Introduction

Examination of the anterior segment of the eye includes the assessment of the external eye and adnexa, tear film, ocular surfaces, anterior chamber and crystalline lens. The choice of examination procedures is based on the structure to be examined, the level of detail required and the specific abnormality anticipated.

Evaluation is conducted either to establish baseline conditions or to evaluate specific symptoms or signs. A wide range of instrumentation can be used, ranging from the simplest, such as a hand held slit torch (flashlight), to the more technologically complex optical coherence tomography (OCT) or ultrasound biomicroscopy (UBM). While the slit lamp biomicroscope is the standard method for assessing the integrity of the anterior region of the eye, the need to conduct a detailed examination may also be indicated by other techniques used routinely in optometric examination.

In addition, measurement of the curvature of the anterior corneal surface is performed to quantify the power (and astigmatism) of the anterior corneal surface, the most powerful refractive element in the eye.

Corneal curvature and topography

Keratometry

The goals of keratometry are:

1. To assist with ocular refraction by estimating both the magnitude and direction of ocular astigmatism
2. To determine the site of ocular astigmatism (corneal or non corneal)
3. To assist in the fitting of contact lenses by measuring the corneal radius of curvature
4. To gain information on corneal health from the quality of the reflected mire
5. To gain information as to whether the ocular ametropia is likely to be axial or refractive. For example, in patients having high degrees of ametropia whose keratometry findings are close to the mean value, such as a 10 D myope with corneal power around 42 D, it may be concluded that refractive error is probably axial in nature. In contrast, a 10 D myope having corneal power of approximately 52 D is likely to have refractive aetiology. Differentiating between axial and refractive ametropia is important in the treatment of anisometropia and aniseikonia (Bartlett 1987).

Optical principles

The keratometer uses the anterior corneal surface as a convex mirror. Consider Figure 17.1. The image (h’) of an object or mire (h) contained within the...
The keratometer is produced by reflection at the anterior cornea. Let C be the centre of curvature of the convex surface, F the focal point of the mirror and h and h’ the height of the object and image, respectively.

Now triangles FDO and FEO are similar. Therefore FA/FO = DA/EO = h'/h.

But FA = f, where f is the focal length of the mirror.

If FO = b, then DO is approximately equal to b (since AO is large).

And h'/h = f/b.

But h'/h = m (where m is the magnification of the optical system).

Therefore, f/b = m.

Since f = -r/2 (where r = radius of curvature of the curved mirror)

Then r = -2mb.

This equation, r = -2mb, is known as the approximate keratometer equation, due to the approximation that IO is approximately equal to FO. Therefore, the radius of curvature of the cornea can be calculated provided b (the approximate distance from the mire to the reflected image), h (the height of the mire) and h’ (the height of the reflected image) are known.

**Distance from the object to the image (b)**

The optics of the keratometer ensures that this distance remains constant, provided both the focusing graticule and the image are kept in focus throughout the measurement procedure. As shown in Figure 17.2, the focusing graticule, objective lens and mire are all fixed within the keratometer. While the spacing between these elements is fixed and remains constant, focusing of the reflected mire is achieved by moving the whole instrument either towards or away from the patient’s cornea.

The first step in keratometry is to focus the eyepiece, thereby making the observer’s retina conjugate with the focusing graticule. This is achieved by turning the eyepiece fully anticlockwise, and then rotating it in a clockwise direction until the graticule just comes into focus. The instrument is then moved either towards or away from the patient’s cornea until h’ (the image of the mire formed by reflection) appears clear. Many keratometers use the Scheiner disc principle so that the image seen will be doubled when out of focus. At this point h’ is conjugate with both the focusing graticule and the observer’s retina. Since the distance between the focusing graticule and the objective is fixed, then h’ will appear clear when it lies at a constant distance away from the objective lens.

Accordingly, when both the graticule and h’ appear clear, the distance from h’ to the objective lens is known. Additionally, the distance of the mire (h) from the objective lens is fixed and constant. Therefore, provided h’ is in focus, then the distance between h’ and h (i.e. b) will be constant for a particular instrument. The size of the object (h) is also fixed. To calculate r, the only unknown variable in the approximate keratometer equation is h’ (the size of the reflected image). This can be measured using the principle of doubling.

**Using the principle of doubling to measure the height of the image (h’)**

Since the cornea (the convex reflecting surface), and therefore the reflected image, is moving constantly, the height of h’ cannot be assessed using a measuring graticule. Rather, the principle of doubling is used to measure the height of this image.

If a prism is introduced into the optical system, then h’ will be seen diplopically, as shown in Figure 17.3. The magnitude of deviation (in centimetres) is equal to the product of the prism power (in prism dioptres) and the distance between the prism and the image (in metres). By varying this distance, the degree of deviation created by the prism will change. A position can be reached where the two diplopic images just touch one another. At this point

---

**Figure 17.1** Principle of keratometry. The anterior corneal surface is considered as a convex mirror. An image (h’) is formed by reflection at f from the object or mire (h) positioned at O. F and C represent the focal point and centre of curvature of the mirror, respectively.

**Figure 17.2** Schematic representation of the keratometer. The observer first ensures that the focusing graticule is seen in focus. A mire (h) positioned at the front of the instrument produces an image (h’) by reflection at the patient’s anterior corneal surface. The keratometer is moved antero posteriorly until this reflected image appears clear when viewed through the optical system. Since the distance between the objective lens and the focusing graticule is constant, the distance between h’ and the objective lens will also be constant (provided h’ is seen clearly). If the distance from the object mire (h) to the objective lens is known, then b, the approximate distance between the mire and the reflected image will also be known.
the amount of deviation is equal to the height of \( h' \). For example, consider when part of the reflected image is viewed through a 4\( \Delta \) prism to create diplopic images. The diplopic images just touch one another when the prism lies 33 cm away from the image. Therefore, the deviation = \( 0.33 \times 4 = 1.32 \) cm, and this is equal to the height of the image.

**Variable and fixed doubling**

In the Bausch and Lomb type keratometer, the magnitude of prismatic deviation (or doubling) is varied by altering the position of the prisms within the instrument, and therefore from \( h' \) (the image formed by reflection at the cornea). This is known as a variable doubling instrument. Other types of keratometers such as the Haag Streit (or Javal Schiötz type) instrument use the principle of fixed doubling. Here, the degree of doubling (or prismatic deviation) remains constant since both the magnitude and position of the prisms are fixed. However, the size of the object (h) is varied until the diplopic images just touch one another. At this point, the prismatic deviation is equal to the image height. The size of the object (h) can be measured easily to calculate \( r \).

**One- and two-position keratometers**

The Bausch and Lomb type of keratometer is a one position instrument because it can measure both principal meridia without having to reposition the instrument. In contrast, the Haag Streit (Javal Schiötz) type of instrument is termed a two position instrument because it only measures one meridian at a time. After measuring the first principal meridian, the instrument must be rotated through 90° to determine the second meridian. One potential advantage of a two position instrument is for patients having irregular astigmatism, i.e. where the principal meridia are not 90° apart. However, the Bausch and Lomb type of one position instrument may still be used by aligning the lower two mires only, and treating the device as if it were a two position instrument. The lower two mires are aligned along one of the principal meridia, and then the instrument rotated to identify the second principal meridian, and the same two mires realigned.

Mires may be of three principal types: the circular (Bausch and Lomb) mire, the cross (Zeiss) mire and the rectangular (Javal Schiötz) mire. In all cases there are linear components to the mires which must align with each other to identify the astigmatic axes. Examples of different types of mires, and their appearance when positioned along, or away from, the principal meridia are shown in Figure 17.4.

**Curvature or power?**

Keratometers actually measure the radius of curvature of the anterior corneal surface. If this is to be expressed in terms of dioptric power, then the equation \( F = (n' - n)/r \) is applied, with \( n' \) and \( n \) representing the refractive index of the cornea and air, respectively. Unfortunately, different manufacturers use dissimilar values of \( n' \) in this calculation. For example, if two keratometers from different manufacturers assume a corneal refractive index of 1.332 and 1.3375, then when measuring a cornea having a radius of curvature of 8.2 mm, these two instruments would give powers of 40.49 D and 41.16 D, respectively, i.e. a difference of 0.67 D.

**Procedure**

The procedure described below is for the one position, Bausch and Lomb type of keratometer. If a two position instrument is used, then a similar procedure is adopted, except that after the first principal meridian has been identified and measured, the instrument is rotated through 90°, and the second principal meridian identified and measured.
1. Focus the eyepiece for the examiner’s refractive error. This is facilitated by placing a piece of white paper in front of the instrument objective in the plane of the patient’s eye, while viewing the eyepiece graticule. Alternatively, have the patient close their eyes and view the graticule against their closed eyelid. Turn the eye piece fully anticlockwise (maximum plus) and then return it in a clockwise direction until the graticule is just seen in sharp focus.

