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Clinical assessment of anterior chamber depth

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Introduction

The anterior chamber angle is formed by the posterior surface of the cornea, the anterior border of the ciliary body, the trabecular meshwork and the root of the iris. Evaluation of the width of this angle has long been of interest to clinicians as it can potentially identify those patients most at risk of angle closure glaucoma. In addition, angle evaluation may serve to identify patients in whom pupillary dilation may precipitate an attack of angle closure glaucoma. In clinical practice, direct viewing of the anterior angle is not routinely undertaken as it requires a degree of proficiency in the technique of gonioscopy. More commonly, practitioners assess the depth of the anterior chamber. The anterior chamber depth is defined as the distance, measured along the eye's optical axis, from the posterior vertex of the cornea to the anterior surface of the crystalline lens exposed by the pupil.

In common with other ocular dimensions, anterior chamber depth has been studied as a function of age, sex and refractive status. All three are found to influence the depth of the chamber (Tornquist, 1953; Jansson, 1963; Pitts and Millodot, 1966). Typically the chamber depth is 3 mm (normal range 2.6–4.6 mm). However, due to lens growth throughout life, the equatorial diameter of the lens is increased, and as a result the chamber depth is reduced by approximately 0.13 mm per decade from 20 to 70 years of age (Spooner, 1983). This process reverses the increases in chamber depth which accompany eye growth in the first two decades. In general, males have deeper anterior chambers than females of a comparable age (Jansson, 1963). The influence of refractive status on chamber depth has proved more difficult to ascertain. Specifically, the depth of the chamber is influenced by the interactive factors of axial length, corneal and lenticular curvatures, as well as lens location and thickness. However, a general rule of thumb is that deeper chamber depths are associated with axial myopia, and shallow chamber depths are more frequently found in patients with hyperopia. This fact should be borne in mind by clinicians when evaluating anterior chamber depth (ACD).

The techniques currently available for actual measurement of anterior chamber depth can be divided into three categories. The first group comprises the photographic methods which are based upon Scheimpflug's principle (Scheimpflug, 1906; Brown, 1969). The second group comprises the ultrasonic methods. The use of ultrasound is based upon the property of reflection of sound waves at boundary surfaces (Jansson, 1963). Optical methods comprise the third category of techniques. This review is primarily concerned with the measurement of anterior chamber depth rather than evaluation of the anterior angle itself, such as would be carried out using gonioscopy. For a review of gonioscopic methods the reader is referred to recent papers by Prokopich and Flanagan (1996, 1997).

Photographic evaluation of anterior chamber depth

Photography is a useful tool for any type of clinical measurement since it provides a permanent record against which future measurements can be compared. Slit-image photography of the anterior segment of the eye can provide two useful sources of information. Firstly, it can be used to record ocular dimensions such as anterior chamber depth or lens thickness. Secondly, it can provide

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information on the optical densities of the refracting structures within the eye, such as the crystalline lens. This technique is often used to provide densitometric measurements in longitudinal studies of patients with lenticular opacities (Magno *et al.*, 1994).

In order for a photograph of the anterior segment to be useful for measuring ocular distances, the slit beam needs to be directed along the optical axis, observed by a camera placed at an angle to the optical axis, and in focus at all depths. The focusing problem is dealt with by cameras constructed according to Scheimpflug's principle (Scheimpflug, 1906). The solution is to tilt either the objective lens of the camera, the film plane, or both. By doing this the entire plane of the slit-beam can be maintained in focus. A tilted film plane gives a better display of the crystalline lens while a tilted objective lens is preferable for investigating the anterior chamber (Brown, 1969). An example of an image taken by a Scheimpflug camera is shown in *Figure 1*. Contemporary Scheimpflug imaging systems use video systems rather than conventional cameras and on-line computers which capture, store, and analyse video images of the anterior segment of the eye. The high cost of the cameras and the computing hardware/software restrict this technique to research environments.

Figure 1. A Scheimpflug image of the anterior segment of the eye. Ocular dimensions such as anterior chamber depth are directly provided by dedicated software.

