the rings onto the cornea. Focusing was achieved using a primary-focusing system where the disc was pushed forward until light was reflected from both peripheral mirrors (Figure 5). If light could not be focused in this way, a secondary focusing system was used in which an X was focused onto the fourth ring.

For relatively normal corneal topographies this was an accurate focusing system, although in some cases, for example post-RK, the system was out of focus half the time. Another disadvantage of this system was that shadows from the nose or eyebrows disrupted the focusing mechanisms.

Technique

Many of the comments made about patient set-up for keratometry also apply to keratoscopy. The patient must be comfortable and relaxed when the measurement takes place and, as with keratometry, fixation is important. A measurement taken off the corneal axis may give the appearance of an early keratoconus. If such an image is seen in the absence of any other signs or symptoms, the practitioner should repeat the measurement before making a diagnosis.

Presentation of data

The presentation of data collected from photokeratoscopy is increasingly sophisticated and it would be easy to allow the impressive appearance of the output to mask the value of the data collected. The data can be presented graphically in a variety of forms,[4] such as colour-coded power maps, photokeratoscopic images, wire mesh models, 3D reconstruction and cross-sections are all possible. The most common and useful information is a corneal contour map, which shows changes in contour changes across the surface of the cornea. Figure 6 provides diagrammatic representation of patterns observed in colour-coded topographic maps of normal eyes.

Corneal contour maps allow the practitioner to visualise the shape of the cornea (Figures 7 and 8) after surgery or during the development of corneal disease such as keratoconus (Figure 9).
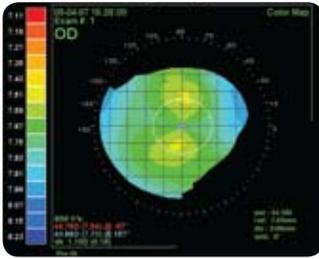
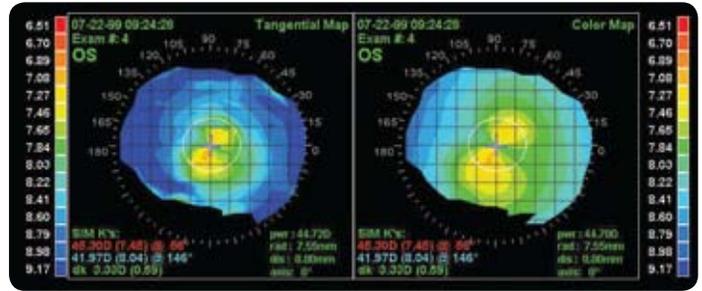**FIGURE 7** Colour-coded topographic map of a normal cornea (e = 0.45)

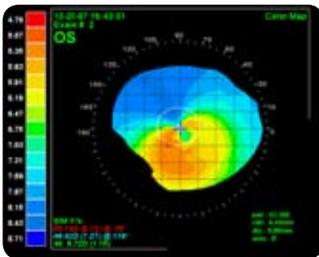**FIGURE 8** Colour-coded topographic map of a cornea exhibiting a high degree of astigmatism

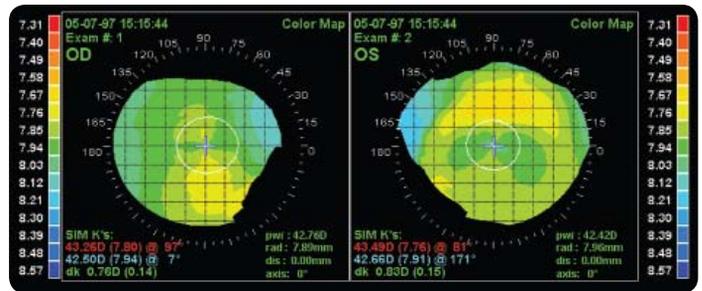**FIGURE 9** Colour-coded topographic map of a keratoconic patient

FIGURE 10 Colour-coded topographic map showing corneal distortion, due to a poor RGP fit

They also allow the practitioner to locate precisely the axis of corneal astigmatism and provide help in understanding reasons why a rigid contact lens is not fitting as expected (Figure 10). Information provided also includes pupil size and standard k readings, and some instruments now record corneal thickness.

Some instruments are fitted with software to assist in RGP lens design and fitting. These programmes will show the fluorescein fit of an RGP lens on the cornea and recommend suggested parameters. To date, the literature has been inconclusive in showing the value of this technique over and above traditional fitting assessment.

One unquestionable value of videokeratoscopy is in demonstrating to a patient their corneal contour and helping explain why a particular lens fit may be taking more time or proving difficult. This may be of particular importance following refractive surgery if the desired acuity cannot be obtained.

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Summary

Understanding, measuring and monitoring the corneal contour is vital in contact lens practice. Although the keratometer provides a reliable and accurate assessment of the central corneal curvature, more recent advances in keratoscopy provide much more extensive information of the corneal contour.

Indications for keratometry

- All contact lens assessment: providing base line and aftercare examination values of corneal curvature and any induced changes
- All contact lens assessment: providing crude assessment of corneal distortion
- RGP lens fitting: providing data to assist with initial lens choice
- All contact lens fitting: determining the site of astigmatic surface
- Measurements of non-invasive tear break-up times
- Measurement of rigid contact lens flexure
- Monitoring corneal pathology.

Indications for keratoscopy

- Understanding contours of irregular corneas to assist in contact lens fitting
- Diagnosis and monitoring of keratoconus or other corneal pathology
- Demonstration of corneal contour to patient to enhance information and satisfaction
- Identification of visual axis prior to excimer laser
- Pre- and postoperative corneal assessment before surgery. ■

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