2. Adjust the height of the instrument and/or patient’s chair to be at a comfortable level for both patient and examiner. Ensure that the instrument headrest and chinrest are clean. An alcohol wipe is suitable for this purpose.

3. Explain the purpose of the test to the patient; for example, this machine will measure the shape of the front of your eye.

4. Ask the patient to place their chin on the chinrest and forehead against the headrest. Note that during the examination, patients sometimes allow their forehead against the headrest. Note that during the examination, patients sometimes allow their forehead to move away from the headrest. This will make obtaining accurate readings more difficult. Emphasize to the patient that they should try to keep their head and eye as still as possible during the test. Occlude the non tested eye to ensure measurement along the visual axis.

5. The height of the instrument may be approximately aligned by raising or lowering it until the levelling markers are at the same height as the patient’s outer canthus. Then turn the instrument on, and the horizontal alignment can be completed by centring the reflection of the keratometer mires on the patient’s cornea. An alternative method of aligning the instrument is to place a small light source, e.g. a penlight or a trans illuminator, against the eyepiece and adjust the keratometer so that the emergent light falls on the patient’s cornea. The patient should now be able to see an image of their eye in the instrument and should be instructed to look at this. Complete the alignment procedure by looking into the eyepiece and making adjustments so that the graticule is centred in the lower right hand corner.

6. Focus the instrument until the doubling mire (lower right hand circle) is single.

7. Adjust the horizontal and vertical power wheels until the mires are in close apposition.

8. Rotate the barrel of the instrument until the horizontal markers between the two lower circles are superimposed. This aligns the instrument along a principal meridian.

9. While maintaining the exact focus of the instrument by keeping one hand on the focusing knob (it may be necessary to re focus frequently because of movement of the patient’s eye), adjust the horizontal power wheel until the horizontal plus signs are superimposed.

10. While maintaining the image in focus, adjust the vertical power wheel until the minus signs are superimposed. The correct final appearance of the mires should be as shown in Figure 17.4.

11. From the horizontal power wheel, record the power of the horizontal meridian.

12. From the vertical power wheel, record the power of the vertical meridian.

13. From the instrument protractor, record the location of the two principal meridia.

**Recording findings**

**Method 1**

The result may be recorded by stating the dioptric power and orientation of the two principal meridia, e.g. either:

\[42.00@45/43.75@135\]

or

\[42.00 M 45/43.75 M 135\]

(where \(M =\) meridian)

**Method 2**

The result can be quantified in terms of the radius of curvature in millimetres, e.g. either:

\[7.80@25/8.05@115\]

or

\[7.80 M 25/8.05 M 115\]

**Method 3**

The result may be recorded as the cylinder required to correct the corneal astigmatism. If minus cylinder form is preferred, then the cylinder axis corresponds with the orientation of the weaker powered meridian. Therefore, the example shown in Method 1 above can be written as:

\[1.75 \times 45 AM 42.00\]

(where AM indicates the power in the axis meridian, which in this case is 45°).

**Extending the range of the keratometer**

The normal range of the keratometer is from 36.00 to 52.00 D, but for extremely steep corneas (such as those found in keratoconus patients), the range can be extended by holding a +1.25 trial lens against the front of the instrument. Readings must be corrected by reference to a conversion table, such as that presented by Horner et al (2006). Similarly, the lower range can be extended by approximately 6 D (e.g. in a post LASIK patient) with a −1.00 trial lens.

**Javal’s rule**

In 1890, Javal proposed an equation to predict the ocular astigmatism from keratometric measurements, namely:

\[OA = (1.25 + CA) + k\]

where \(OA =\) ocular astigmatism

\(CA =\) corneal astigmatism

\(k = 0.50 D\) against the rule astigmatism.

For those patients where objective and subjective techniques to determine the refractive error of the eye (see Chs 13 and 14) are unsuccessful, this equation can be applied
to the keratometry findings to estimate the magnitude and direction of ocular astigmatism.

This equation assumes that patients with a spherical cornea will have 0.50 D of against the rule non corneal astigmatism; an assumption that is not born out in practice. Javal did state that the constants 1.25 and 0.50 in the equation above were not definitely established, and that a new factor as a function of age would have to be added. However, Mote and Fry (1939), Grosvenor and Ratnakaram (1990) and others have offered alternative equations. For example, Grosvenor and Ratnakaram (1990) suggested that a better equation is \( OA = CA + k \). In addition, Portello et al (1996) reported a significant change in the relationship between ocular and corneal astigmatism with increasing age. Accordingly, while these relationships are useful for examining average data from large populations, they are of limited value when estimating the astigmatism of an individual patient.

Potential sources of error in keratometry have been reviewed elsewhere (Edwards 1997).

**Topographical keratoscopy**

If the cornea were a spherical surface, keratometry would be a suitable method for determining overall corneal curvature. However, on average, the corneal surface is aspheric, approximating an evolute and usually described as a flattening ellipse (Douthwaite et al 1996; Guillon et al 1986) although there is considerable variation between individuals. Additionally, the conventional keratometer measures an annulus around (but not including) the corneal apex. The precise position and area measured varies with the corneal radius of curvature, and also with the type of instrument used.

In order to gain more information about the overall shape of the cornea, it is necessary to collect data outside the central corneal cap. Corneal topography can also be assessed with off axis keratometry. In its simplest form this can be achieved using keratometers modified with peripheral fixation targets (Wilms & Rabbets 1977; Lam & Douthwaite 1994). For a general review of corneal topography, see Fowler and Dave (1994).

More recently, automated keratometers have been used to assess both central and paracentral curvature and corneal asphericity (Rabbets 1985; Port 1987). However, these may provide only limited information if only the horizontal corneal meridian is used to determine the degree of eccentricity. Small but significant differences have been observed between corneal eccentricity for the horizontal and vertical meridia (Guillon et al 1986; Douthwaite et al 1996). For a more thorough estimation of corneal shape, topographers are required that take measurements from a large number of points on the corneal surface. Two principal methods are used in topographers, based on either videokeratoscopy, which reflects concentric rings onto the corneal surface, or using scanning slits to build up elevation maps of the corneal surface.

**Videokeratoscopy**

By reflecting concentric rings from the anterior corneal surface, multiple data points can be analysed in each corneal meridian. The separation of the rings imaged in the cornea is compared to the known separation of the object, and corneal power can be estimated on a point by point basis. These analyses are used to generate colour coded corneal power maps and show overall topographical data (Fig. 17.5).

While all videokeratoscopic devices are based on the same principle, the methods of image capture and analysis algorithms vary, and this can give rise to differences in output for the same cornea. Comparisons of different topographers on the same eyes have shown that their outputs cannot be used interchangeably and may not be reliable when used with young children (Cho et al 2002; Chui & Cho 2005). The reproducibility of results has also been questioned, with multiple readings being necessary to improve precision. In addition, the number of readings varies with instrument manufacturer (Hough & Edwards 1999; Cho et al 2002). There is also some doubt about the accuracy of the
Instruments when measuring human corneas as opposed to fixed plastics surfaces (Douthwaite & Matilla 1996; Pardhan & Douthwaite 1998; Douthwaite 2003).

Different analyses can be used to measure various aspects of corneal power. Axial power can be calculated at any point by considering rays that are parallel to the axis of rotation of the cornea. A more robust optical approach is to calculate ‘instantaneous’ or tangential power where rays approaching normal to the surface at any given point are considered. Asymmetry in the corneal shape determined by videokeratoscopy may also be an artefact. Since the instrument is aligned around the fixation axis, which may not coincide with the axis of rotation of the cornea, some apparent tilt may become evident. As a result, further data analysis might be necessary to eliminate these artefacts (Douthwaite et al 1996; Douthwaite & Pardhan 1998; Douthwaite 2003).

More recently, experimental devices have been examined to determine their utility in assessing non rotational, symmetric shape features of the cornea such as might arise from pathology or trauma (Sicam & Van der Heijde 2006). Preliminary results suggest that they achieve this goal without sacrificing the ability to model the normal aspects of corneal shape.

**Scanning slit keratoscopy**

An alternative approach to topography can be achieved by scanning the cornea with a slit object and capturing the reflected images. An elevation map can be constructed subsequence by combining the images to create a single model of the cornea being scanned. Since the output of such a reconstruction algorithm will be different from that determined by optical calculation, instruments such as the Orbscan (Bausch and Lomb Inc., Rochester, NY) also include a keratometric disc to allow the calculation of optical power by similar means to other videokeratoscopes. Other instruments such as the Pentacam (Oculus, Inc., Lynnwood, WA) combine slit scanning corneal topography with a Scheimpflug camera.

Comparisons of scanning slit and videokeratoscopes have shown both to be valuable for research and clinical purposes (Gonzalez et al 2004). While the print outs are very similar to those of videokeratoscopes, additional data can be included (Fig. 17.6).