Evaluation of anterior chamber depth using ultrasonography

In ultrasonography a quartz crystal, termed the 'transducer', is used to transmit high frequency sound waves (above 20 kHz) through the ocular structures of the globe. Output from the transducer is pulsed at approximately 1000 Hz and, in between pulses, echoes returning from the various internal structures are received, converted and analysed. Ultrasonography serves two main purposes for eye care professionals. Firstly, it enables structures of the eye which are otherwise optically inaccessible to be imaged. Secondly, it permits very precise measurements to be made of distances between optical structures. The technique is rarely performed in routine optometric practice. However, ocular ultrasonography forms an essential part of the pre-operative assessment of patients about to undergo cataract extraction and intra-ocular lens implantation.

Ultrasonography can be divided into three general categories depending on the mode of image display: A-scan, B-scan and M-mode ultrasonography. The latter two categories are of little use when attempting to measure anterior chamber depth. B-scan ultrasonography (Baum and Greenwood, 1958) is used to provide a multi-meridional section of the eye via a composite image of a number of scans taken along different meridians. This technique provides only qualitative information, and allows practitioners to identify areas of interest which can then be quantitatively assessed using alternative techniques. M-mode systems (Coleman and Weininger, 1969) use B-scan echo spots from ocular interfaces in a temporal imaging system. If internal ocular structures remain static the sweep produces parallel lines on the screen. Any movements in the structures, such as the crystalline lens during accommodation, are detected as deviations from straightness of the lines. The technique of choice for measuring anterior chamber depth, or any other biometric measurements for that matter, is axial A-scan ultrasonography. In

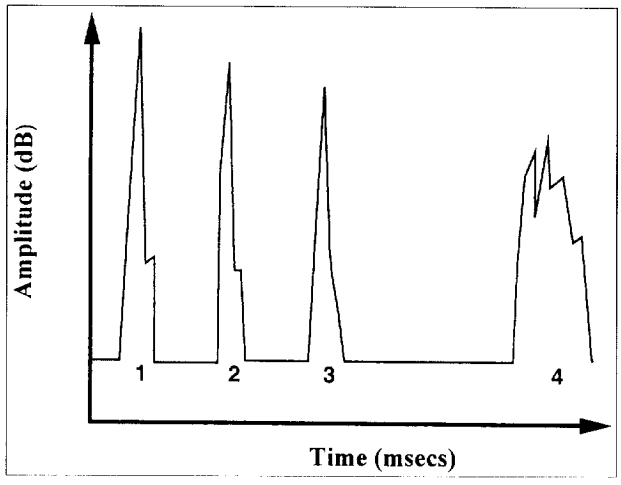

Figure 2. Schematic representation of axial A-scan ultrasonography. Ocular components are identified by spikes from the baseline: (1) cornea; (2) anterior lenticular surface; (3) posterior lenticular surface; (4) retina. The distance between (1) and (2) corresponds to the anterior chamber depth.

this system a static transducer is used to direct high frequency ultrasound, usually along the optical axis of the eye. The resultant echoes from the various ocular interfaces are detected and stored. The deflections which return from structures deeper within the eye, such as the retina, take longer to return and therefore appear further along the time/distance axis of the display (*Figure 2*).

For ophthalmic use, frequencies of 10–12 MHz are necessary and provide a level of precision of approximately ±0.07 mm. However, when examining the anterior segment of the eye, higher frequencies (20–30 MHz) can be employed, since shorter wavelengths will still provide sufficient penetration of the anterior structures and afford improved resolution. Measurement of anterior chamber depth should always be carried out with the eye open and pupil dilated. If the eye is scanned through the lids, anterior structures are subjected to near field distortions, which may render measurements unreliable. The transducer should be held approximately half a centimetre away, with a fluid contact to the front of the eye, usually provided in the form of a stand-off saline couple. The fluid contact is essential since ultrasound travels at a significantly higher velocity in fluid as opposed to air. Alternatively, a non-immersion technique can be employed where the transducer probe is placed in direct contact with the anaesthetised corneal surface, in a manner similar to applanation tonometry. Such an approach is employed by instruments such as the Humphrey ultrasonic biometer (Model 820; Humphrey Instruments, Welwyn Garden City, UK). The advantage of this method is that repeatable results of acceptable accuracy can be obtained with an undilated pupil (Steele *et al.*, 1992). Most modern A-scan systems which are used for biometric measurements provide a fixation light embedded in the transducer tip and record the measurements electronically. Measurement begins when the retinal echo reaches a pre-determined height (*Figure 2*).

