Sonomed Quarterly Bulletin
Volume One, January 2008

Dear Sonomed Colleagues:

Sonomed is proud to announce the VuMAX II Ultrasound Biomicroscope is experiencing huge success in the global ophthalmic markets. The incredible resolution in conjunction with the wider scanning area opens up new opportunities in anterior segment imaging.

Together with the traditional use of the high frequency ultrasound devices (glaucoma, trauma, tumors, etc.), the VuMAX II also provides valuable images for applications in almost every anterior segment lens implanting procedure.

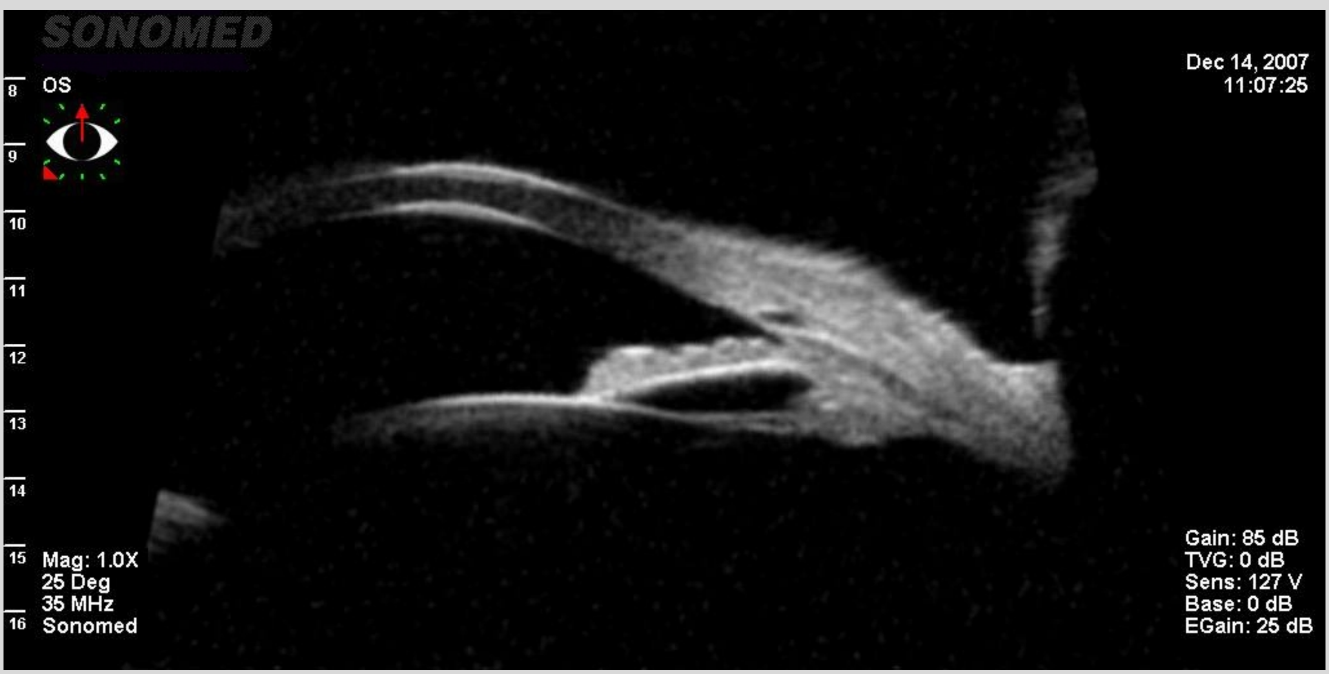
This quarterly bulletin will keep everyone related to the VuMAX II project up to date on new features, unique applications and new methodologies.

The most recent implemented feature is the ability to process angle images with the Ishikawa Pro2000® software. This feature has been added to the VuMAX II software and works with all images of the anterior chamber showing the required landmarks.

A detailed explanation of the procedure and the benefits of the Pro2000 software are attached to this bulletin.

We are also attaching a basic description of the various applications that the VuMAX II offers during anterior segment imaging.

In the following paragraph you will find a very interesting image (video clip attached as Schlemm Canal.pps) of the Schlemm Canal. The Schlemm Canal is usually collapsed and therefore, very difficult to image.



Viscocanalostomy, 30 moths ago.Quatroelle Centri Oftalmochirurgici, Carlo Lovisolo M.D.

Please feel to contact Sonomed for any suggestions, comments or request about this bulletin.
Jaquaffreda@escalonmed.com

Sonomed VuMAX II

High-frequency ultrasound biomicroscopy (UBM) provides high-resolution in vivo imaging of the anterior segment in a noninvasive fashion. In addition to the tissues easily seen using conventional methods (ie, slit lamp), such as the cornea, iris, and sclera; structures including the ciliary body and ciliary processes, previously hidden from clinical observation, can be imaged and their morphology assessed. Pathophysiologic changes involving anterior segment architecture can be easily evaluated.

Equipment and technique,

The technology for UBM, originally developed by Pavlin, Sherar, and Foster, is based on 35 and or 50 MHz transducers incorporated into a B-mode clinical scanner. Higher frequency transducers provide higher resolution of more superficial structures, whereas lower frequency transducers provide greater depth of penetration with less resolution. Room illumination, fixation, and accommodative effort affect anterior segment anatomy and should be held constant, particularly when quantitative information is being gathered.

The image acquisition technique has been described elsewhere and is similar to traditional immersion B-scan ultrasonography.

Unlike other units, the VuMAX II has a small, lightweight probe which avoids the use of uncomfortable counterbalanced arms to hold big and heavy probes. Scanning is performed with the patient in the supine position. A plastic eyecup of the appropriate size is inserted between the eyelids, holding normal saline coupling medium. To maximize the detection of the reflected signal, the transducer should be oriented so that the scanning ultrasound beam strikes the target surface as perpendicularly as possible.

The normal eye,

In a normal eye, the different anatomical structures can be easily recognized.

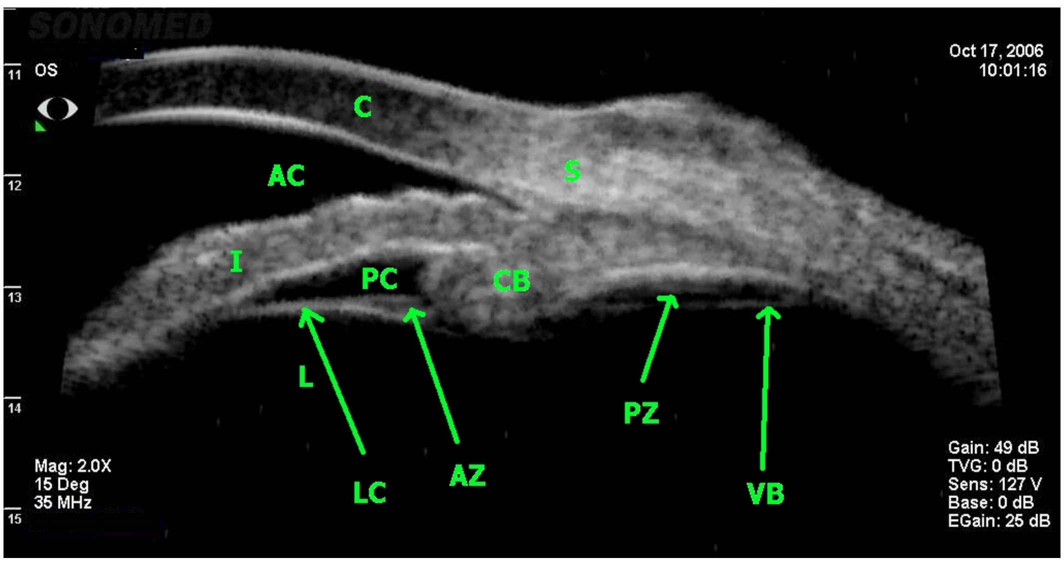


Fig. 1: Ultrasound biomicroscopic appearance of a normal eye. The cornea (C), sclera (S), anterior chamber (AC), posterior chamber (PC), iris (I), ciliary body (CB), lens capsule (LC), lens (L), anterior and posterior zonula (AZ – PZ) and Vitreous base (VB) can be identified. The scleral spur is shown in the following image.

