Introduction

Glaucoma is a progressive optic neuropathy characterized by optic disc changes, nerve fiber layer damage, and visual field defects, and it is the second leading cause of blindness in the world [1,2]. In 2010, it is estimated that 60.5 million people worldwide will have glaucoma, 74% with primary open-angle glaucoma (POAG) and 26% with primary angle-closure glaucoma (PACG) [3]. Asians account for 47% of those with POAG and 87% of those with PACG, indicating that Asia has a much higher prevalence of PACG than the Western world [3–12]. The prevalence of PACG and the blindness caused by PACG are characteristically higher than that of POAG among Taiwanese [6], Chinese [8–12], Mongolians [7], and Eskimos [4,5]. The risk of bilateral blindness, in general, is 2.5 times higher in PACG than in POAG [3]. Thus, the diagnosis and treatment of PACG is a very important public health issue in Asia.

PACG is identified in the presence of angle closure with glaucomatous optic neuropathy, visual field defect, or both. Angle closure is defined as an occludable angle in which ≥270° of the posterior trabecular meshwork cannot be seen. In addition, there are features which indicate that the meshwork is obstructed by the peripheral iris, such as peripheral anterior synechiae (PAS), elevated intraocular pressure (>21 mmHg), iris whorling, or excessive pigment deposition on the surface of the meshwork [13]. Glaucomatous optic neuropathy is indicated by a cup-to-disc ratio (CDR) of ≥0.7, CDR asymmetry of ≥0.2, a neuroretinal rim width reduced to ≤0.1

Ocular Biometry in Primary Angle-closure Glaucoma

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Primary angle-closure glaucoma, which is more prevalent in Asia than in Western countries, causes considerable visual morbidity. Compared with normal eyes, eyes with primary angle-closure glaucoma are characterized by a shallow anterior chamber, thick lens, relatively anterior lens position, and short axial length. The biometric characteristics of chronically affected eyes tend to be midway between those of normal eyes and those with acute angle closure. A disproportionately thick, anteriorly situated lens in a small eye poses the greatest risk of acute angle closure. A-scan ultrasound is useful for assessing ocular biometry and can therefore be used in screening for and diagnosing angle closure.

KEY WORDS — anterior chamber depth, ocular biometry, primary angle-closure glaucoma

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of the CDR, vertical elongation of the cupping, focal thinning of the neuroretinal rim, and nerve fiber layer defects [13]. A visual field defect is defined as three or more contiguously non-edged points (except at the nasal horizontal meridian) abnormally depressed to the \( p < 0.05 \) level [14]. Early detection of angle closure or an occludable angle at risk of closure is crucial, because laser iridotomy is effective in preventing further closure, elevated intraocular pressure, and glaucomatous optic neuropathy [15–18]. Currently, gonioscopy is the gold standard for identifying angle closure or an occludable angle. However, it is a subjective assessment requiring considerable experience to perform correctly, and there is no quantitative measurement for comparison and follow-up. More advanced technologies have been developed to evaluate the angle, such as Scheimpflug photography, ultrasound biomicroscopy, and anterior segment optical coherence tomography. These methods, however, may not be available or practical for rural areas or developing countries in Asia where PACG is such an important public health issue. A simple and rapid screening method to detect a narrow angle is needed. A-scan ultrasound is one such method in use since the late 1970s [19,20]; it is an inexpensive, portable, easily administered technique for assessing ocular biometry [21–24] and is therefore an important tool in screening for PACG [6,25,26].

### A-Scan Ultrasound

A-scan ultrasound is a one-dimensional acoustic display commonly used in ophthalmology to assess ocular biometry and intraocular lens variables, diagnose microphthalmos, and monitor congenital glaucoma. A-scan ultrasound operates at a frequency of 10 to 15 MHz, with a sound velocity of 1,550 m/sec for phakic eyes or 1,532 m/sec for aphakic or pseudophakic eyes, with the addition of an appropriate correction factor for the composition of the intraocular lens [27]. The examination can be performed by either the contact or immersion technique. In the contact technique, the probe is either placed on the chin rest (applanation method or slit-lamp ultrasound) or held by the examiner (hand-held ultrasound) and is applied gently to the center of the cornea. In the immersion technique, the probe is placed in fluid within an immersion shell without touching the cornea. Both techniques provide accurate results, but immersion is generally believed to be more precise, because direct contact may introduce some degree of corneal compression. The axial length (AL) measured by immersion is reportedly 0.14 to 0.36 mm longer than that obtained by the contact technique [27]. The contact echogram demonstrates four spikes, the first representing the probe tip on the cornea, followed by the anterior lens capsule, posterior lens capsule, and retina (Figs. 1 & 2).

