Imaging of the Anterior Segment in Glaucoma

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INTRODUCTION
Glaucoma is the leading cause of irreversible blindness worldwide, and has been projected to affect 79.6 million people by the year 2020.1 Primary angle-closure glaucoma (PACG) causes more visual morbidity than its primary open-angle glaucoma (POAG) counterpart and is particularly more prevalent among East Asians.2

Just as our current management of open-angle glaucoma has shifted from detecting worsening of visual fields to using imaging to detect earlier structural changes in the optic nerve and retinal nerve fiber layer, our management of angle-closure glaucoma is also shifting towards earlier detection of narrow angles that are at risk of closure.

Eyes with PACG tend to share similar biometric features, including shallow anterior chamber depth, thick or anteriorly positioned lens, short axial length and small corneal diameter or radius of curvature.3-5 Ultrasound biomicroscopic parameters such as anterior chamber angle, angle-opening distance, area of recessed angle, trabecular ciliary process distance and scleral-ciliary process angle have also been reported to be smaller in PACG eyes.6 Furthermore, studies have shown that simple laser procedures such as laser peripheral iridotomy and laser iridoplasty effectively widen the anterior chamber angle,7-9 and hence may be a good prophylactic measure to reduce the risk of progression onto PACG, provided that these eyes at risk are detected early enough, before the formation of peripheral anterior synechiae. Hence, it is both possible and desirable to screen for and detect early angle-closure, and to initiate prophylactic measures before significant glaucomatous optic neuropathy results, with its accompanying visual morbidity, as well as healthcare costs and economic burden to the society.

Recently, various ophthalmic imaging technologies including the anterior segment optical coherence tomography and the scanning peripheral anterior chamber depth analyzer have been developed to evaluate the anterior chamber and its angle. Their uses, accuracy and repeatability, advantages and disadvantages as well as their ease of use are all important to consider, whether they are intended for use in the clinical setting or if they are to be incorporated into mass screening programs. Furthermore, their place alongside gonioscopy and more established technologies such as the ultrasound biomicroscopy must also be considered carefully. The aim of this article is to review these new technologies.

ULTRASOUND BIOMICROSCOPY (UBM)
The UBM was first developed around the late 1970s in the laboratories of Stuart Foster and Charles Pavlin in Toronto, Canada.

Principles
This imaging technology uses a high frequency piezoelectric transducer, coupled to a microprocessor-controlled radio-frequency signal generator, to convert electrical signals into ultrasonic sound waves of a specific high frequency ranging from 35 to 100 MHz. This transducer is mounted on a vibration-free mechanism in a probe which is positioned over the cornea. The ultrasonic sound waves are delivered to the eye through saline solution that is held either in a reservoir within an eye cup or within the distal end of the probe (in some newer models of UBM), that is placed on the cornea. These sound waves are propagated through the various ocular tissues at different speeds as they encounter tissue of varying acoustic impedance (density) and are reflected back after different time intervals. The reflected sound waves are then collected and assembled by the computer and magnified to provide a high resolution sectional B-scan image. Operating at 50 MHz, it gives an axial resolution of up to about 20 μm.

Uses and Advantages
UBM allows real-time imaging of ocular structures in the anterior chamber as well as certain structures of the posterior chamber such as the ciliary body, the lens zonules and the anterior choroid. Such dynamic in vivo imaging allows study of the relationships between ocular tissues such as between the peripheral iris and the trabecular meshwork, hence enabling the glaucomatologist to evaluate the width of the anterior chamber angle and its occludability under varying illumination intensities. Its main advantage lies in its ability to image structures behind the iris such as the ciliary body.10 This allows evaluation of the underlying mechanisms that may be responsible for angle-closure,11 such as an anterior rotation or anterior position of...
the ciliary body giving rise to a plateau iris (Fig. 1) configuration, or the presence of an iridociliary cyst or tumor that may be causing an apparently similar pseudoplateau configuration (Fig. 2). These causes may hence be differentiated from other mechanisms of angle-closure such as pupil block or peripheral angle crowding which require different forms of treatment. Hence, UBM is useful in assisting the glaucomatologist to decide on an appropriate form of treatment depending on the underlying mechanism of angle-closure. UBM is also useful in the evaluation of open-angle glaucoma such as in pigment dispersion syndrome where the posterior pigmented surface of the iris can be seen to drape over the anterior lens surface and lens zonules. This reverse pupil block can be seen to be relieved by a laser peripheral iridotomy. In pseudoexfoliation syndrome, the presence and extent of lens zonulysis may also be evaluated with UBM.