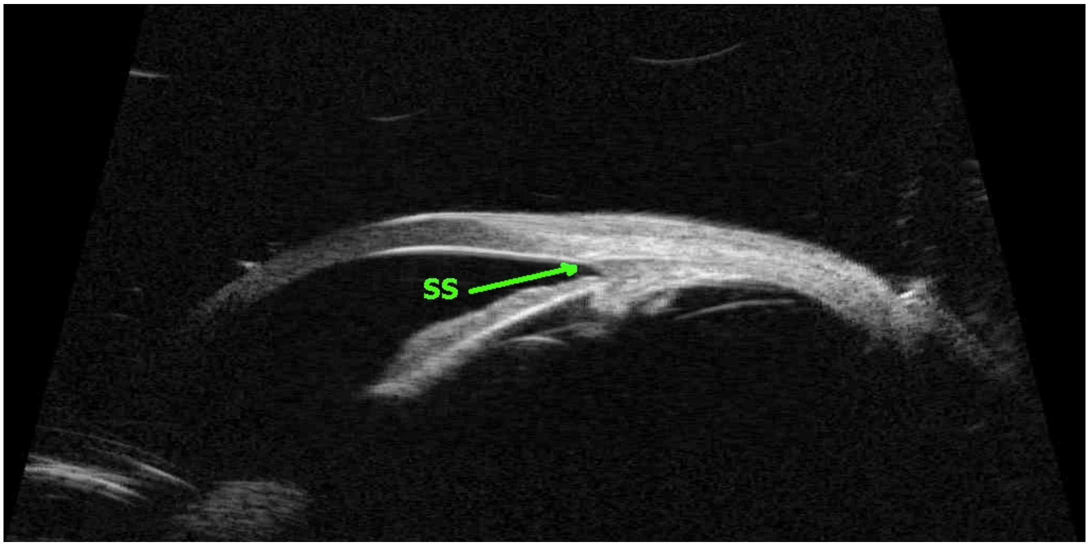


Fig. 2: Scleral Spur (SS).

The scleral spur is the only constant landmark allowing one to interpret UBM images in terms of the morphologic status of the anterior chamber angle and is the key for analyzing angle pathology. The scleral spur is located where the trabecular meshwork meets the interface line between the sclera and ciliary body.

Generally, in the normal eye, the iris has a roughly planar configuration with slight anterior bowing, and the anterior chamber angle is wide and clear. Morphologic relationships among the anterior segment structures alter in response to a variety of physiologic stimuli (ie, accommodative targets and light); then maintaining a constant testing environment is critical for cross-sectional and longitudinal comparison.

Glaucoma

Angle-closure Glaucoma

Iris apposition to the trabecular meshwork is the final common pathway of angle-closure glaucoma, which represents a group of disorders. This condition can be caused by one or more abnormalities in the relative or absolute sizes or positions of the anterior segment structures, or by abnormal forces in the posterior segment that alter the anatomy of the anterior segment.

Forces are generated to cause angle closure in four anatomic sites: the iris (pupillary block), the ciliary body (plateau iris), the lens (phacomorphic glaucoma), and behind the iris by a combination of various forces (malignant glaucoma and other posterior pushing glaucoma types). Differentiating these affected sites is the key to provide effective treatment.

UBM is extremely useful for achieving this goal.

Angle occludability

Examining eyes with narrow angles requires careful attention to the occludability of the angle. Although provocative testing, such as dark room gonioscopy, is useful for detecting the angle occludability it is now rarely used, because it is subjective, time consuming, and prone to false-negative results owing to the difficulty of standardizing the slit-lamp light intensity. With UBM, dark room provocative testing can be performed in a standardized environment generating objective results by providing information on the state of the angle under normal light conditions and its tendency to occlude spontaneously under dark conditions.

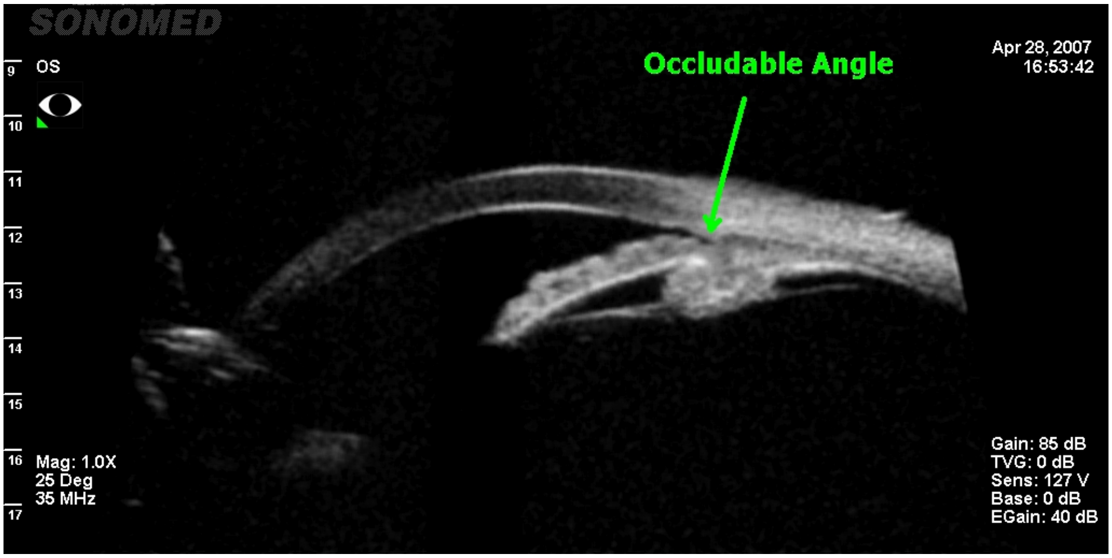


Fig. 3: Occludable angle.

Pupillary block

Pupillary block is the most common type of angle-closure glaucoma. At the iridolenticular contact, resistance to aqueous flow from the posterior to the anterior chamber creates an unbalanced relative pressure gradient between the two chambers, pushing the iris up toward the cornea. This abnormal resistance causes anterior iris bowing, angle narrowing, and acute or chronic angle-closure glaucoma. The other anterior segment structures and their anatomic relationships remain normal.

Laser iridectomy equalizes the pressure gradient between the anterior and posterior chambers and flattens the iris. The result is a widened anterior chamber angle.