A significant benefit of the scanning slit technology is that it allows imaging and therefore modelling of both the anterior and posterior cornea. As a result, corneal thickness can be calculated at any point on the cornea. Since the iris is also imaged, the anterior chamber depth can be determined. While there are differences between optical pachymetry from scanning slit devices and ultrasound pachymetry (see Ch. 24), both are capable of measuring changes in corneal thickness (Basmak et al 2006; Buehl et al 2006; Cheng et al 2006; Thomas et al 2006).

---

Figure 17.6 A print out from the Orbscan scanning slit keratoscopy. The upper left plot shows the anterior surface elevation relative to a best fit sphere. The upper right plot shows posterior corneal surface elevation relative to a best fit sphere. The values of each best fit sphere are shown between the two plots. The lower left plot is axial power and the lower right plot shows corneal thickness at predetermined points. Thickness at other points can be read by moving the cursor over the map. The central value is the thinnest measure and its exact location is shown.
Applications of video and scanning slit keratometry

There are a number of applications for corneal topographic mapping systems. Much interest has been given to the use of these systems for fitting contact lenses, especially rigid gas permeable lenses (Arffa 1992; Szczotka et al 1994; Szczotka 1997; Iani & Szczotka 2000). This is particularly true for patients having keratoconus (Rabinowitz et al 1991; Soni et al 1991; Ucakhan et al 2006) or a corneal graft (Gomes et al 1996; Eggink & Nuijts 2001; Gruenauer Kloevorkon et al 2005), where the corneal shape may be abnormal and where central keratometry does not show the full extent of the abnormality. In particular, both tangential power maps and the zonal corneal pachymetry associated with slit scanning systems have been shown to be useful in the detection of keratoconus (Azar et al 1996; Demirbas & Pfluggleider 1998; Auffarth et al 2000).

In addition, topographical mapping may be a prerequisite for techniques such as orthokeratology (see Ch. 23), where the impact of the lenses on the corneal shape must be evaluated fully (Edwards 2000). Further, the utility of topography in rigid lens fitting increases after refractive surgery (Choi et al 2004; Gemoules 2006; Gonzalez Mejome et al 2006).

A more recent problem has been the calculation of intraocular lens (IOL) power for cataract patients who have had previous refractive surgery. Since IOL power is usually calculated from axial length and corneal power, any surgical changes to the corneal power will cause postoperative refractive surpises, with patients being left with significant refractive error. It has been shown that postrefractive surgery corneal topography can help improve accuracy of IOL calculation formulae (Qazi et al 2007) or can be used in conjunction with new formulas to gain the same benefit (Borasio et al 2006).

Slit-lamp biomicroscopy

When evaluating the anterior segment of the eye, the slit lamp biomicroscope is generally the primary examination instrument. It combines an illumination system having a focused beam with well defined edges that may be narrowed to a slit aperture, and an observation system comprising a high resolution microscope with variable magnification. Both systems pivot about a common centre of rotation which provides constant focus as one moves over the curved surfaces of the eye. This ensures that the structure focally illuminated by the slit beam is in focus for the observation system.

Illumination system

The slit lamp illumination is provided by an optical system that projects an image of a mechanical aperture onto the surface being illuminated. This ensures that there is a sharp cutoff at the edges of the beam and no diffusion of light away from the area being illuminated, unless there are irregularities within the optical media being examined. The slit can be varied in both height and width and can usually be supplemented with the following filters:

- **Neutral density**: Permitting larger slit widths to be employed without a commensurate increase in brightness as an aid to patient comfort.
- **Yellow**: Some instruments include a yellow filter for increased patient comfort during prolonged examinations.

**Observation system**

The observation system comprises a microscope which may have convergent or, more commonly, parallel eyepieces. This includes a turret of objective lenses to create a wide range of magnification levels. Systems with an optical zoom provide no step progression from lowest to highest magnification. Supplementary eyepieces permit a wider range of magnification to be made available. In addition, eyepieces may be fitted with reticules for the measurement of structures or anomalies, although calibration at each magnification is necessary for absolute values to be determined.

**Illumination methods**

By rotating the observation and illumination systems relative to one another, the appearance of structures and anomalies within the ocular media can be altered to provide optimal visibility. Six standard illumination methods are most commonly used, as described below.

1. **Diffuse illumination**

A wide beam is used, typically at low magnification (1x), to obtain a general overview of the eye which can then direct subsequent and more detailed investigation. The structures to be viewed with this technique include the lids, lid margins, puncta, eyelashes, bulbar and palpebral conjunctiva, cornea, pupil, and iris. An overview of the preocular tear film is also obtained.

2. **Direct focal illumination (DFI)**

In this technique both the slit beam and the microscope are focused at the same point. By varying the width of the slit beam, the degree of magnification and the angle between the illumination and observation systems, one can move from a general view of the anterior segment to a three dimensional optic section of the cornea, anterior chamber or crystalline lens.

**DFI: Parallelepiped**

When observed with a 1 2 mm beam, a parallelepiped shaped section is seen (Fig. 17.7). This method of illumination allows structures to be viewed in three dimensions. In addition, one may observe tear debris, corneal nerves, abrasions, scars, striae (subtle, thin, white vertical folds located in the posterior stroma secondary to corneal oedema which is often associated with contact lens wear), ghost and blood vessels with this illumination method. Examination of the crystalline lens, vitreous (with or without the aid of an auxiliary lens) and retina (with the aid of an auxiliary lens; see Ch. 18) can be viewed with DFI parallelepiped illumination.

**DFI: Optic Section**

An optic section is formed with a narrow beam (approximately 0.2 0.3 mm in width) and typically a 60° angle between the observation and illumination systems (Fig. 17.8). After an object of regard has been located using the parallelepiped illumination, the optic section is employed to isolate the layer of tissue where the object lies. When viewing a corneal optic section, the anterior bright band is the tear film layer and epithelium, the posterior...
bright band is the endothelium, while the thicker, dim band between these two bright layers is the corneal stroma. The DFI optic section allows observation of corneal nerves located within the middle third of the stroma, changes in corneal thickness due to keratoconus, corneal scars or infiltrates, corneal abrasions or foreign bodies. When viewing an optic section of the crystalline lens, zones of discontinuity and lens opacities may be observed. This technique is also employed when estimating the depth of the anterior chamber angle by the Van Herick method (see p 269).

When examining the anterior chamber, the aqueous fluid of a healthy eye will appear optically empty when a light beam traverses it. However, in the case of an inflamed eye such as one with anterior uveitis, cells (white blood cells) and flare (excess protein) from the iris and ciliary body can be visualized within the beam of light focused on the aqueous. Red blood cells or pigment from the iris (usually due to trauma) may also be observed within the beam. Blood cells and/or pigment generally appear as floating particles whereas flare is seen as a milky haze. This phenomenon, which occurs when the scattering particles are larger than the wavelength of the radiation being scattered, is termed the Tyndall effect.

To examine the anterior chamber, a conical beam is used to produce a small patch of light having a small vertical dimension which is viewed under high magnification (25×). All ambient illumination should be extinguished when assessing the anterior chamber using this technique. To view the anterior chamber, first focus the conical section on the central cornea so that it may be observed against the dark background of the pupil. Then move the biomicroscope forward approximately 2–3 mm to bring the focus within the anterior chamber. Both the cornea and iris should now be out of focus. Observe the anterior chamber for at least 30 to 60 seconds to look for any floating debris. Cells and flare should be graded as shown in Table 17.1.

### Table 17.1

<table>
<thead>
<tr>
<th>Grade</th>
<th>Cells</th>
<th>Flare</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None</td>
<td>Absent</td>
</tr>
<tr>
<td>1</td>
<td>1–3</td>
<td>Mild</td>
</tr>
<tr>
<td>2</td>
<td>4–8</td>
<td>Moderate</td>
</tr>
<tr>
<td>3</td>
<td>9–15</td>
<td>Marked</td>
</tr>
<tr>
<td>4</td>
<td>&gt;15</td>
<td>Severe</td>
</tr>
</tbody>
</table>

3. **Sclerotic scatter**

This is produced by the total internal reflection that occurs within the cornea as light is directed onto the limbus. In a clear cornea, the limbus will glow around its circumference while the central area remains dark. However, any defect within the cornea (such as oedema, haze or infiltrates) will scatter light and can be seen as an area of brightness within the cornea, and viewed against the dark background of the pupil or iris. The illumination system is generally uncoupled (out of the click stop position) from the observation system for this technique. This procedure may also be performed by the practitioner viewing the cornea directly without the microscope.