Disadvantages

However, as this technology requires sound waves to be propagated through a water bath to the eye being imaged, contact with the eye is necessary either in the form of an eye cup placed on the sclera or in the form of a probe placed on the cornea. This contact with the eye introduces discomfort to the patient and the possibility of image artifacts due to inadvertent indentation of the eye. There are also risks of corneal abrasions and infections. Furthermore, older UBM models that use an eye cup to hold the water bath require patients to be imaged in a supine position. This may induce an artifactual widening of the anterior chamber angle. Other disadvantages of UBM include the need for a skilled and experienced operator. Even in the best of hands, the procedure can be rather time-consuming. Difficulty in determining precisely the exact meridian of the area being examined also implies a lack of standardization between UBM scans that makes quantification of angle parameters more variable.

ANTERIOR SEGMENT OPTICAL COHERENCE TOMOGRAPHY (AS-OCT)

The AS-OCT is a recently developed technology that offers an alternative method of anterior chamber imaging.

Principles

This technology uses low-coherence interferometry to produce in vivo cross-sectional images of tissue structure and is analogous to UBM in that a probe beam is directed onto biological tissue, and reflections returning from the tissue are analyzed to obtain depth information. Light, however, is used instead of sound. Anterior segment imaging using OCT was first demonstrated in 1994 using light of wavelength 830 nm. More recently, AS-OCT using light of wavelength 1310 nm has been reported to demonstrate better detail of non-transparent tissues due to its increased penetration, while allowing sufficient illumination power to be used to enable high-speed imaging (Fig. 3).

Using high-speed Fourier domain optical depth scanning technology, it scans rapidly at a speed of 2000 A scans per second and minimizes motion artifact. It gives an axial resolution of 18 µm and a transverse resolution of 60 µm. It is able to scan the anterior segment up to a depth of 6 mm and a width of 16 mm.

Uses and Advantages

The cross-sectional imaging capability of AS-OCT is similar to that of UBM, with the added advantage of higher spatial resolution. Its main advantage is its rapidity of image acquisition,
where the anterior segment may be imaged along up to 4 meridians (a total of 8 angles) with just one acquisition in 0.5 seconds. The preciseness of the meridian being scanned allows standardization of scans between different eyes so that quantification, especially for purposes of research, becomes much more accurate. The technology can be easily operated with minimal expertise by a technician, and both intra- and interobserver reproducibility of measurements has been reported to be high.15 With minimal requirements for expertise and rapidity of image acquisition, this suggests a possible role of AS-OCT in mass screening for patients with angle-closure in the primary care setting.

AS-OCT has been demonstrated to be useful in the evaluation of trabeculectomies, including assessment of bleb morphology and patency of the sclerostomy16 (Figs 4A and B).

It can also be used to assess patency and position of the tubes of glaucoma drainage devices (Fig. 5).

The non-contact nature of AS-OCT also implies that patients may be imaged immediately preoperatively or postoperatively without the worry of introducing infection or corneal abrasion. The absence of contact also ensures that there is no inadvertent distortion of the anterior segment during image acquisition. Other advantages of AS-OCT includes its uses outside of glaucoma such as for corneal pachymetry, measurement of thickness of LASIK flaps and residual stromal beds, and for dynamic measurements in response to an accommodative stimulus.