Plateau iris

A plateau iris configuration occurs owing to a large or anteriorly positioned ciliary body (pars plicata), which pushes the iris root mechanically up against the trabecular meshwork (Fig. 4). The iris root may be short and inserted anteriorly on the ciliary face, creating a narrow and crowded angle. The anterior chamber is usually of medium depth, and the iris surface looks flat or slightly convex, just like in a normal eye.

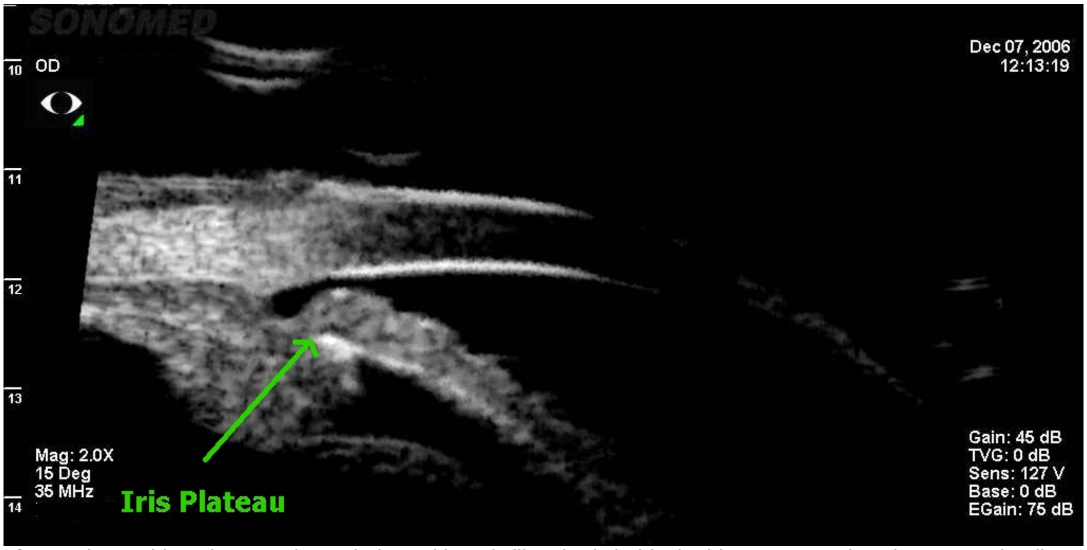


Fig. 4: Plateau iris. A large and anteriorly positioned ciliary body holds the iris root up against the cornea, leading to a partially occluded angle.

Phacomorphic glaucoma

Anterior subluxation of the lens may lead to angle-closure glaucoma because of the lens pushing the iris and ciliary body toward the trabecular meshwork.
Another circumstance is large size of the crystalline lens which is associated with aging cataracts (Fig. 5).

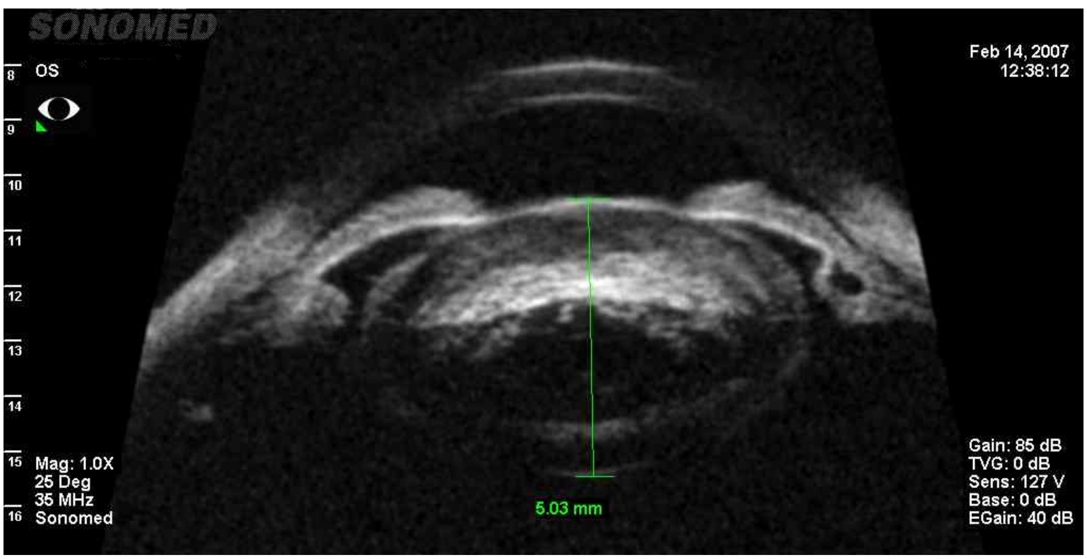


Fig. 5: Mature Cataracts showing a big Lens pushing and narrowing the anterior chamber angle.

Malignant glaucoma

Malignant glaucoma, also known as ciliary block or aqueous misdirection, presents the greatest diagnostic and treatment challenge. Forces posterior to the lens push the lens-iris diaphragm forward, causing angle closure. UBM clearly shows that all anterior segment structures are displaced and pressed tightly against the cornea with or without fluid in the supraciliary space.

Other causes of angle closure

Iridociliary body cysts can produce angle-closure glaucoma. The anterior chamber angle is occluded partially or intermittently owing to singular or multiple cysts (Fig. 6).
UBM is extremely useful in making the diagnosis in these cases.

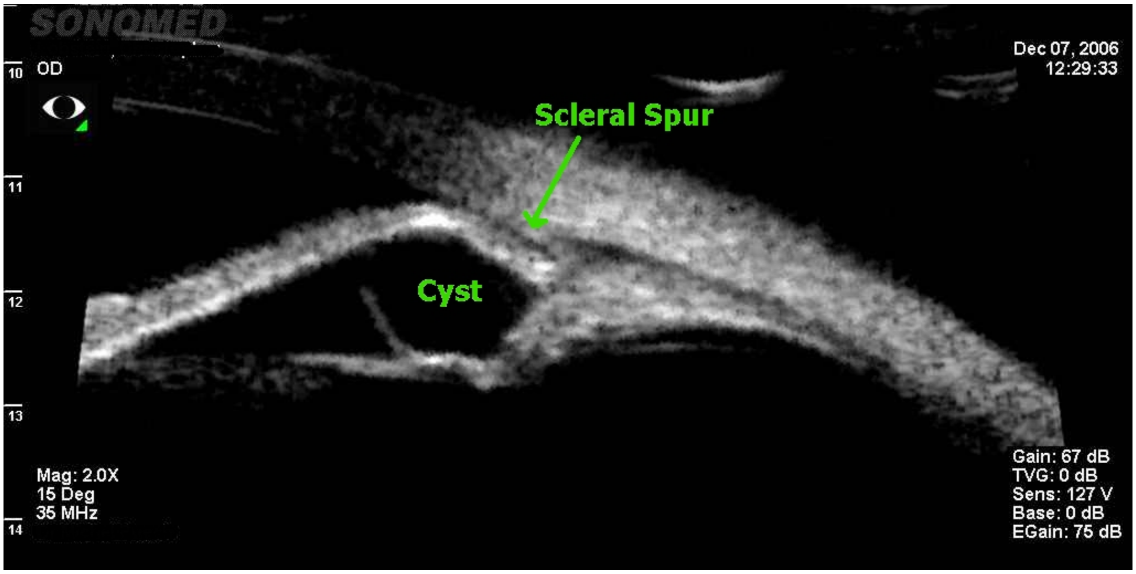


Fig. 6: Iris cyst.