There are four principal areas of concern in making accurate ultrasonic measurements of anterior chamber depth.

1. The transducer beam must be carefully aligned along the optical axis of the eye. Significant errors can be introduced by a shift of a few degrees in transducer orientation.
2. With immersion methods the transducer stand-off must not compress or distort the cornea, and when using contact methods there should be minimum contact between the probe and cornea.
3. The measuring beam must be narrow in order to avoid errors when attempting to measure curved surfaces. In addition, the highest frequency transducer which is able to provide the desired depth of penetration should be used to obtain optimum accuracy.
4. The time/distance between echoes must be accurately determined and appropriate tissue velocity correction factors must be applied for conversion into millimetres. Measurements are usually made electronically using an interval counter.

Although not used routinely in optometric practice, accurate A-scan measurements of anterior chamber depth represent the 'gold standard' for this biometric dimension. It is therefore important that clinically viable alternative techniques are assessed relative to this standard. For a more detailed treatment of ocular ultrasonography the interested reader should consult Coleman *et al.* (1977) and Storey (1988).

Optical evaluation of anterior chamber depth: pachometry

In clinical practice the pachometer is normally used as a means for monitoring corneal thickness in contact lens patients. This technique has increased in popularity following the commercial availability of the pachometer attachment for the Haag–Streit slit-lamp. In addition to corneal

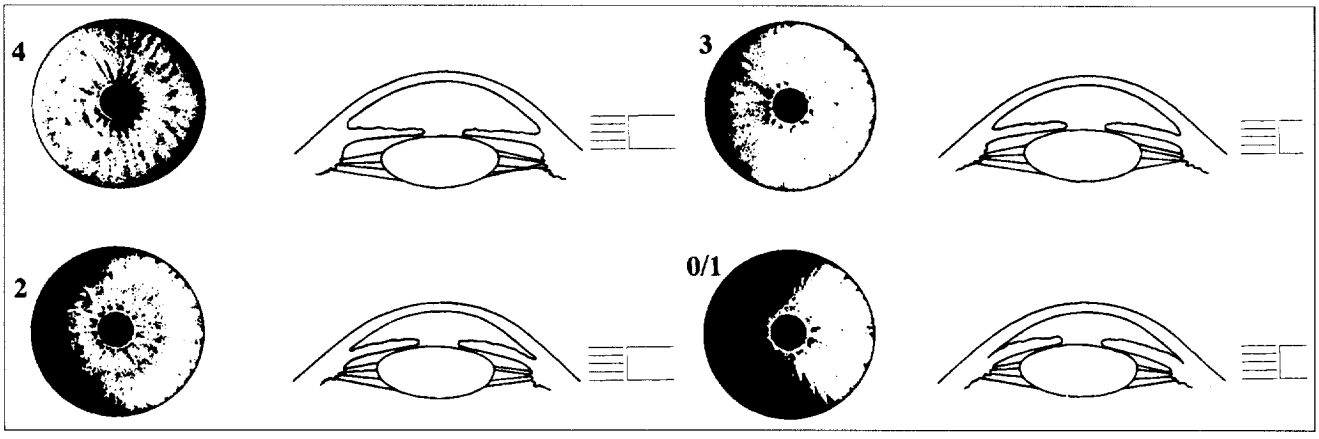

Figure 3. The pen light test for anterior chamber depth estimation. Examples of four different angle grades are given, each of which corresponds to the grades given in *Table 1*.

thickness measurement, this device provides an optical means by which the anterior chamber depth can be measured.