**Fig. 1.** Contact axial A-scan echogram of a normal phakic eye. The distances between I and A, A and P, and I and R are the anterior chamber depth (ACD), lens thickness (LT), and axial length (AL), respectively. In this example, the ACD is 3.33 mm, the LT is 4.1 mm, and the AL is 23.17 mm. A = anterior lens capsule; I = initial spike; P = posterior lens capsule; R = retina.

**Fig. 2.** Contact axial A-scan echogram of a phakic eye with primary angle-closure glaucoma. In this example, the anterior chamber depth is 2.0 mm, the lens thickness is 5.71 mm, and the axial length is 22.10 mm. A = anterior lens capsule; I = initial spike; P = posterior lens capsule; R = retina.
The immersion echogram has the same four spikes but also yields a double-peaked corneal spike. The ocular biometry measurements obtained by either of the techniques are the anterior chamber depth (ACD), lens thickness (LT), and AL.

Ocular Development

Ocular biometry changes dramatically in the first several years of life. The anterior segment of the neonatal eye is about 75% to 80% of the size of an adult, whereas the posterior segment is more than 50% smaller than an adult [28]. The AL at birth is approximately 16 mm [28], after which it continues to grow until it reaches the adult length at about 13 years of age [29]. There is a rapid postnatal growth phase in the first 18 months, adding 4.3 mm to the AL. From 2 to 5 years (i.e. the infantile phase), it increases by 1.1 mm, followed by the final, slower juvenile phase from the age of 5 to 13 years, during which time it grows an additional 1.3 mm [30]. In an adult, the AL is approximately 23.6 mm [31,32], the ACD is about 3.24 mm [31], and the LT is about 4.63 mm [32]. The depth of the anterior chamber decreases and the thickness of the lens increases with age, although these trends seem to reverse in the seventh decade and beyond [32,33].

Biometric Characteristics of PACG

Compared with normal eyes (Fig. 1), eyes with PACG have a shallower anterior chamber [21–24], a thicker lens [21–23], a more anterior lens position [21,22], and a shorter ocular AL (Fig. 2) [21–23]. The ACD of eyes with PACG is less than 3.0 mm (range, 2.29–2.77 mm), about 0.5 to 1.0 mm shallower [21,34] than that of normal eyes (range, 2.81–3.33 mm) [35–37]. The LT in PACG is usually greater than 5.0 mm (range, 4.73–5.43 mm), while that of normal eyes is about 4.5 mm (range, 4.3–4.73 mm) [22,34,38], which is a difference of about 0.3 to 1.0 mm [21,22,34–37]. The AL in PACG (range, 22.01–22.48 mm) is about 1.0 mm less than that of normal eyes (range, 23.16–23.38 mm) [21,22,35–37]. As a result, eyes with PACG usually have a relatively thicker lens (lens/axial length factor [LAF]=[LT/AL]×10) than normal eyes. In addition, the lens in PACG is situated more anteriorly than in normal eyes [22,34,38]. All of these factors contribute to the development of angle closure and, eventually, to glaucoma.

The depth of the anterior chamber depends on the position of the anterior lens surface and is determined by the thickness and the position of the lens inside the eye. Lowe compared Australians with angle closure to normal patients and concluded that 66% of the difference was attributable to a more anteriorly positioned lens and 33% to a thicker lens [21]. In Chinese patients, however, Friedman et al found that LT was the major contributor to a shallow anterior chamber [39]. Regardless of the precise anatomic factors in any particular eye, a shallow ACD is generally considered to be the most important biometric feature indicating a risk for angle closure.

Anterior chamber depth

The association between a shallow ACD and the risk of PACG has been documented in Inuit [4,40], Mongolians [25], Indians [41], and Australians [21]. The risk is significantly increased when the true ACD (i.e. from the posterior surface of the cornea to the anterior surface of the lens) is reduced from 2.5 mm to 1.0 mm [42]. Furthermore, there is an inverse relationship between the ACD and both PAS and glaucomatous optic neuropathy [43], although there is some variation in this correlation in different populations. For example, in patients from Singapore, PAS increases consistently across the entire range of ACD, whereas Mongolians do not appear to develop PAS until the ACD drops below a threshold of 2.4 mm [43]. The varied patterns of PAS development suggest that the mechanism of PACG might differ among different populations.