Other entities, such as Iridociliary tumors (Fig. 7), enlargement of the ciliary body owing to inflammation or tumor infiltration may also present angle closure.

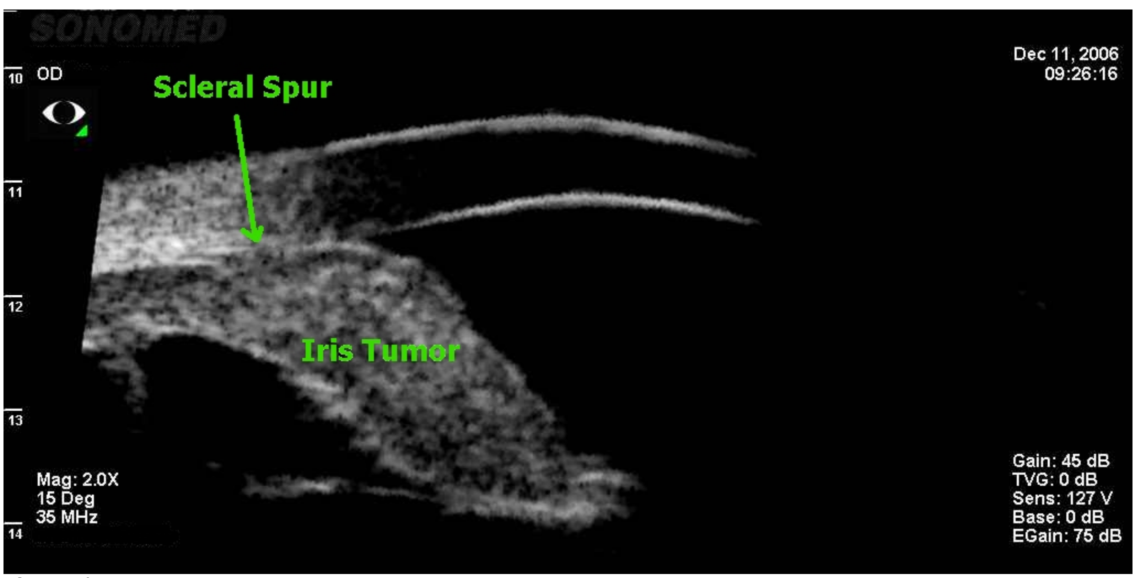


Fig. 7: Iris Tumor.

Open-angle glaucoma

The only type of open-angle glaucoma that shows characteristic findings on UBM is the pigment dispersion syndrome. In this familial autosomal dominant disease, mechanical friction between the posterior iris surface and anterior zonular bundles releases iris pigment particles into aqueous flow. These particles are deposited on structures throughout the anterior segment.

Abnormalities of the iris and ciliary body

Ultrasound biomicroscopy is helpful in differentiating solid from cystic lesions of the iris and ciliary body. The size of these lesions can be measured, and the extent to which they invade the iris root and ciliary face can be evaluated.
In hypotony cases, UBM can distinguish tractional from dehiscence ciliary body detachment, which requires different management approach.

Ocular trauma

Ocular trauma often limits the visibility of the ocular structure owing to the presence of hyphema (Fig. 8).

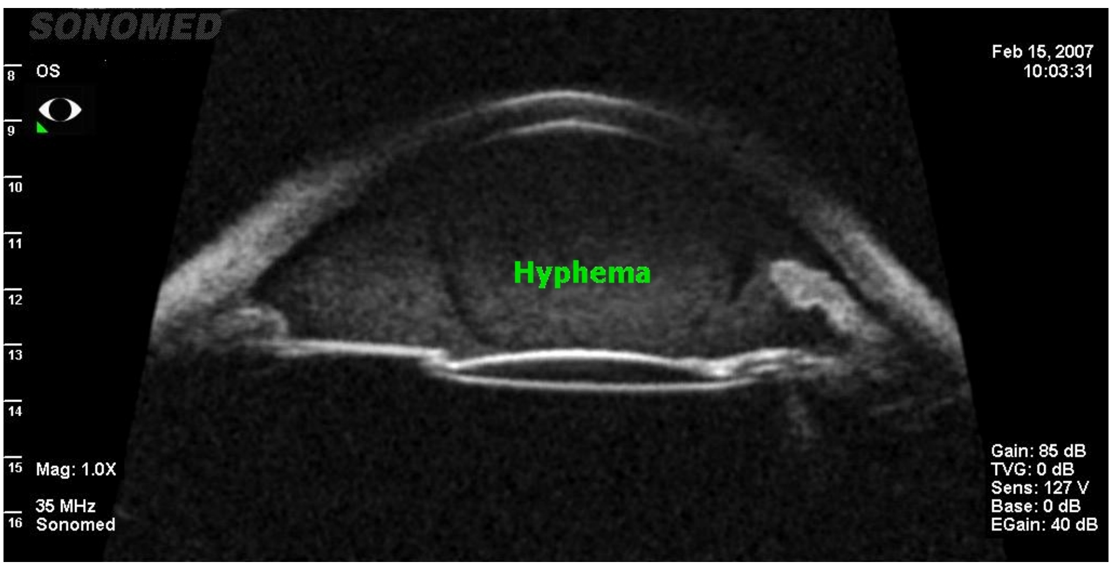


Fig. 8: Hyphema.

Accurate assessment of the structural damage and locating small foreign bodies can be a challenging task when clear direct visualization is not achieved.

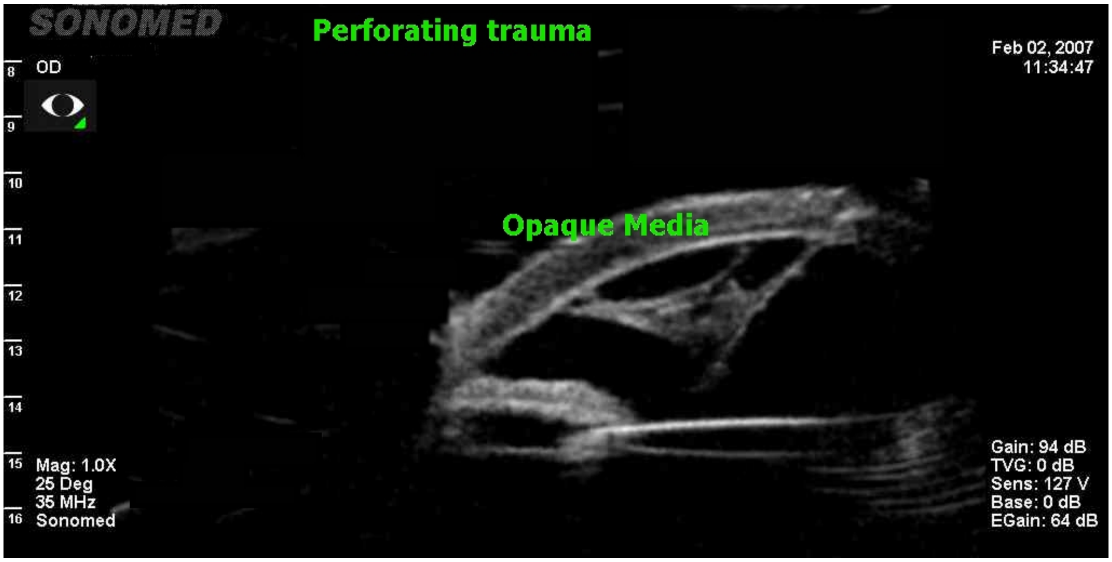


Fig. 8: Trauma, opaque media.