The design of the pachometer is based upon Jaeger's principle (Jaeger, 1952). The device is attached to the slit-lamp such that it occludes the left eyepiece of the microscope whilst, at the same time, locating two glass blocks in front of the right eyepiece. The glass blocks are oriented horizontally such that the junction between them bisects the objective. When the top block is rotated, the image seen through it moves by an amount which depends upon the angle of rotation. In the case of the Haag–Streit pachometer the angle between the microscope and the illumination system should be set at 40°. For corneal thickness measurement the operator notes the location of the two corneal optical sections. The separation of the sections is altered by rotating the plate connected to the top glass block until the outer surface of the epithelium of one section is just touching the inner surface of the endothelium of the other (Henson, 1996). The amount of rotation which yields just touching images is read from the pachometer scale which is calibrated in millimetres. In order to improve the accuracy with which the judgement of just touching surfaces can be made, a special eyepiece is available. The introduction of this eyepiece has the effect of eliminating the upper half of one corneal section and the lower half of the other section. For a more detailed description the reader should consult Henson (1996). The technique is exactly the same when the device is used for anterior chamber depth measurement. In this case the amount of rotation necessary to align the endothelium of the corneal section (lower image) with the anterior lens surface (upper image) is read from the scale as the anterior chamber depth in millimetres.

The pachometer provides an accurate and rapid means of estimating the anterior chamber depth (Barrett *et al.*, 1997) and is more suited to clinical optometric practice than the photographic or ultrasonic methods. However, the pachometer is a costly and often incompatible slit-lamp accessory. This has prompted a search for a slit-lamp technique for chamber depth estimation which does not require any extra attachments (Smith, 1979; Jacobs, 1979; Douthwaite and Spence, 1986).

Optical evaluation of anterior chamber depth: alternative qualitative methods

Assessment of anterior chamber depth in clinical practice typically involves the use of some *qualitative* grading scale to label the chamber depth as shallow, medium or deep (van Herick, 1969). A variety of techniques are available for this classification procedure, including pen light shadow techniques and van Herick's method.

Angle estimation by pen light

The following description of the pen light shadow technique is taken from Elliott (1997).

1. Dim the room lights and ask the patient to look straight ahead.
2. Hold a pen light at an angle of 100° temporally in the horizontal plane of the patient's right eye and rotate it around to 90°. The temporal side of the iris will illuminate.
3. Observe the nasal iris carefully and note how much of it is in shadow (see *Figure 3*)*.
4. Repeat for the left eye.

As is evident from *Figure 3*, increased amounts of shadow on the nasal iris are associated with shallower anterior chamber depths. The angle depth is graded

*Reprinted with permission (Elliott, 1997).

Table 1. Angle estimation by pen light grading system (Elliott, 1997)

Grade	*% Nasal iris in shadow*	*Probability of angle closure*
0	100	Certain
1	75	Highly likely
2	50	Possible
3	25	Unlikely
4	0	Improbable