4. **Indirect illumination**

This occurs when the microscope is focused directly adjacent to the illuminated area. Accordingly, the illumination system must be uncoupled (out of click stop) from the observation system for this technique. This procedure is useful for observing the surface of the iris (Fleming & Semes 2006) or epithelial corneal oedema, corneal microcysts, map dot and fingerprint dystrophy (a dystrophy of the epithelial basement membrane), pigment spots and corneal foreign bodies (Bartlett 1991).

5. **Retroillumination**

This is produced when areas of interest are illuminated by light reflected from a more posterior surface. For example, the cornea can be lit by light reflected from the iris. Similarly, the iris or crystalline lens can be viewed against the red reflex of light reflected from the fundus. Since the object of regard is viewed against a bright background, it will appear dark or in shadow (Fig. 17.9). The observation system may be coupled (direct retroillumination) or uncoupled (indirect retroillumination) from the illumination system for this technique. In direct retroillumination of the cornea, the microscope is focused on the cornea while the beam of light is reflected from the iris onto the cornea. Opacities
such as scars and blood vessels will appear dark against the bright background. Lesions which scatter light, e.g. epithelial oedema or corneal precipitates, will appear lighter.

For indirect retroillumination, the observation system is uncoupled (out of click stop) from the illumination system, and the area illuminated by light reflected from the surface of the iris will lie directly adjacent to the lesion. Light may also be reflected from the anterior crystalline lens to view the cornea or from the retina to view opacities within the cornea and/or crystalline lens. When reflecting light from the retina, the light source is positioned in the primary position and directed through the pupil. Any opacities in the crystalline lens or cornea will appear dark against the red orange retinal reflex. One can also check for holes in the iris (transillumination) with this method.

6. Specular reflection

This can be used to image surfaces and allows assessment of surface texture. It occurs when the observation and illumination systems are set at equal angles to a line perpendicular to the structure being observed. This technique is valuable for examining the tear film, the corneal endothelium (Fig. 17.10) and the anterior and posterior surfaces of the crystalline lens. These surfaces are generally examined under high magnification (25–40×).

In reality, the distinctions between these methods of illumination are arbitrary since the field of view of the microscope is greater than the area illuminated by the slit beam. Therefore, several types of illumination will be evident within the field of view at the same time. For a summary of the settings for the various types of slit-lamp illumination see Table 17.2. In addition, during the course of a slit lamp examination the light is moved across the eye, and the angle between illumination and observation system varied. The main methods of focal illumination will occur sequentially

---

**Figure 17.9** Keratic precipitates (KPs) viewed simultaneously in direct and in retroillumination. Multiple, large KPs are easily seen in this patient with recurrent iritis, secondary to sarcoid. The KPs on the right of the image are seen in direct focal illumination and appear white. The KPs on the left are viewed in retroillumination, being lit by light reflected from the iris, and therefore appear dark brown in colour.

**Figure 17.10** Specular reflection from the corneal endothelium. The hexagonal endothelial cells can be seen in the top right portion of the corneal section.

---

**Table 17.2** Summary of settings for various slit-lamp illumination settings

<table>
<thead>
<tr>
<th></th>
<th>Diffuse</th>
<th>DFE: parallelepiped</th>
<th>DFE: optic section</th>
<th>Conical section</th>
<th>Sclerotic scatter</th>
<th>Indirect retroillumination</th>
<th>Specular reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam angle</td>
<td>45° to 60°</td>
<td>45° to 60°</td>
<td>45° to 60°</td>
<td>60° to 75°</td>
<td>60°</td>
<td>45° to 60°</td>
<td>60° (when reflected off iris) 0° (when reflected off the retina)</td>
</tr>
<tr>
<td>Beam height</td>
<td>Maximum</td>
<td>Maximum</td>
<td>Maximum</td>
<td>3–4 mm</td>
<td>Maximum</td>
<td>Maximum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Beam width</td>
<td>4 mm to wide open</td>
<td>1.2 mm</td>
<td>0.2–0.3 mm</td>
<td>0.5–0.6 mm</td>
<td>1 mm</td>
<td>1.2 mm</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>Magnification</td>
<td>Low</td>
<td>Start low (6x), and then increase</td>
<td>Start at 10–12x, and then increase as necessary</td>
<td>20–30x</td>
<td>Low (6x), Low to high as necessary</td>
<td>Low to high as necessary</td>
<td>High (20–45x)</td>
</tr>
<tr>
<td>Illumination level</td>
<td>Low</td>
<td>Low</td>
<td>Moderate to high</td>
<td>Maximum</td>
<td>Moderate</td>
<td>Low to moderate</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
for different structures within the eye. As the light passes over defects in otherwise optically clear media, areas of interest pass from one method of illumination to another and may seem, on initial observation, to become visible and then invisible with a specific method of illumination. This effect is enhanced by the sharply defined slit image, making these transitions in illumination more dramatic. Further examination can then be concentrated in that area. Specific illumination and examination techniques to enhance the visibility of various structures and/or abnormalities are shown in Table 17.3.

**Use of the slit lamp**

To ensure maximum overlap of the field of view and the area of illumination, the instrument has coincident centres of rotation for both the illumination and observation systems. This ensures that the slit image is produced in the same plane as the focus of the microscope and that the slit image is centred in the field of view. However, the microscope must be focused accurately for the observer. Before beginning the examination, it is important that the eyepieces are focused for the individual user. This is achieved either by focusing each eyepiece using the internal graticule that is normally present or by using a focusing bar that provides a suitable reference plane on which to focus. Alternatively, one can focus the instrument on the patient’s closed lid or viewing the outer section of the sclera. Once a particular instrument has been focused for an individual observer, the reading on the oculars might be noted, to facilitate refocusing for that individual. If the eyepieces are not adjusted for the individual observer, then the microscope and illumination system will not share a common focus and the slit beam will be imaged off centre within the field of view.

In normal usage, the observation system is positioned normal to the surface being examined with the illumination system to one side. The angle between observation and illumination system should be as large as possible, perhaps 70° when viewing a corneal section but much less when viewing the crystalline lens, where the view is restricted by the iris. During a comprehensive slit lamp examination the slit width, angle between observation and illumination system and magnification are continuously varied to obtain the best view of the structures being examined.

**Method of examination**

The patient should be seated comfortably at the instrument with the outer canthus of the eye to be examined in line with the marker on the vertical post of the headrest. This will ensure that the instrument is at the centre of its vertical travel, thereby permitting examination of the peripheral cornea and sclera without the need to readjust the chin rest height.

For corneal examination, focal illumination is used with a moderate width slit. The microscope should be positioned normal to the surface being examined with the illumination system at a specific angle. The patient fixating straight ahead, one sweep from temporal to nasal will examine the central area. As the patient looks down and the sweep is reversed, the superior region is examined. Finally, with the patient looking up, a third sweep examines the inferior region. At any time an area of interest

---

Table 17.3: Illumination and examination techniques with the slit lamp

<table>
<thead>
<tr>
<th>Structure/abnormality to be observed</th>
<th>Magnification</th>
<th>Illumination</th>
<th>Slit width</th>
<th>Filters/accessories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lids/general view of external eye</td>
<td>Low medium</td>
<td>Diffuse</td>
<td>Wide</td>
<td>Diffuser</td>
</tr>
<tr>
<td>Lashes</td>
<td>Medium</td>
<td>Direct focal</td>
<td>Narrow to medium</td>
<td>None</td>
</tr>
<tr>
<td>Localised oedema</td>
<td>Low</td>
<td>Sclerotic scatter</td>
<td>Medium</td>
<td>Uncoupled system</td>
</tr>
<tr>
<td>Corneal defects</td>
<td>Medium high</td>
<td>Direct/indirect focal</td>
<td>Medium to narrow</td>
<td>None</td>
</tr>
<tr>
<td>Depth of opacity</td>
<td>Medium high</td>
<td>Direct focal</td>
<td>Narrow</td>
<td>Observation system normal to surface and wide separation between observation and illumination system</td>
</tr>
<tr>
<td>Corneal microcysts</td>
<td>High</td>
<td>Indirect/indirect retro</td>
<td>Narrow</td>
<td>None</td>
</tr>
<tr>
<td>Corneal striae</td>
<td>High</td>
<td>Indirect</td>
<td>Narrow</td>
<td>None</td>
</tr>
<tr>
<td>Corneal vascular change/ghost vessels</td>
<td>Medium high</td>
<td>Indirect retro</td>
<td>Medium to narrow</td>
<td>None. red free filter may help if there is blood flow through vessel</td>
</tr>
<tr>
<td>Corneal endothelium</td>
<td>High</td>
<td>Specular reflection</td>
<td>Medium</td>
<td>None</td>
</tr>
<tr>
<td>Dystrophies</td>
<td>Low medium</td>
<td>Direct retro/focal or sclerotic scatter</td>
<td>Medium</td>
<td>None</td>
</tr>
<tr>
<td>Fluorescein staining</td>
<td>Low medium</td>
<td>Direct focal or diffuse</td>
<td>Wide</td>
<td>Blue exciter filter in illumination system, yellow barrier filter in observation system</td>
</tr>
</tbody>
</table>
Stained tears will normally drain via the puncta and be assessed by examination of the nasal puncta, but is more inflammation of the drainage system. Blockage may be the lid. Alternatively, there may be suspected occlusion or examination and palpation of the superior lateral region of may be swelling of the lacrimal gland that is apparent from an assessment of tear layer quality or quantity. Rarely, there can be deposits or scales on the cilia (irregularities of the number or direction of the cilia, and/or made with low magnification and a diffuse beam. Observe A general view of the external eye, lids and lashes can be held in place as the patient continues to look downwards. Pressure is then applied at the top of the lid with a finger or cotton bud and the lid pulled slightly downwards and upwards. The everted lid will reveal the palpebral conjunctiva and will remain in position provided it is held in place as the patient continues to look downwards. Figure 17.11 Examination of the cornea in three sweeps.

can be examined in detail by changing slit width, brightness and observation system magnification, as well as varying the angle between the two systems.