Intraocular lens position

An intraocular lens is an easy target for UBM visualization, because it is a type of foreign body. Optic and haptic locations can be assessed accurately by looking for a strong echo at their interface plane.

Because the capsular bag cannot always be visualized, the most peripheral portion of the haptic defines its position in the capsular bag, ciliary sulcus, or a dislocated point (Fig. 9).

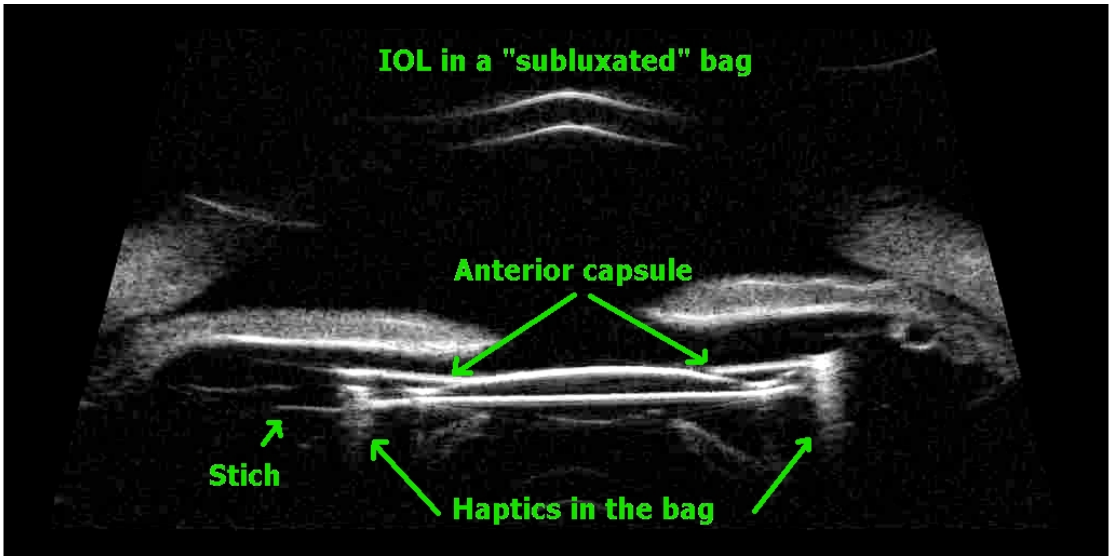
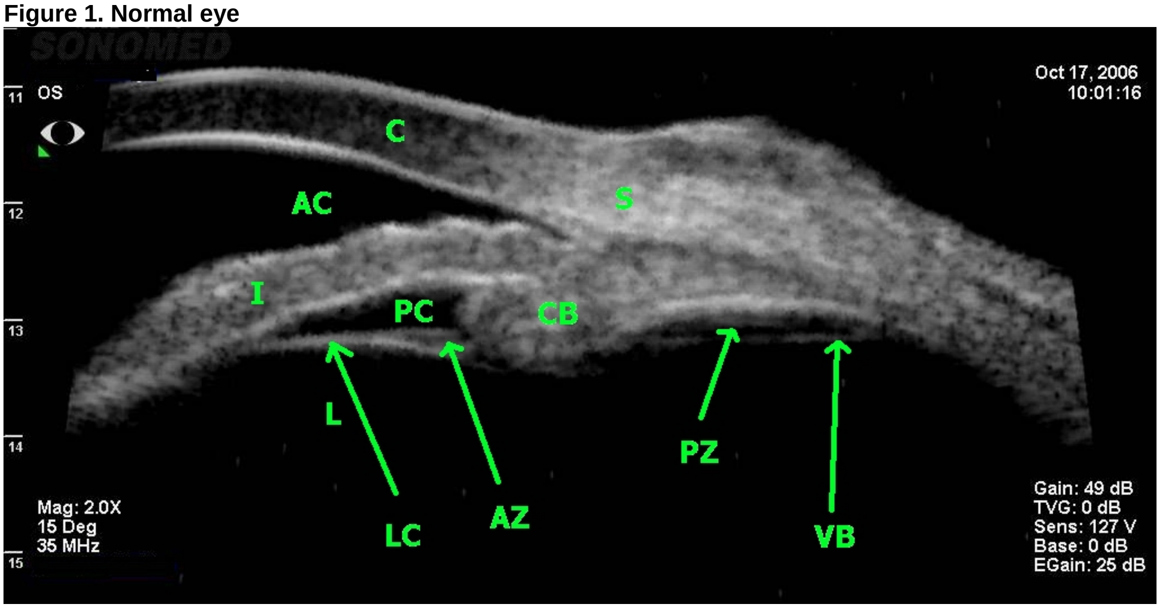


Fig. 9: Marfan Syndrome, an IOL has been implanted in a “subluxated” bag. A suture holds the IOL centered.

Anterior segment evaluation using the VuMAX II

The development of ocular imaging devices has progressed rapidly during the past 10 years. Ultrasound biomicroscopy has revolutionized the evaluation of the anterior segment of the eye. The qualitative information gathered using this technology has contributed to our understanding of the pathophysiology of angle-closure glaucoma, pigmentary glaucoma, and a variety of other anterior segment disorders. However, the area of quantitative analysis of ultrasound biomicroscopic images remains largely to be developed. This review describes the role of ultrasound biomicroscopy in the measurement of the anatomic structures and their configurations within the anterior segment. Application of quantitative image analysis techniques should yield significant information about mechanisms of appositional angle closure, dynamic functions of the iris, accommodation, and presbyopia.
Emerging imaging technologies are providing important information regarding disease pathophysiology, diagnosis, progression, and treatment.
High-frequency ultrasound biomicroscopy allows high resolution, *in vivo* imaging of the anterior segment. The structures of the posterior chamber, previously hidden from clinical observation, can be assessed. The relationships between tissues and their architectures in disease can be evaluated. Although a large body of literature on qualitative UBM findings now exists, quantitative analysis largely remains to be developed. Qualitative assessment of UBM images has already provided significant insights into a wide variety of diseases such as angle-closure glaucoma and pigmentary glaucoma. The development of quantitative image analysis techniques has the potential to significantly improve our knowledge about various anterior segment conditions.

Figure 1. Normal eye



C= Cornea, S= Sclera, AC= Anterior Chamber, I= Iris, PC= Posterior Chamber, L= Lens, LC= Lens Capsule, CB= Ciliary body, AZ-PZ= anterior and posterior zonula, VB= Vitreous base

Basics of ultrasound biomicroscopy

Equipment

The technology of UBM is based on 35- to 50-MHz transducers incorporated into a B-mode sector scanner. Higher frequency transducers provide finer resolution of more superficial structures, and lower frequency transducers provide greater depth of penetration with less resolution. The commercially available unit operates at 35 and/or 50 MHz and provides lateral and axial physical resolution of approximately 50 and 25 µm, respectively. Tissue penetration is approximately 18 mm. The scanner produces a field of up to 14 × 18-mm, with 256 vertical image lines (or A-scans). The scan rate can as high as 22 frames per second.
The real-time image is displayed on a video monitor and can be saved as frames or recorded on video (AVI) for later analysis. Room illumination, fixation, and accommodative effort affect anterior segment anatomy and should be held constant, particularly when gathering quantitative information.