A study comparing AS-OCT with gonioscopy found that AS-OCT detected more closed angles than gonioscopy.17 This disparity was attributed to differences in illumination (AS-OCT was performed in total darkness, while gonioscopy was performed with a minimal slit-lamp light beam in a totally darkened room) and possible distortion of the anterior segment by contact gonioscopy.

Disadvantages

Its main disadvantage is its inability to image structures posterior to the iris.

SCANNING PERIPHERAL ANTERIOR CHAMBER DEPTH ANALYZER (SPAC)

The SPAC was even more recently developed to enable assessment of the peripheral anterior chamber depth.

Principles

The SPAC takes consecutive slit lamp images from the optical axis of the eye to the limbus. These images are captured on a small charge-coupled device camera and are automatically analyzed by the computer. In total, 21 measurements of the anterior chamber depth are obtained at 0.4 mm intervals and are converted into numerical and categorical grades by comparison with a normative database.18
Uses and Advantages

The SPAC device requires minimal expertise to operate and measurements are rapidly obtained in a non-contact method. An improved version of the SPAC comes equipped with an autofocus system for anterior chamber depth, an automeasuring system for determining central corneal thickness and corneal radius of curvature, an autodiagnosing program for differentiating eyes with narrow angles and an auto-classifying program for categorizing eyes in subgroups according to anterior chamber depth values. This improved system has been demonstrated to measure anterior chamber depth with good accuracy and reproducibility and therefore has been suggested as a useful tool for glaucoma screening.\textsuperscript{19,20}

While one study found that SPAC measurements of anterior chamber configuration correlated with conventional methods such as Shaffer grading, van Herick grading and UBM,\textsuperscript{21} another study found that the device showed a lower sensitivity and specificity in the detection of angle-closure in comparison with modified van Herick grading when gonioscopy was used as the reference standard.\textsuperscript{22}

Central corneal thickness and corneal radius of curvature measurements may also be obtained with the SPAC system.

Disadvantages

The SPAC is able to measure anterior chamber depth only on the temporal side of the eye. Measurement becomes difficult when peripheral corneal opacities are present. In addition, the SPAC is not able to detect the presence or absence of peripheral anterior synechiae. Another disadvantage is its use of visible light which may induce pupil miosis and hence artifactual widening of the angle.

PENTACAM

Principles

The Pentacam uses a rotating Scheimpflug camera to image the anterior segment from the cornea to the posterior surface of the lens in three dimensions. It is based on Scheimpflug photography, a technique that was invented and patented by Theodor Scheimpflug in 1904 in Vienna for the creation of accurate maps in the military. A Scheimpflug slit imaging device was only later developed for ophthalmological purposes in the 1970s\textsuperscript{23} (Fig. 6).

Uses and Advantages

The Pentacam is a non-contact device that offers a rapid 3-dimensional analysis of the anterior chamber. It may be used to measure anterior chamber depth and volume, anterior chamber angle, corneal pachymetry, corneal radius and diameter of curvature and lens position\textsuperscript{24} (Fig. 7). The measurement process takes less than 2 seconds. Measuring a total of 25,000 true elevation points, precise representation, repeatability and analysis are possible.

Disadvantages

As the angle recess cannot be directly visualized, the Pentacam does not allow any angle assessment in detail. The width of the anterior chamber angle is measured by extrapolating from the corneal endothelial and anterior iris surfaces.

CONCLUSION

With budgetary constraints and different training experiences, the types of devices used by clinicians will vary from center to center. The wide biological variability in ocular structures and pathogenic mechanisms underlying angle-closure also affect the usefulness of the imaging devices. There is therefore a need to establish which device, or combination of devices, may be reliably used as a standard in clinical practice. As more information becomes available through research and our understanding of the various imaging devices increases, their
integration into clinical practice will continue to refine and shape our management of glaucoma. While some devices may be improved upon or even become obsolete in future, let us hope that we will be able to retain those that are of value.

REFERENCES