ACD normally varies with the same demographic factors that are associated with PACG risk, which include older age, female gender [5,44,45] and ethnicity (Tables 1 and 2). ACD increases from birth
to the age of 20 because of the axial growth of the globe, and then decreases with age as the lens thickens. Among a series of Belgians without eye disease, for example, the ACD was 2.5 mm at birth, 3.25 mm at 20 years (end of growth), and 2.65 mm after 60 years [46]. A similar pattern of ACD that changes with age has been found in Inuits [47], with an increase between 7 and 15 years of age, a rapid decrease from 16 to 40, and a slower but continued decline thereafter. The end result is an ACD that is shallower in older people compared with young people [48–51]. Women have a 0.08 to 0.18 mm shallower ACD than men [50–53] and a faster age-related change (0.21 mm vs. 0.15 mm per decade) [48]. Women, therefore, have a correspondingly greater age-related decrease in the angle than do men [54,55]. Ethnic groups with a higher prevalence of PACG generally have a shallower ACD [48,56]. The Eskimos of Alaska, Canada and Greenland with a relatively shallow ACD have a PACG prevalence of 2.65% to 5% [5,57–59], compared with Caucasians whose ACD tends to be deeper [33,46,60] and among whom the prevalence of PACG is only 0.1% to 0.4% [61,62]. Both the ACD and the disease prevalence among Chinese and Mongolians are intermediate between the above-mentioned groups. The mean ACD among Chinese in Singapore is 2.9 mm [51] with a prevalence of PACG of 1.1% [9], similar to values in Chinese living in China (mean ACD, 2.57 mm [63,64]; PACG prevalence, 1.3% to 1.66% [11,65]). The ocular biometry has been compared among Alaskan Eskimo, Taiwanese Chinese, and white and black residents of Baltimore, all using the same methodology [33,60], Eskimos have a significantly shallower ACD and thicker lens than any of the other groups. The AL of Eskimos is shorter than that of Taiwanese Chinese and blacks, but not whites. Chinese in general have ocular biometric parameters similar to those of whites and blacks, but they have a higher prevalence of PACG. It appears that the anterior chamber angle declines more rapidly among Chinese and Eskimos than among blacks or whites [33], which may partially explain the higher risk for PACG. Other factors that may contribute to the risk among Chinese include creeping angle and a plateau iris configuration [66–69].

**Lens thickness and position**

The lens continues to grow throughout life at the rate of 0.02 mm per year until after the seventh decade [50,51,70]. Among whites, the LT in the fifth decade is 4.57 mm, that of Mongolians is 4.2 mm, and that of Chinese is 4.4 mm. The respective mean measurements in the seventh decade are 4.99 mm, 4.5 mm, and 4.89 mm. The lens moves forward about 0.4 to 0.6 mm by around the age of 70 [22,32,34,38,71]. The observed faster lens growth in eyes with PACG suggests that an abnormal growth pattern may play an additional role in the development of PACG [70]. No significant differences in LT have been found between men and women [33,50,51].

### Table 1. Anterior chamber depth (ACD) of normal eyes by age, ethnicity and gender

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>ACD for ages 40–49 years (mm)</th>
<th>ACD for ages 60–69 years (mm)</th>
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<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td>Mongolian [48,50]</td>
<td>3.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Chinese in Singapore [51]</td>
<td>3.25</td>
<td>3.08</td>
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<tr>
<td>Chinese in Taiwan [49]</td>
<td>3.15</td>
<td></td>
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</tbody>
</table>

### Table 2. Anterior chamber depth (ACD) of normal eyes by ethnicity and gender

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>ACD in men (mm)</th>
<th>ACD in women (mm)</th>
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</thead>
<tbody>
<tr>
<td>Mongolian [50]</td>
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<tr>
<td>Chinese in Singapore [51]</td>
<td>2.99</td>
<td>2.81</td>
</tr>
<tr>
<td>Indian [52]</td>
<td>3.06</td>
<td>2.91</td>
</tr>
<tr>
<td>Eskimo [53]</td>
<td>2.57</td>
<td>2.49</td>
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</table>
Biometric characteristics of acute angle closure