Physical resolution and measurement precision

Understanding the difference between physical axial resolution and measurement precision is important in understanding the potential and limitations of quantitative analysis of UBM images. Axial resolution specifies how close two objects can be along the axis of the beam and yet remain distinct. This resolution specifies the smallest object detectable along the axis of the beam.
Measurement precision refers to the width and height of a single pixel on the screen that can be identified by the operator using the screen cursor. The measurement software calculates distance by counting the number of pixels along the measured line and multiplies that number by the width or height of a single pixel. Thus, the result of the calculation always equals the width or height of a single pixel (18 microns) multiplied by some integer in a measurement along the vertical or horizontal line.
However, it is possible for measurement precision to have a smaller value than the physical axial resolution. The theoretical axial measurement precision on the monitor is approximately 18 µm. This means that although UBM cannot distinguish two small objects less than 25 µm apart, it is still possible to measure the distance between two objects far enough apart (>50 µm; *eg,* corneal thickness and anterior chamber depth) with 12-µm precision.

Quantitative measurement methods

Proposed methods

Pavlin and Foster proposed various quantitative measurement parameters that have been used as established standards (Table 1; Fig. 2). The position of the scleral spur is used as a reference point for most of their parameters, because it can be consistently distinguished in the anterior chamber angle region.

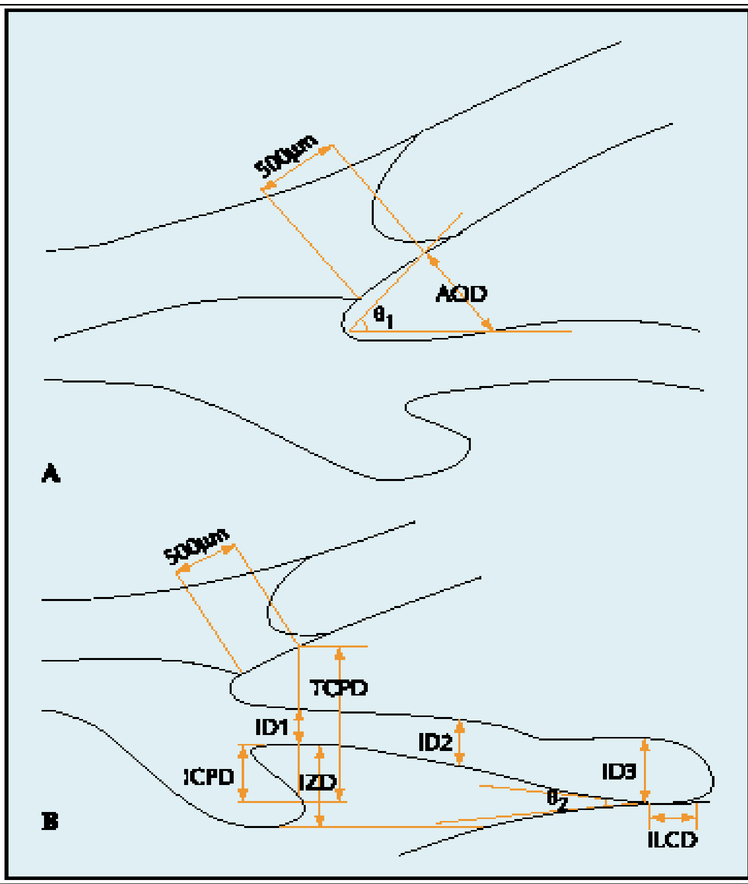
Iris concavity and convexity

It is also known the importance of iris concavity, to observe dynamic configurational changes. A line is first created from the most peripheral point to the most central point of iris pigment epithelium. A perpendicular is extended from this line to the iris pigment epithelium at the point of greatest concavity or convexity (Fig. 3).

Table 1. Parameters proposed by Pavlin and Foster

Name/Abbreviation	Description	Figure
Angle opening distance (AOD)	Distance between the trabecular meshwork and the iris at 500 µm anterior to the scleral spur	**2A**
Trabecular-iris angle (TIA_1)	Angle of the angle recess	**2A**
Trabecular-ciliary process distance (TCPD)	Distance between the trabecular meshwork and the ciliary process at 500 µm anterior to the scleral spur	**2B**
Iris thickness 1 (ID1	Iris thickness at 500 µm anterior to the scleral spur	**2B**
Iris thickness 2 (ID2)	Iris thickness at 2 mm from the iris root	**2B**
Iris thickness 3 (ID3)	(ID3) Maximum iris thickness near the pupillary edge	**2B**
Iris-ciliary process distance (ICPD)	Distance between the iris and the ciliary process along the line of TCPD	**2B**
Iris-zonule distance (IZD)	Distance between the iris and the zonule along the line of TCPD	**2B**
Iris-lens contact distance (ILCD)	Contact distance between the iris and the lens	**2B**
Iris-lens angle (Θ2)	Angle between the iris and the lens near the pupillary edge 2B	**2B**

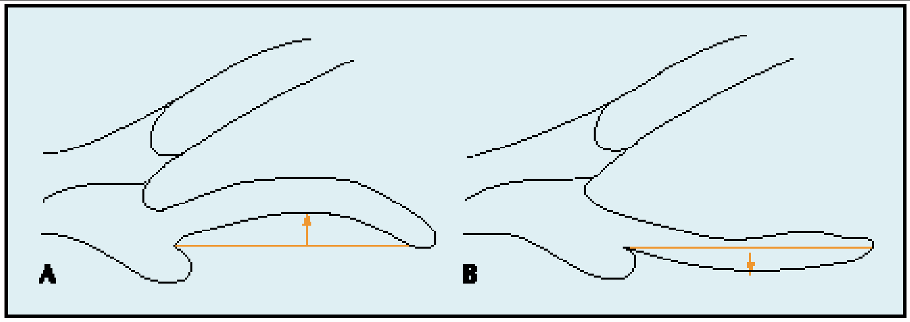
Figure 2. Angle Opening and trabecular ciliary distances



A. The angle opening distance (AOD) is defined as the length of the line drawn from the point on the endothelial surface 500 µm anterior to the scleral spur to the iris surface perpendicular to the corneal endothelial surface. Angle Θ is defined as an angle formed with the apex at the iris recess and the arms passing through the point on the meshwork 500 µm from the scleral spur and the point on the iris perpendicularly opposite (TIA).
B. The trabecular ciliary distance (TCPD) is defined as the distance between a point 500 µm from the scleral spur and the ciliary process on the line that is perpendicular through the iris. The iris thickness (ID1) is defined along this line, as is the iris-ciliary process distance (ICPD). Iris thickness can also be measured 2 mm from the iris root (ID2) and at its thickest point near the margin (ID3). Iris-zonule distance (IZD) is defined as a part of TCPD at a point just clearing the ciliary process. The length of iris-lens contact (ILCD) and the angle at which the iris leaves the lens surface (Θ2) are easily measured.

Figure 3. Iris concavity

Determined by first creating a line from the most peripheral to the most central points of iris pigment epithelium. A perpendicular line is extended from this line to the iris pigment epithelium at the point of greatest concavity or convexity.
A. Iris convexity measurement is shown (arrow).
B. Iris concavity measurement is shown (arrow).