Structures of the anterior eye and their assessment

Ocular adnexa

A general view of the external eye, lids and lashes can be made with low magnification and a diffuse beam. Observe for abnormalities such as elevations, deposits or exudates, irregularities of the number or direction of the cilia, and/or deposits or scales on the cilia (Fig. 17.12). With a wide paral lelipiped beam, have the patient to look up and gently pull down the lower lid. Examine the lid margin, noting the shape, tissue colour, meibomian gland openings, and look for abnormalities such as swelling, exudates, or localized growths. Examine the palpebral conjunctiva for injection, haemorrhage, swelling, wounds, discharge, concretions, follicles or papillary hypertrophy. Note if the punctum is patent, and check the caruncle for growths or unusual pigment. Sub sequently, have the patient look down and gently pull up the upper lid, noting any abnormalities of the lid margin as described above. With the upper lid still raised observe the bulbar conjunctiva, noting abnormalities such as unusual pigmentation, blood vessels engorgement, growths, injection, or chemosis. Additionally, have the patient look to the right and left while observing the bulbar conjunctiva. Sub sequently, evict the upper lid to examine the palpebral con junctiva. This is achieved by pulling the upper lid downwards and away from the eye as the patient continues to look downwards. Pressure is then applied at the top of the lid with a finger or cotton bud and the lid pulled slightly towards and upwards. The everted lid will reveal the palpe bral conjunctiva and will remain in position provided it is held in place as the patient continues to look downwards.

A summary of possible findings when examining the external eye are shown in Table 17.4. Examination of the lacrimal system should also include an assessment of tear layer quality or quantity. Rarely, there may be swelling of the lacrimal gland that is apparent from examination and palpation of the superior lateral region of the lid. Alternatively, there may be suspected occlusion or inflammation of the drainage system. Blockage may be assessed by examination of the nasal puncta, but is more readily tested with the introduction of fluorescein stain. Stained tears will normally drain via the puncta and be found in the nasal secretions. By shining a blue or ultraviolet light source onto the contents of the nasal passages expressed onto a tissue, the integrity of the lacrimal system can be determined. Fluorescent mucous indicates that stained tear fluid has reached the nasal passage and con firms that there is no substantial blockage. A lack of fluorescence after a suitable delay (2–3 minutes) suggests an obstruction in the nasolacrimal system.

A tender, inflamed swelling in the region of the inner canthus may suggest an inflammatory reaction in the lacri mal sac resulting in dacryocystitis. In severe cases, discharge from the puncta can be elicited by mild pressure in the region of inflammation. This may be visible to the naked eye or can be observed by the use of the slit lamp with low magnification and diffuse illumination

Tear film

An adequate pre corneal tear film is a prerequisite for the maintenance of an intact, optically clear anterior corneal surface. The tear film comprises a superficial lipid or oily layer, an intermediate aqueous layer and an inner mucus layer. Each contributes unique properties to the tears and both the quantity and quality of the tear film will impact a patient’s signs and symptoms.

Tear volume

The majority of the tear volume originates from the lacrimal gland and is contained in the aqueous layer. An inadequate volume of tears will give rise to clinically dry eye, although the aetiology may be more complex than a simple under secretion of aqueous tears. Unfortunately, procedures to assess tear volume are prone to artefacts since anything which either comes into contact with or is added to the tear film, or requires a light bright enough to create reflex lacrimation can alter tear production. Both the Schirmer and phenyl red thread tests are used to obtain a base measure of overall tear volume.

Schirmer tear tests These comprise small strips of absorbent filter paper of pre set dimensions. The end of the strip is bent over at a right angle and is hooked over the lower lid in contact with the bulbar and palpebral conjunctiva. Tears are absorbed onto the strip and after a predetermined time, usually 5 minutes, the strip is removed and the length of wetted strip measured. A normal eye will usually wet between 10 and 30 mm of the test strip in the 5 minute test period.
The main issue with the Schirmer strip is that it creates a foreign body sensation which may stimulate secretion above the normal background level. This will be exacerbated if the patient moves their eye so that the strip makes contact with the cornea. However, this effect can be minimized by placing the strips in the outer third of the palpebral aperture, and asking the patient to keep their eyes as still as possible. Some clinicians recommend the use of topical local anaesthetic prior to conducting the test as a means of avoiding the foreign body sensation. Both the volume of the drop and the initial stinging created following instillation of the anaesthetic may also increase tear production. Therefore, one should wait at least 1 minute after the anaesthetic has been instilled before introducing the strips, and, additionally, take care to wipe away any excess volume before beginning the test. Following this interval, a normal eye will moisten at least 8 mm of the test strip after a 5 minute period.

**Phenyl red thread test** The phenyl red thread (PRT) test was developed in the 1970s as an alternative to the Schirmer test (Tomlinson et al 2001). It consists of a thin cotton thread impregnated with phenol red dye which is hooked over the lower lid for just 15 s (Doughty et al 2007). In a review of the technique, Tomlinson et al concluded that the procedure probably measures uptake of a small amount of fluid residing in the eye while stimulating reflex tearing. They indicated that while it was more comfortable for patients than the Schirmer test, it may not offer a valid assessment of reflex tear facility. Miller et al (2004) suggested that the test provides a useful measure of tear meniscus volume, while Doughty et al (2007) noted the absence of clearly stated protocols for this procedure. To avoid misinterpretation of the results due to the rapid capillary action of the thread, it is important to measure the degree of wetting quickly as the tears advance rapidly along the thread. One advantage of the PRT test is that it can be performed while contact lenses are being worn.

**Tear break-up time test** The tear break up time (TBUT) test measures the stability of the pre corneal film using fluorescein dye (Fleming & Semes 2006). Fluorescein solution is instilled into the lower bulbar conjunctiva using an impregnated strip. The patient should be instructed to blink several times and then asked to avoid blinking. With the cobalt filter in place, the cornea is viewed via the slit lamp biomicroscope under low magnification (6 10×) until one or more black dry spots appear (Fig. 17.13). A normal result is 10 15 seconds or longer (Casser et al 1997). However, Johnson and Murphy (2005) noted that TBUT values vary with the volume of fluorescein instilled, and that accurate assessment requires averaging of multiple measurements.

**Rose bengal and lissamine green** To assess the integrity of the cornea and conjunctiva, either rose bengal or lissamine green stain may be employed. Rose bengal was first used by Sjögren in 1933 in patients with keratoconjunctivitis sicca (Manning et al 1995). It has an affinity for degenerated or dead cells and mucous strands. It appears to stain epithelial surfaces that have been deprived of protection from mucin or albumin. It can also be used for evaluating epithelial dendrites of herpes simplex and zoster as well as conjunctival squamous neoplasia (Wilson 1976). The dye has significant antiviral properties.
and can interfere with the isolation of viruses from conjunctival or corneal cultures (Schnider 1995).

Rose bengal is supplied as both a 1% solution and an impregnated filter strip. After instillation, it can cause severe ocular irritation and stinging for up to 24 hours. Therefore, it is recommended to instil a drop of topical anaesthetic before administrating rose bengal to reduce stinging and reflex tearing. It is important to avoid getting excess dye on the eyelid, skin and clothing as it will stain these also. The volume introduced into the eye can be minimized by placing a drop onto the superior conjunctiva and allowing the dye to migrate inferiorly over the eye (Bron et al 2003). While the appearance of the stained eye can be viewed using white light (Fig. 17.14), coloured filters will enhance observation. For example, a red free filter may be used to increase the contrast of the dye. Under this illumination, stained areas will appear black.

Since staining is dose dependent, the effect will be proportional to the volume of dye instilled. Therefore, if less dye is introduced to minimize stinging, this will also reduce the amount of staining observed. At the end of the examination, patients should be warned as to the possible presence of residual dye, as the red appearance may cause them to believe that blood is present in or around their eyes.