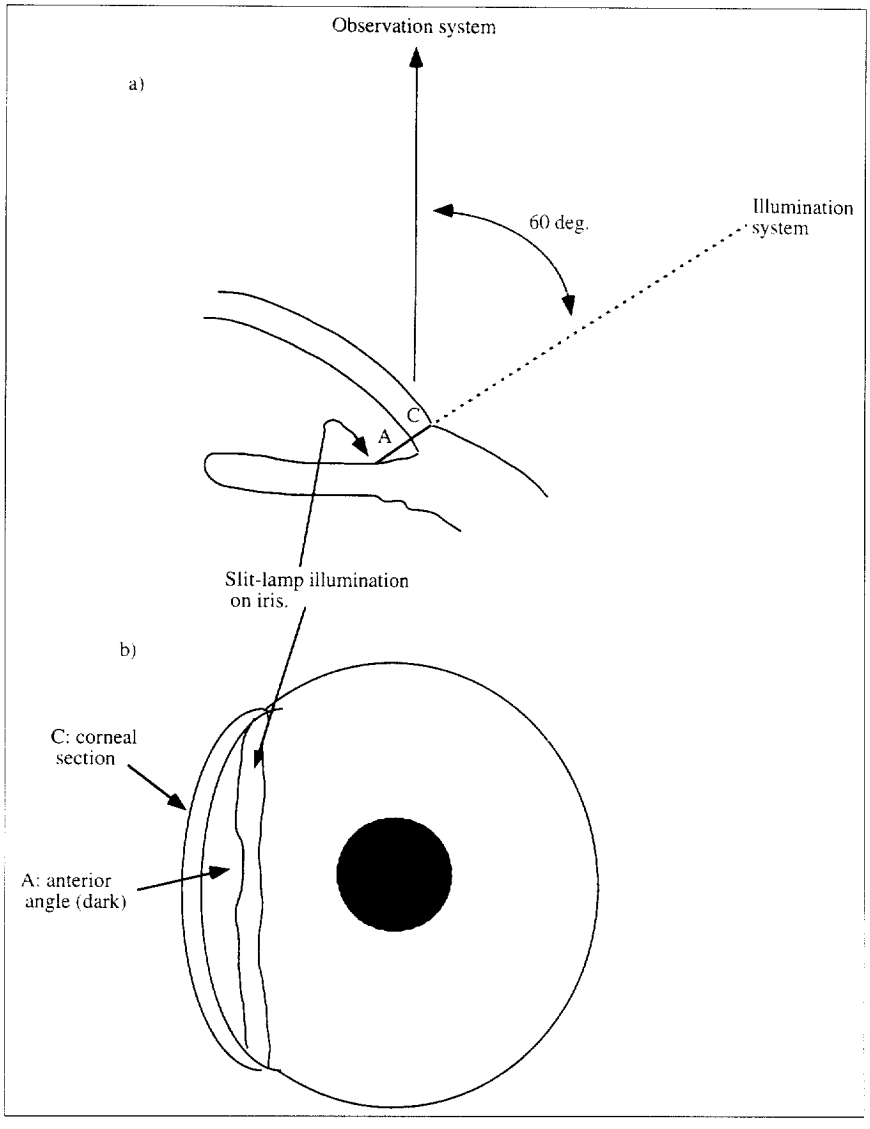

Figure 4. Schematic representation of van Herick's method for anterior chamber depth estimation.

using *Table 1*, and in theory these grades agree with depth assessments carried out using van Herick's method.

*Reprinted with permission (Elliott, 1997).

The advantages of the pen light shadow technique are that it is quick and simple to perform. Furthermore, it is suitable for use in cases where slit-lamp assessment may not be performed, such as in wheelchair-bound patients. Despite these advantages, however, van Herick's method (van Herick, 1969) is preferred where circumstances permit.

van Herick's angle assessment

Elliott (1997) recommends the following procedure for angle assessment using van Herick's method (van Herick, 1969):

1. Seat the patient at the slit-lamp biomicroscope. Adjust the biomicroscope magnification to the medium setting (~16×).
2. Narrow the beam to an optic section with the illumination at 60° temporal to the microscope. Adjust the illumination temporally to the very edge of the limbus, keeping the cornea in focus. Judge the depth of the anterior chamber by the width of the optically clear space between the cornea and the iris. Compare this width to the width of the cornea (*Figure 4*)*. Record the result using a ratio or van Herick's grading system (*Table 2*).
3. Repeat for the nasal edge of the cornea. In the uncommon event that the nasal and temporal grades differ, it is suggested that the narrower angle should be accepted as the angle grade.
4. Repeat for the other eye.

This technique is popular because it is simple to perform and because good agreement exists between chamber classifications determined using the technique when compared to gonioscopic gradings. The principal disadvantage of van Herick's method and the pen light shadow technique is that they do not provide an actual measure of the anterior chamber depth. Contrary to popular belief, accurate chamber depth *measures* can be obtained quickly, and without the need for supplementary

Table 2. Angle estimation by van Herick's grading system (Elliott, 1997)

Grade	*Cornea : ACD*	*Probability of angle closure*
0	Closed	Certain
1	<1:0.25	Highly likely
2	1:0.25	Possible
3	1:0.50	Unlikely
4	1:1	Improbable

equipment. The method is described in the following section.

Optical evaluation of anterior chamber depth: alternative quantitative methods

In 1979, Smith suggested a slit-lamp method for measuring the depth of the anterior chamber which does not require any extra attachments. The only requirement is that the slit-lamp has a calibrated, variable slit-length facility. A second method for measuring anterior chamber depth without the need for slit-lamp accessories was described by Jacobs (1979) at around the same time. This method is very similar to that described by Smith (1979), therefore only Smith's method will be described here.