Measurement reproducibility

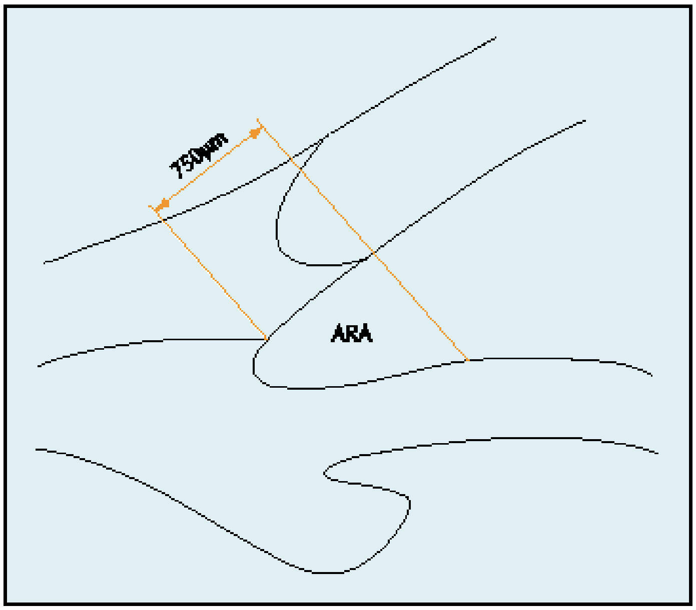
There are reports about the reproducibility of the measurement of the parameters described by Pavlin and Foster. Intra-observer reproducibility was reasonably good, except for angle-opening distance (AOD), but inter-observer reproducibility was not.
Other publications also found good intra-observer and poor inter-observer reproducibility.
Image acquisition was the major cause of this variability. However, the variability of the measurement process itself cannot be ignored.
All these methods require measurements of a distance or an angle. The parameters are measured on the UBM monitor, which allows measurement of point-to-point distance or an angle composed of two straight lines. Therefore, it is both difficult and not quite reproducible to measure a distance along a line drawn apart from a specific reference point.
In addition, each observer tends to have his or her way of setting the reference point on any measurement. For example, in measuring corneal thickness, one observer may tend to select a reference point slightly more external on the epithelial surface than another. This situation results in the first observer's tending to measure greater corneal thickness, assuming that each chooses the same point as an endothelial surface point. However, repeated measurement by the same observer is reasonably reproducible.
To minimize the variability of the measurement process, automated selection of reference points is ideal. With current technology, it is difficult for software to identify the location of the scleral spur, a useful landmark for many quantitative parameters. Allowing software to perform a calculation after the observer locates the scleral spur is presently the most practical method. Hiroshi Ishikawa has developed a software program (Sonomed Pro 2000) that is capable of measuring AOD in a semi-automated fashion. This has dramatically improved overall reproducibility (7.3 to 2.5, coefficient of variation)

Accuracy

Good qualitative agreement of UBM images with histological sections has been confirmed. Some publications showed good quantitative agreement by measuring the distance from the anterior margin of peripheral choroidal melanomas to the scleral spur, both on UBM images and histological sections. Other studies compared the corneal thickness measured by UBM with that measured by ultrasound and optical pachymetry. They found that the UBM measurement was similar to the ultrasound pachymetry, whereas optical pachymetry showed poor correlation with both UBM and ultrasound pachymetry. It was also published a study measuring a specially prepared plastic material with both UBM and scanning electron microscopy and found that the axial and lateral accuracy of UBM measurements was good and reliable.

An improved method for assessing anterior chamber angle.
The AOD treats the iris surface as a straight line. Irregularities of iris contour and curvature are important considerations in angle-closure glaucoma. We define the angle recess area (ARA) as the triangular area bordered by the anterior iris surface, corneal endothelium, and a line perpendicular to the corneal endothelium drawn to the iris surface from a point 750 µm anterior to the scleral spur (Fig. 4).

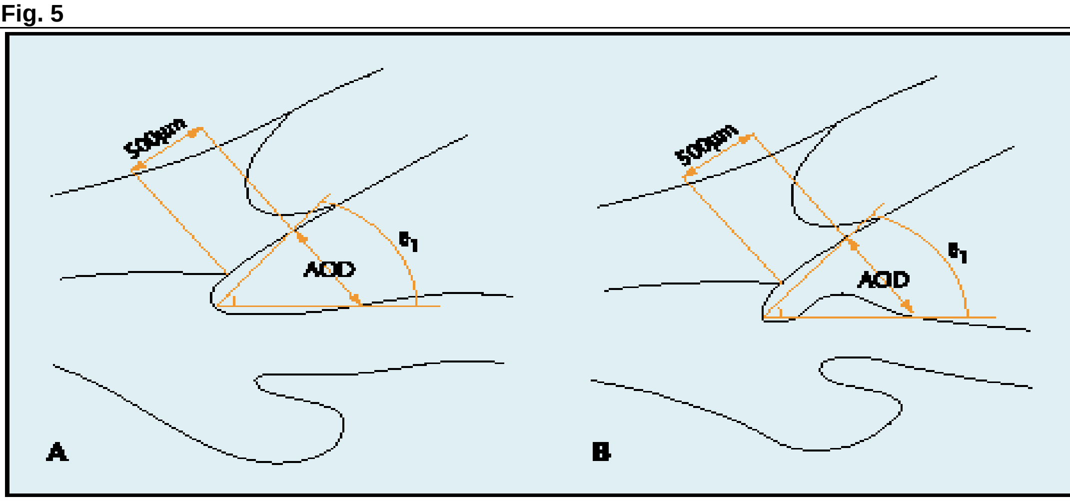
Figure 4. Angle recess area



A triangular area bordered by the anterior iris surface, corneal endothelium and a line perpendicular to the corneal endothelium drawn from a point 750 µm anterior to the scleral spur to the iris surface.

Figure 5 shows two schematics of the angle, demonstrating exactly the same value for AOD and angle 1. However, it is evident that the angle on the right is gonioscopically narrower and is more likely to be occludable than the one on the left. The software program described earlier was designed to calculate the ARA as well. After the observer selects the scleral spur, the program automatically detects a border, processes the image, and calculates the ARA. The program plots consecutive AODs from the base of the angle recess to 750 µm anterior to the scleral spur and performs linear regression analysis of consecutive AODs, producing two figures: the acceleration and the *y*-intercept.

Fig. 5



A and **B**. Value is exactly the same for the angle-opening distance (AOD) and angle Θ. However, it is evident that the angle in **B** is gonioscopically narrower and is more likely to be occludable than the normal appearing angle in **A**.