Acute angle closure (AAC) is characterized by dramatic symptoms, which may include eye pain, blurred vision, headache, halos around lights, nausea, and vomiting. Ophthalmologic findings include markedly elevated intraocular pressure, corneal edema, iris bombe, a nonreactive mid-dilated pupil, and a shallow anterior chamber with angle closure. Laser iridotomy to widen the angle [72] is the accepted initial treatment for AAC to relieve pupillary block [15,68,73]. It is performed bilaterally even when the AAC is unilateral, because approximately half of individuals with AAC in one eye will subsequently have an attack in the other eye within 5 years [74]. The visual prognosis in AAC is guarded. Half of the patients have glaucomatous optic nerve damage and nearly one-fifth are blind in the affected eye on long-term follow-up [75].

The biometric characteristics in eyes with AAC are of interest, particularly in comparison with eyes with chronic angle closure. As in PACG, eyes with AAC and their fellow eyes have a much shallower ACD, thicker lens, and shorter AL than normal eyes [35,36,39,49]. Eyes with acute and intermittent PACG are at the opposite extreme from normal eyes in terms of ACD, LT, LAF, and relative lens position \((\frac{\text{ACD} + \frac{1}{2} \text{LT}}{\text{AL}} \times 10)\), with eyes with chronic angle closure falling between the extremes [35,36]. Eyes affected with AAC have a shallower ACD (by 0.07 to 0.12 mm) and more anterior lens position than their unaffected fellow eyes, which may themselves not fall within the normal range [35,76]. Measurements of LT and AL, however, have been inconsistent. A study in Taiwan [35] demonstrated that eyes with AAC had a thicker lens but an AL similar to that of fellow eyes. In contrast, a study in Singapore [76] found a shorter AL but not a thicker lens in eyes with AAC.

The differences between AAC eyes, unaffected fellow eyes, and chronic PACG eyes in ocular biometry may help clarify factors that predispose to AAC. Compared with eyes with chronic PACG, eyes with AAC have the shallowest ACD, thicker lens, shorter AL, larger LAF, and more anterior lens position. The LT tends to be similar in the unaffected fellow eyes and chronic PACG eyes. The shorter AL in unaffected fellow eyes results in a larger LAF, compared with that calculated in eyes with chronic angle closure. The difference between eyes with AAC and fellow eyes is only in the ACD and relative lens position. Briefly, a disproportionately thick lens, especially when located in an eye with shorter AL, constituted the predisposing factor of AAC. It is the anteriorly situated lens which plays a crucial role in AAC [77].

Screening for PACG by Ocular Biometry

Ocular biometry has been evaluated as a screening tool for an occludable angle and angle closure. In terms of receiver operator characteristics, the area under the curve for detecting an occludable angle is good at around 0.8 to 0.9 [25,26], although the diagnostic accuracy depends somewhat on the measurement method used. Optical pachymetry performs better than ultrasound. When using ultrasound, the slit-lamp technique is slightly better than hand-held ultrasound [25,26]. In Mongolians, an ACD of less than 2.53 mm as measured by hand-held ultrasound has a sensitivity of 86% for detecting an occludable angle and a specificity of 73% [25]. Comparable values reported for Singaporeans are 76% for sensitivity and 74% for specificity [26]. A study in Taiwan reported a sensitivity of 77% and a specificity of 87% using a cutoff value of 2.7 mm [6]. A Taiwanese study assessed the risk of AAC using the biometry of the fellow eyes of those previously affected by AAC, suggesting the following cutoff values: ACD < 2.7 mm, LT > 4.7 mm, AL < 22.8 mm, and LAF > than 2.1 [49].

Conclusion

In summary, eyes with PACG are relatively small and have a crowded anterior segment. A shallow ACD is the most important risk factor for PACG and is statistically associated with the formation of PAS,
glaucomatous optic neuropathy, and demographic risk factors for PACG. A disproportionately thick, anteriorly situated lens is the key risk factor for AAC. Ocular biometry by A-scan ultrasound is a good, easy way to assess these characteristics and is therefore recommended both in screening for PACG and in assessing patients with either acute or chronic angle closure in daily clinical practice.

References


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