The method of anterior chamber depth measurement suggested by Smith involves the following procedure. The biomicroscope is placed in the straight ahead position directly in front of the eye under investigation. The illumination system is located in the subject's temporal field, such that an angle of 60° is formed between the observation and illumination systems. The right eyepiece is used for the patient's right eye, and vice versa. The patient is instructed to fixate the biomicroscope. A moderately thick slit-beam (1–2 mm) is oriented horizontally and is focused on the cornea. A second image of the slit is formed by the anterior lens capsule/iris (*Figure 5*)*. Beginning with a short slit, the slit length is slowly increased. This reduces the gap between the corneal and lenticular/iris slits. The length of the slit is further increased until the two appear to be just touching (*Figure 5*). The slit length which yields this endpoint is noted.

*Figure 6** shows a simplified optical diagram of the situation depicted in *Figure 5B*. The slit length for which the two images are just touching, AB, is clearly not a direct measure of the anterior chamber depth, AC. If no refraction occurred at the cornea, however, the chamber depth could be determined by simple calculation, because the length of one side of the triangle ABC is known (AB), and the angle ACB is also known (60°). The anterior chamber depth, AC, would therefore be determined as follows:

$$\text{Sin } 60^\circ = AB/AC, \quad \text{so}$$
$$AC = AB/\text{Sin } 60^\circ.$$

The slit beam is, of course, refracted by the cornea. The situation is further complicated by the fact that the extent to which the slit-beam is refracted is dependent upon the length of the slit (Smith, 1979). Taking these factors into account makes it extremely difficult to determine the chamber depth accurately and would therefore, appear to render the technique impractical for clinical use. However, the problem has been circumvented by examining the relation between the length of slit which yields just-touching images (*Figure 5B*) and the anterior chamber depth estimates obtained

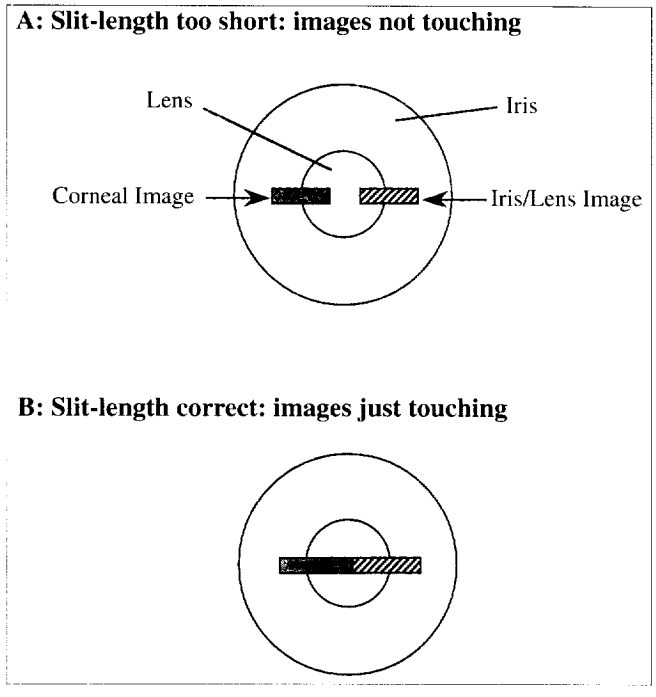

Figure 5. Schematic representation of the observer's view of corneal and lenticular/iris images produced using Smith's slit-length method.

*Reprinted with permission (Barrett *et al.*, 1997).