Rose bengal and lissamine green ophthalmic dyes have similar staining characteristics. Unlike rose bengal, lissamine green is not toxic to the ocular surfaces and is better tolerated by patients (Manning et al 1995). Accordingly, lissamine green is preferred, and has become more widely used than rose bengal (Kim & Foulks 1999).

Lissamine green is supplied in a 1% solution or as an impregnated filter strip. It is generally instilled without an anaesthetic because of its non-irritating properties. Staining should be evaluated 1–4 minutes after the dye has been introduced into the eye. Further, lissamine green staining is best evaluated under low illumination and increasing the level until the lissamine green staining becomes most visible. However, using excess illumination will decrease the visibility of the stained regions.

Van Herick angle estimation

The Van Herick technique can be used to assess the depth of the anterior chamber (AC) angle. This is most important before any mydriatic pharmaceutical agent is instilled. With this technique the patient is directed to look straight ahead and an optic section of their cornea created on the edge of the limbus. The illumination system is positioned 60 degrees away from the microscope and the magnification set at approximately 16×. The illumination is positioned temporally when grading the temporal angle and nasally when assessing the nasal angle. The anterior chamber will appear as a black space between the cornea and the iris. With the optic section focused on the cornea, the width of the anterior chamber (i.e. the black space) is compared with the width of the corneal section.

The method of grading the angle is shown in Table 17.5.

Gonioscopy

While the Van Herrick technique can be used to estimate anterior chamber depth and therefore the likelihood of angle closure, detailed examination of the angle both to determine the degree to which it is open and to view the anatomical structures can only be achieved with a gonioscopy lens. With such a lens, light reflected from the angle is totally internally reflected within the eye and is not visible externally. Gonioscopic lenses are placed in contact with the cornea, necessitating the use of topical anaesthesia and lubricating

Table 17.5 Grading of Van Herick technique to estimate the depth of the anterior chamber angle

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
<th>Likelihood of angle closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Width of AC is less than ¼ of the width of the corneal section</td>
<td>Angle is extremely narrow and will probably close with full pupillary dilation</td>
</tr>
<tr>
<td>2</td>
<td>Width of AC is approximately ¼ of the width of the corneal section</td>
<td>Angle is narrow and capable of closure</td>
</tr>
<tr>
<td>3</td>
<td>Width of AC is ¼ to ½ of the width of the corneal section</td>
<td>Angle is unlikely to close</td>
</tr>
<tr>
<td>4</td>
<td>Width of the AC is equal or greater than the width of the optic section</td>
<td>This is a wide open angle</td>
</tr>
</tbody>
</table>

Adapted from Casser et al 1997.
drops. Most typically, these include mirrors to obtain a clear view of the angle. For a detailed review of the history of gonioscopy, see Fisch (1993).

Gonioscopy lenses can be divided into those that require cushioning fluid to provide suction to hold the lens onto the cornea and lenses which do not use fluid to obtain suction. The most commonly used fluid lens is the Goldmann 3 mirror lens, although 1 and 2 mirror lenses are also available. The 3 mirror lens contains three mirrors and a centre lens. The centre lens (a Hruby lens) is used to view the posterior pole (see Ch. 18) while the two rectangular shaped mirrors are utilized to view the mid periphery and peripheral retina through a dilated pupil. The D shaped (also termed bullet shaped) mirror is used for assessing the anterior chamber angle through an undilated pupil. This lens has to be rotated 360° to observe all the quadrants of the angle.

The 4 mirror goniolens, which does not require cushioning solution, allows all quadrants of the angle to be viewed without the need for lens rotation. However, the field of view is smaller than with the 3 mirror lens. Although the inexperienced practitioner may initially find 4 mirror lenses more difficult to use, they are valuable for providing rapid evaluation of the angle since the overall procedure is quicker. However, the image quality may be poorer than that observed with fluid cushioned lenses.

Method of examination

- Disinfect the lens with either 70% ethanol or isopropyl alcohol, or 3% hydrogen peroxide. Firstly, apply the disinfecting agent to a tissue, then wipe only the ocular surface of the lens. Rinse with saline or irrigating solution and wipe dry. However, Volk (Volk Optical Inc., Mentor, OH) recommend that their gonioscopy lenses be disinfected by soaking in either a 2% solution of glutaraldehyde for 20–25 min or a solution of sodium hypochlorite (household bleach) composed of 1 part bleach to 10 parts water for 10–12 min. The lens should then be rinsed thoroughly and dried.

- A lubricant drop should be used to fill the concave surface of the 3 mirror gonioscopy lens (although the ‘no flange’ 3 mirror Volk lenses do not require cushioning solution). Lubricant solutions include hydroxypropyl methylcellulose (2.5%), hydroxyethylcellulose (2.5%) and carboxymethylcellulose sodium (1%). The latter is less viscous than hydroxypropyl methylcellulose, and patients seem to have less corneal reactions to this solution. Further, post examination irrigation seems less necessary when compared with hydroxypropyl methyl cellulose. However, carboxymethylcellulose may produce some degradation of image clarity.

- The patient should be seated comfortably at the slit lamp and both corneas anaesthetized with a topical anaesthetic. Since the eye without the goniolens has a tendency to dry out, in order to avoid reflex blinking (which may cause the lens to dislodge) both eyes should be anaesthetized.

- Place the lens onto the eye.

  With a cooperative patient or one with a wide palpebral aperture the following procedure may be used. Have the patient look up, and while holding the goniolens with the thumb and index finger, gently pull the patient’s lower lid down with the index finger of the free hand. Rest the edge of the goniolens onto the lower lid and release this eyelid.

At this point, hold the upper lid with the thumb of the free hand. Then, pivot the lens onto the globe (release the upper lid) and tell the patient to look straight ahead slowly. If they look straight ahead too quickly the lens may come off the eye. Brace the remaining fingers on the headrest band of the biomicroscope. The cushioning solution forms a partial seal between the lens and cornea, so that only a small amount of inward pressure is required once the lens is in position.

When working with an uncooperative patient or one with a small palpebral aperture, they should be instructed initially to look down. Hold the upper lid with the thumb of the free hand. Now tell the patient to look up. As the lens is held between the thumb and index finger, pull the lower lid down with the middle finger of the hand holding the lens. Pivot the lens onto the globe while the patient continues to look up and release the eyelids. Finally, tell the patient to look straight ahead slowly while keeping their eyes wide open. With a very uncooperative patient, have them look down. Holding the upper lid with the free hand, place the lens on the upper part of the globe as the patient continues to look as far down as they can. Then, instruct the patient to look straight ahead slowly. Release the upper lid. The appearance of the lens when centred on the eye is shown in Figure 17.15. If significant bubbles are trapped under the lens, it should be removed from the eye, and the insertion procedure repeated after refilling with lubricant drops. With small bubbles, it may be possible to tilt the lens towards the bubble, thereby flattening it.

- Once the goniolens is in position, set the illumination approximately 5° away from the centre of the biomicroscope. Start with low (approximately 6X magnification and low illumination with a 3 mm wide parallelepiped) to gain orientation. If the D shaped mirror is positioned superiorly, you may need to raise the microscope to focus on the mirror. Push the slit lamp base forward until the front surface of the lens is in focus. Then move forward a further 1–2 cm to obtain a focused image of the chamber angle. The angle viewed lies 180° away from the position of the mirror. Therefore, when the mirror is superior, the inferior angle is being observed. It is customary to

Figure 17.15 A Goldmann 3 mirror gonioscopy lens is centred on the eye. The D shaped mirror is shown superiorly for viewing the inferior angle.
place the goniolens onto the eye first, with the D shaped mirror superiorly. The inferior angle is typically the widest, and therefore easiest to see, whereas the superior angle is typically the narrowest. As one rotates the goniolens to evaluate the other quadrants apply slight pressure to avoid the lens popping off. When viewing both the superior and inferior angles with a vertical beam, it is important to move the illumination across the entire width of the quadrant being examined. Rotating the lens through 360° will allow the whole angle to be examined in a methodical manner.

- To remove the lens, use one of the following techniques:
  - a. Instruct the patient to blink hard or squeeze their lids tightly closed. This will break the suction and the lens will release.
  - b. With the index finger, push on the globe through the lid just temporal to the lens and simultaneously tell the patient to blink hard. Support the lens with the other hand to hold it when suction breaks. Occasionally, one may hear a ‘popping’ sound, indicating that the seal has been broken.
  - c. Instruct the patient to turn their eye in and then blink hard. This utilizes the caruncle or lid margins to break the seal.
  - d. If the lens does not release after performing the three procedures described above, irrigate with sterile saline solution. Gently rock the lens back and forth during irrigation to break the suction.