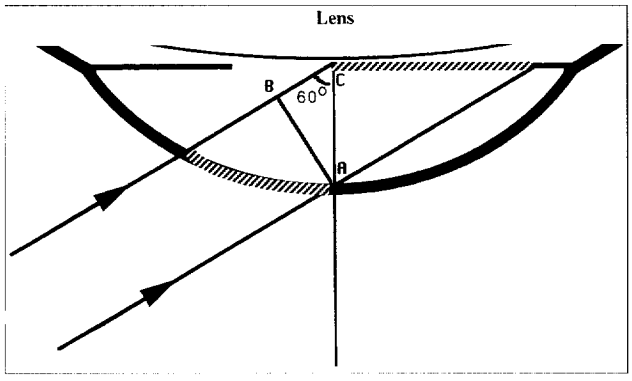

Figure 6. Optical diagram showing the condition where the corneal and lenticular images are just touching. The corneal and lenticular

using a pachometer in large subject samples. Using this approach, Jacobs (1979) and Smith (1979) have found chamber depth estimates obtained using the slit-length technique which are accurate within ±0.2 and ±0.25 mm respectively, relative to standard pachometry estimates. Hence, converting the slit-length which yields just-touching images to an anterior chamber depth simply involves multiplying the slit-length by a constant. Smith found the value of this constant to be 1.4, which is very nearly equal to 1/sin 60°.

Barrett *et al.* (1996) provided further evidence in support of the clinical utility of this technique. Chamber depth estimates were obtained in fifty visually normal subjects using the techniques of ultrasonography, pachometry and Smith's slit-length method. However, the value of the constant yielding best agreement was 1.34 for ultrasonography. For pachometry it was 1.31, and not 1.4 as quoted by Smith (1979). Comparison of the chamber depths obtained across the three techniques reveals that Smith's method provides estimates of anterior chamber depth which are accurate to within ±0.33 mm in 95% of cases relative to pachometry. These values compare well with Smith's own results (95% range: ±0.25 mm). Also, Barrett *et al.* (1996) reported that the slit-length method provides estimates of chamber depth which are accurate within ±0.42 mm in 95% of cases relative to ultrasonography. The conversion from the just-touching slit-length to the ACD, using the constant calculated for ultrasonography, is presented in *Table 3*.

Chamber depths of 2 mm or less should arouse caution with respect to pupillary dilation (Smith, 1979).

Douthwaite and Spence (1986) described a modification of the method suggested by Smith (1979) for use in cases where a variable slit length is not available. The procedure suggested is identical to that described above for Smith's method, with the exception of the fact that it is the angle between the illumination and observation system of the biomicroscope which provides the means for estimating anterior chamber depth. Prior to using this technique the practitioner should note the position on the slit-length scale which corresponds to a slit length of 2 mm. This simple calibration procedure needs to be done only once. In carrying out the technique, the illumination system is placed in front of the eye. A horizontally oriented slit of 2 mm is centred in the pupillary aperture. The practitioner views the horizontal slit images (identical to those depicted in *Figure 5*) with the observation system located 80° on the temporal side and the illumination system in the straight ahead position. The microscope eyepiece nearest the illumination system is used for observation. As the angle between the observation and illumination systems is reduced by moving the microscope, the image of the slit formed on the cornea will move close to the image of the slit formed on the lens/iris. The angle is reduced until the images are just touching, as shown in *Figure 5B*. Douthwaite and Spence (1986) verified the accuracy of the technique relative to standard pachometry measures. The chamber depth may be read from a table, such as that shown below. A useful approximation is that a 1° change in the angle between the observation and illumination systems corresponds to a change in anterior chamber depth of about 0.1 mm (*Table 4*).

This review highlights the fact that a number of options exist for measuring anterior chamber depth. While ultrasonography pro-

Table 3. Conversion between slit-lengths yielding just-touching images and ACD measures

Slit-Length (mm)	ACD (mm)
1.5	2.01
2.0	2.68
2.5	3.35
3.0	4.02
3.5	4.69

Table 4. A comparison of the angle between illumination and observation systems yielding just-touching images and corresponding ACD measures

Angle (degrees)	*ACD (mm)*
35	4.22
40	3.87
45	3.52
50	3.17
55	2.83
60	2.48

vides the most precise measure of chamber depth, alternative techniques which can be performed using standard clinical equipment are available. Van Herick's angle grading system and the penlight technique remain the most common methods used for assessing chamber depth in optometric practice. However, these are qualitative techniques and clinicians should be aware that quantitative methods, such as that described by Smith (1979), provide accurate measurements without the need for slit-lamp accessories. It is suggested that such simple techniques should be used in all patients prior to dilation and in patients whose signs/symptoms are suggestive of angle-closure glaucoma.

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