- Finally, if cushioning solution was used with the goniolens, then the eye must be irrigated after lens removal to wash out the viscous solution. Give the patient a few tissues to place on their cheek and have them tilt their head back while looking up. Pull their lower lid down and direct a stream of irrigating solution (sterile ophthalmic saline) into the lower cul de sac. Next, tell the patient to look down and again direct a stream of solution under the upper lid. Repeat if necessary. Do not spray the irrigating solution directly onto the cornea.

- The patient’s vision will be blurry due to any residual methylcellulose, corneal punctate staining and lack of oxygen while the lens was on the eye. Reassure the patient their vision should clear in approximately 20 minutes.

**Anatomy of the angle**

The following structures should be visible during gonioscopic examination:

- **Iris**: This should appear flat. Any bowing (whether convex or concave) should be noted in terms of its extent and location. A concave iris configuration is more commonly seen in myopic patients.

- **Ciliary body**: Usually appears as a narrow grey or brown band beyond the iris. It tends to be wider in myopic eyes compared with emmetropic or hyperopic eyes.

- **Scleral spur**: A bright white band lying immediately anterior to the ciliary body.

- **Trabecula**: Seen as a grey band anterior to the scleral spur. It may contain more pigment on its posterior edge. Two layers may be visible, and, since the more posterior layer (the one closer to the iris) filters most of the aqueous, this is more likely to accumulate pigment or debris.

- **Canal of Schlemm**: While not normally visible, pressure on the episcleral vessels may cause it to fill with blood, in which case it will be seen as a dark band within the trabecula (Fig. 17.16).

- **Schwalbe’s line**: Seen as a very thin white line anterior to the trabecula.

- **Iris processes**: These may be observed as thin lacy fibres or spoke like projections that bridge the angle from the iris periphery to the uvea. They are more commonly found nasally, compared with other quadrants.

Figure 17.17 presents a diagrammatic representation of the angle, while a gonioscopic view is shown in Figure 17.18. The angle is judged by the number of structures visible and by estimating the angle between the anterior surface of the iris and the posterior surface of the cornea, also known as the approach to the angle. If all structures are visible, the angle will generally be open, and the estimated angle between the iris and the cornea will be approximately 40°. If the structures between the iris and scleral spur are seen, this usually indicates a moderately open angle in

**Figure 17.16** Blood in Schlemm’s canal. Intentional pressure on the episcleral vessels during gonioscopy allows blood to back up into the canal of Schlemm, thereby enabling the examiner to identify the position of a lightly pigmented trabecular meshwork. Other causes of blood in Schlemm’s canal include trauma and sickle cell anaemia.

**Figure 17.17** Schematic illustration of the structures of the angle seen during gonioscopy. (Reproduced with permission from Janikoun 1988.)
the region of 20°. When the trabecula is not visible, the angle is closed and the angle between iris and cornea will be close to zero. However, the angle structures may also not be visible due to the iris being bowed, appositional closure or peripheral anterior synechiae (PAS).

Compression gonioscopy may be performed to differentiate between appositional and synechial closure, or in the presence of a narrow approach to the angle (i.e. the angle between the anterior surface of the iris and the posterior surface of the cornea). Use of the 4 mirror goniolens allows the cornea to be flattened due to its flatter base curve and the smaller diameter of the ocular surface. Pressure applied to the cornea pushes aqueous into the angle thereby forcing the iris away from its insertion. In the case of appositional closure, the iris will move away from the angle, thereby allowing deeper structures to become visible. However, if the iris remains attached to the wall of the angle, then synechiae are present.

In addition, it may be difficult to view the angle structures in an iris with a steep contour. This can be facilitated by using a 3 mirror goniolens and instructing the patient to look towards the D shaped mirror. In order to determine whether an angle is at risk to closure, change the slit lamp to look towards the D shaped mirror. In order to determine the presence or peripheral anterior synechiae (PAS).

Recording gonioscopy. In each quadrant both the most posterior structure visible and the degree of pigmentation is recorded. The iris configuration, presence of iris processes (IP) and other abnormalities such as neovascularization should also be noted.

Additionally, pigment cells may be present in the trabecular meshwork. The amount of pigment is generally graded on a scale from 0 to 4 as follows:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Amount of pigment</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Dense</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>2</td>
<td>Mild</td>
</tr>
<tr>
<td>1</td>
<td>Minimal</td>
</tr>
<tr>
<td>0</td>
<td>None</td>
</tr>
</tbody>
</table>

The iris configuration (flat, concave, convex) and other abnormalities such as neovascularization or anomalous vessels should be noted. Furthermore, when describing the iris architecture one should observe the uniformity of the surface and note any irregularities such as a lacy or thread like appearance.

This information is usually recorded on a cross, denoting the superior, nasal, inferior and temporal quadrants as shown in Figure 17.19.

**Figure 17.19**

_Recording gonioscopy. In each quadrant both the most posterior structure visible and the degree of pigmentation is recorded._

**Slit-lamp examination of the iris**

For iris examination, focal illumination will be used and the slit should be of moderate width. The microscope should be positioned normal to the iris. In patients with a history of proliferative diabetic retinopathy or central retinal vein occlusion, it is essential to scrutinize the iris immediately adjacent to the pupil since this is often the first site to develop iris neovascularization or rubeous. The iris examination at the pupilary border should be conducted with bright light, high magnification and good focus on the anterior region. The new blood vessels are rarely perceptible and often easily missed (Fig. 17.20). Detection of subtle rubeosis, when present, followed by timely panretinal photocoagulation, can generally prevent the development of neovascular glaucoma.

**Slit-lamp examination of the crystalline lens**

A normal crystalline lens when viewed via optic section has distinct boundaries which define the various nuclei and cortex. These zones assist in the localization of lens abnormalities. The most anterior border is the interface between the aqueous humour and the anterior lens capsule. The dark zone immediately posterior includes the anterior capsule and lens epithelium. Moving further posteriorly, a second bright zone marks the anterior limit of the lens cortex. Further boundaries divide...
the cortex from the adult nucleus, and then the adult from the fetal nucleus. On occasion, in younger subjects, a faint stripe separates the juvenile from the adult nucleus, although in most eyes the juvenile nucleus blends into the adult nucleus. The fetal nucleus surrounds the central dark area or embryonic nucleus in the very centre of the crystalline lens. A thick, bean shaped zone defines the inner layers of the fetal nucleus. Lying posterior to the embryonic nucleus is a similar pattern of dark and light boundaries, although the posterior regions generally have steeper radii of curvature (Phelps 1992).

For slit lamp examination of the crystalline lens, an optic section at medium magnification is most often employed since this affords the best approach to differentiate between anterior cortical, nuclear, posterior cortical and posterior sub capsular (PSC) cataracts (Fig. 17.21). A dilated pupil allows improved observation of peripheral cortical spokes and PSC cataracts as well as permitting indirect retroillumination of various lens opacities. As the angle of the illumination system is decreased and nearly matches the microscope which is positioned normal to the crystalline lens, the view abruptly changes at some point and lens opacities can be seen to block the light reflected from the retina. For the inexperienced examiner, it is important to remember that an optically empty structure such as the normal anterior chamber appears black. Similarly, a normal crystalline lens appears darker than a cataract. A patient with a nuclear cataract only will reveal a milky white, yellow or brown nucleus while the remainder of the lens will appear quite dark, i.e. similar to the appearance of the normal anterior chamber. In addition, specular reflection may be used to observe any irregularities on the anterior and posterior surfaces of the crystalline lens.

**Other applications**

The slit lamp can be used in conjunction with accessories to provide additional examination options. These are considered below.

**Pachymetry**

Optical pachymetry has largely become obsolete with the introduction of ultrasound pachymeters (see Ch. 24) and

---

**Figure 17.20** Rubecosis. Note the presence of fine blood vessels on the iris at the pupillary border from 12 to 5 o'clock. These minute vessels often appear as tiny red dots and represent early to moderate rubecosis, which in this case is due to proliferative diabetic retinopathy. Contrast this zone to the normal appearing iris between 6 and 12 o'clock.

**Figure 17.21** Age related cataract. In this three dimensional optic section of the crystalline lens, the slit beam is entering from the right side. The whole oval zone in the centre of the lens is a nuclear cataract. In addition, this view demonstrates a posterior subcapsular cataract on the left side of the image, which appears granular. Both will contribute to a reduction in vision.

Slit scanning topographical systems that can calculate corneal thickness over its whole diameter from elevation maps of the anterior and posterior surfaces (see Fig. 17.6). Nevertheless, optical pachymetry can still be employed through the use of special accessories. The normal thin slit section of the cornea is doubled, using a doubling eyepiece and prism introduced in front of half the image. In this way the back surface of the endothelium can be aligned with the front surface of the epithelium to provide a measure of apparent corneal thickness. A correction for corneal refractive index will permit the real corneal thickness to be determined. An automated method of optical pachymetry was developed by Holden et al (1982) to allow repetitive measures and more repeatable outcomes.

**Aesthesiometry**

Corneal sensitivity may be of interest in certain ocular conditions such as diabetes, dry eye and following refractive surgery or contact lens wear (Campos et al 1992; Bourcier et al 2005; Tavakoli et al 2007). This can be measured using an aesthesiometer to determine corneal sensitivity (Boberg Ans 1955, 1956; Millodot 1977). The instrument, which is mounted on the slit lamp, includes a unit housing nylon filaments of varying lengths. Using the applicator, the filament is brought forward to touch the cornea perpendicularly and then withdrawn. The patient is asked to respond whenever they feel the stimulus. Longer filament lengths apply less pressure to the cornea than shorter filaments (Murphy et al 1998). However, Murphy et al (1996) noted that the technique could modify corneal touch sensitivity by producing slight trauma to the corneal epithelium. Other limitations of the device have also been noted, and a
non contact aesthesiometer which stimulates the cornea by directing a pulse of air of variable pressure and duration has been proposed (Murphy et al 1996, 1998).

Scheimpflug imaging
When imaging the anterior chamber, a large depth of field is required to capture the anterior segment from the cornea to the posterior capsule of the crystalline lens in a single clear image. This can be achieved with a rotating Scheimpflug camera. The Scheimpflug rule states that the image plane, the subject plane and the plane of the camera lens must con verge along a single line (Drews 1964). This technique is discussed further in Chapter 19.

Most recent digital Scheimpflug cameras, such as the Oculus Pentacam (Oculus, Inc., Lynnwood, WA), allow multiple digital images of the anterior segment to be captured along different axes, thereby permitting three dimensional reconstruction of the anterior segment (see Figs 19.5 and 19.6).

Specular microscopy
Routine slit lamp examination can be used to visualize the corneal endothelium using the method of specular reflection (see Fig. 17.10). Indeed, routine examination of the cornea will usually provide an opportunity to see the endothelial mosaic on six occasions, once on each side of the midline in each of the three sweeps across the cornea. High magnification is required (25 ×45), and even then the view obtained is only adequate to give an overall qualitative appreciation of endothelial cell structure.

Although specular reflection at very high magnification often allows the observer to view the corneal endothelial cells, the procedure requires skill, practice and perseverance. Several innovative systems, such as the Noncon Robo Pachy SP 9000 endothelial cell count (ECC) apparatus (Konan Medical Corporation, Fairlawn, NJ), provide remarkable views and photodocumentation of the corneal endothelium for the endothelial mosaic on six occasions, once on each side of the midline in each of the three sweeps across the cornea. High magnification is required (25 ×45), and even then the view obtained is only adequate to give an overall qualitative appreciation of endothelial cell structure.

Although specular reflection at very high magnification often allows the observer to view the corneal endothelial cells, the procedure requires skill, practice and perseverance. Several innovative systems, such as the Noncon Robo Pachy SP 9000 endothelial cell count (ECC) apparatus (Konan Medical Corporation, Fairlawn, NJ), provide remarkable views and photodocumentation of the corneal endothelium for the endothelial mosaic on six occasions, once on each side of the midline in each of the three sweeps across the cornea. High magnification is required (25 ×45), and even then the view obtained is only adequate to give an overall qualitative appreciation of endothelial cell structure.

Although specular reflection at very high magnification often allows the observer to view the corneal endothelial cells, the procedure requires skill, practice and perseverance. Several innovative systems, such as the Noncon Robo Pachy SP 9000 endothelial cell count (ECC) apparatus (Konan Medical Corporation, Fairlawn, NJ), provide remarkable views and photodocumentation of the corneal endothelium for the endothelial mosaic on six occasions, once on each side of the midline in each of the three sweeps across the cornea. High magnification is required (25 ×45), and even then the view obtained is only adequate to give an overall qualitative appreciation of endothelial cell structure.

Although specular reflection at very high magnification often allows the observer to view the corneal endothelial cells, the procedure requires skill, practice and perseverance. Several innovative systems, such as the Noncon Robo Pachy SP 9000 endothelial cell count (ECC) apparatus (Konan Medical Corporation, Fairlawn, NJ), provide remarkable views and photodocumentation of the corneal endothelium for the endothelial mosaic on six occasions, once on each side of the midline in each of the three sweeps across the cornea. High magnification is required (25 ×45), and even then the view obtained is only adequate to give an overall qualitative appreciation of endothelial cell structure.

Other methods of examination
With developments in technology, other methods of examination for the anterior segment are more readily available. These may be used to image structures not visible to the slit lamp biomicroscope.

Ultrasound biomicroscopy
Ultrasound has long been used to examine the eye, especially where direct visualization was prevented by media opacities, and for providing biometric information. The procedure is described in detail in Chapter 19. Ultrasound biomicroscopy (UBM) provides high resolution imaging of the anterior segment using a frequency of approximately 50 Hz, giving resolution of approximately 50 microns and penetration of 4-5 mm. Ultrasound provides images of structures not visible to light microscopy. Figure 17.22 shows the normal anterior eye imaged with UBM.

To obtain good UBM images, an eyecup filled with saline is used to ensure adequate acoustic coupling between the ultrasound probe and the eye, since ultrasound energy travels much faster in a liquid medium than in air. Patient fixation can be an issue and as a result it can take some time to produce a well aligned image of the area of interest. UBM imaging can be used to provide measurements of anterior structures such as anterior chamber depth and crystalline lens thickness as well as to identify structural anomalies or pathology. The degree to which the angle is open can also be assessed from the images. A UBM image of an iris cyst is shown in Figure 17.23.

Optical coherence tomography
Optical coherence tomography (OCT) is a non-invasive, interferometric technique using broadband light sources such as superluminescent diodes or femtosecond lasers. These provide interference at the short working distances required for imaging of the anterior eye and the images are created due to the different reflectivity of the structures being examined. The technique is described in detail in Chapter 18.
OCT is increasingly a non contact, non invasive technique where the accompanying software can produce cross sectional images or build three dimensional images. Figure 17.24 shows an OCT image of an eye with narrow angle glaucoma.

Unlike UBM, OCT is unable to image through the pigmented iris and so mydriasis is generally required. However, images of structures behind the peripheral iris can be obtained if a trans scleral route is used. Resolution of detail within the structure is superior to that of UBM. Both UBM and OCT have been used to image the anterior segment either for detection of anomalies and/or disease (Radhakrishnan et al 2005) or to investigate aspects of accommodation (Ludwig et al 1999; Baikoff et al 2004). In general, both devices perform similarly but the OCT instrument, being non contact and with an adjustable fixation target, is somewhat more user friendly (Radhakrishnan et al 2005).

Summary

Anterior segment examination is an important aspect of optometric examination. Basic hand held instruments can provide information that suggests the need for more detailed examination. Slit lamp examination provides the basis for many diagnoses and is supplemented by attachments that assess the anterior chamber angle, corneal sensitivity, fundus appearance or permit anterior chamber photographs.

More recent methods of imaging including UBM and OCT can provide more detailed assessment of intraocular structures and may help to diagnose abnormality.

Assessment of corneal topography and/or zonal corneal thickness may improve rigid lens fitting, diagnosis of corneal abnormalities or provide improved outcomes for refractive surgery patients and those requiring cataract extraction.

References

Demirbas N H, Plughelder S C 1998 Topographic pattern and apex location of keratoconus on elevation topography maps. Cornea 17:476 484
Dougherty M J, Whyte J, Li W 2007 The phenol red thread test for lacrimal volume - does it matter if the eyes are open or closed? Ophthalmic Physiological Optics 27:482 489
Douthwaite W A 2003 The asphericity, curvature and tilt of the human cornea measured using a videokeratoscope. Ophthalmic Physiological Optics 23:141 150
Douthwaite W A, Matilla M T 1996 The TMS 1 corneal topography measurement applied to calibrated ellipsoidal convex surfaces. Cornea 15:147 153
Douthwaite W A, Matilla M T 1996 The TMS 1 corneal topography measurement applied to calibrated ellipsoidal convex surfaces. Cornea 15:147 153

276

Manning F J, Doughty M J, Narayanan S et al 2004 A comparison of tear volume (by tear meniscus height and phenol red thread test) and tear fluid osmolarity measures in non-lens wearers and in contact lens wearers. Eye and Contact Lens: Science and Clinical Practice 30:132–137


Sicam V A, Van der Heijde R C 2006 Topographer reconstruction of the nonrotation-symmetric anterior corneal surface features. Optometry and Vision Science 83:910–918


Wilson F M II 1976 Rose Bengal staining of epibulbar squamous cell carcinoma. The Ocular Surface 1:20–30


Rosenfield, 978-0-7506-8778-2