VuMAX Ultrasound Biomicroscope

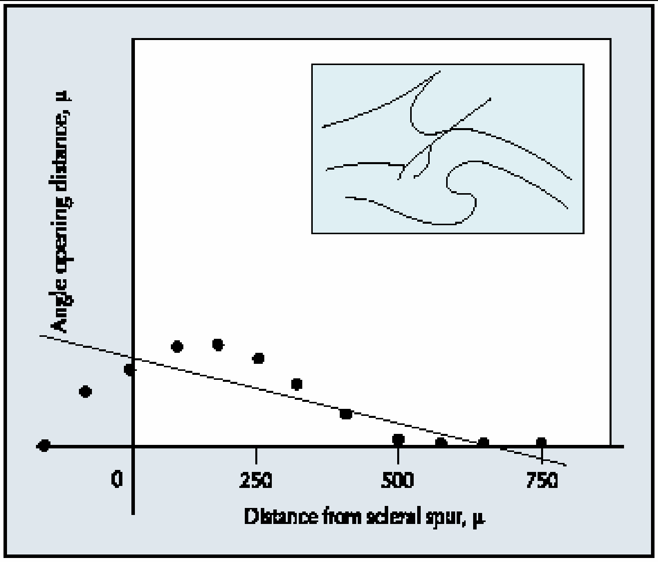
The equation of the linear regression is $y = ax + b$, where a is the acceleration and b is the y-intercept. Acceleration tells how rapidly the angle is getting wider, using the tangent of the angle instead of degrees as the unit. Acceleration is an estimated value used to describe the angle opening, taking the irregular curvature of the iris surface into account. The y-intercept refers to the distance between the scleral spur and the iris surface along the perpendicular to the trabecular meshwork plane. In spite of these similarities to AOD and Θ1, the acceleration and the y-intercept have unique characteristics. Because these values are calculated for linear regression analysis, they can be negative numbers—an impossibility for on-screen measurements. A negative number for acceleration means that the angle has an almost normal configuration at its peripheral part and becomes very shallow or is attached to the cornea at its central part
(*eg,* appositional angle closure starting at Schwalbe's line with space remaining in the angle recess; Fig. 6). A negative y-intercept means that the angle recess is very shallow or is attached to the cornea at its periphery, whereas it is relatively wide centrally (Fig. 7). Therefore, by using three numerical values—ARA, acceleration, and y-intercept —many types of angle configuration can be described quantitatively.

Clinical applications

Glaucoma

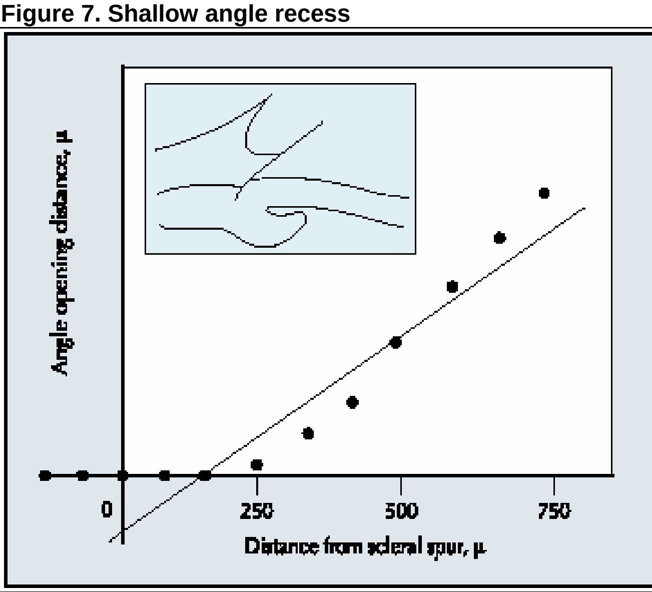
Anterior chamber angle parameters were measured to investigate the development of the angle in normal infants and children in relation to age, the difference between eyes affected by angle-closure and normal eyes, and iris convexity related to age. The Pro 2000 measured ARA, acceleration, and y-intercept under standardized dark and light conditions and reported that the more posterior the iris insertion on the ciliary face, the less likely the provocative test result would be positive. Ultrasound biomicroscopy is also a powerful tool to evaluate the effect of drug instillation on the anterior chamber angle, iris, and ciliary body. Some articles report evaluation of morphological change after surgical procedures. Because there is no standardized way to quantify filtering bleb characteristics, UBM images have been analyzed qualitatively. There are reports about that the iris-lens contact distance increases after laser iridotomy for pupillary block angle closure. It is confirmed quantitatively that the collagen implant dissolved slowly within 6 to 9 months, leaving a tunnel in the sclera.

Figure 6. Linear regression analysis of angle-opening distance versus distance from the scleral spur



The line of linear regression shows negative acceleration, meaning that the angle almost has a normal configuration at its peripheral part and becomes very shallow or is apposed to the cornea at its central part (*eg,* the appositional angle closure began at the level of Schwalbe's line).

Figure 7. Shallow angle recess



A negative *y*-intercept means that the angle recess is very shallow or is attached to the cornea at its periphery, whereas it has a relatively wide angle recess centrally.

Tumors

Ultrasound biomicroscopy is an effective procedure for both the diagnosis and management of anterior segment tumors (Fig. 8 and 9). It is possible to measure the size and extent of anterior segment tumors. This fact turns definitive on the evolution over time of these kinds of pathologies.

Figure 8. Irido-ciliary body tumor and cysts (perpendicular scan)

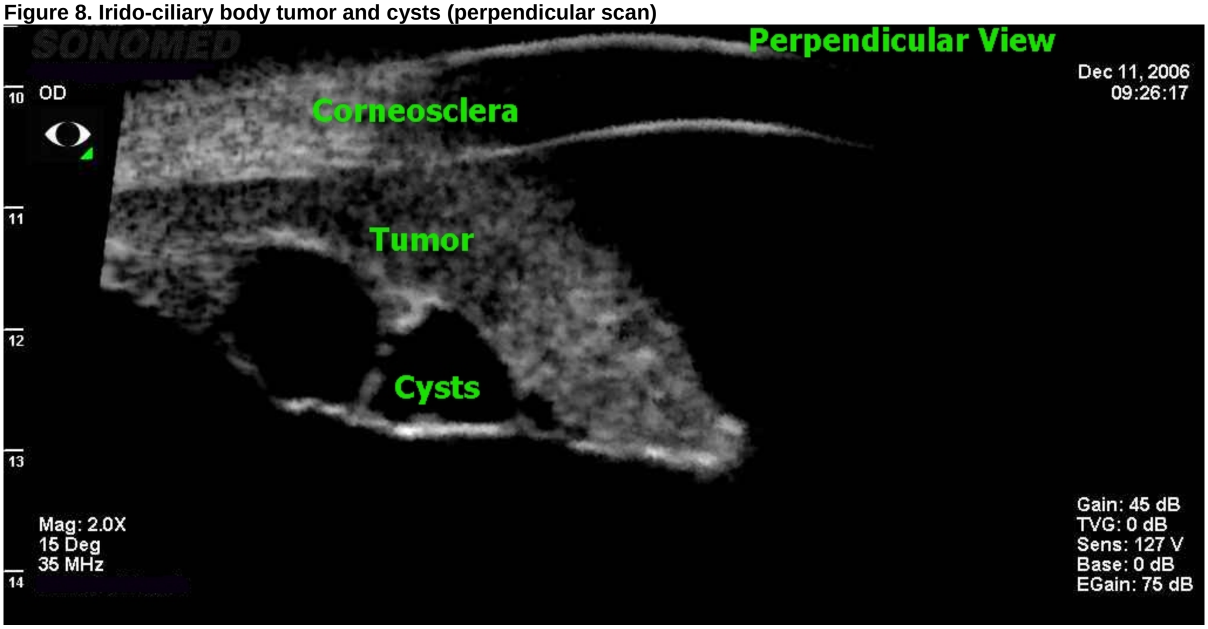
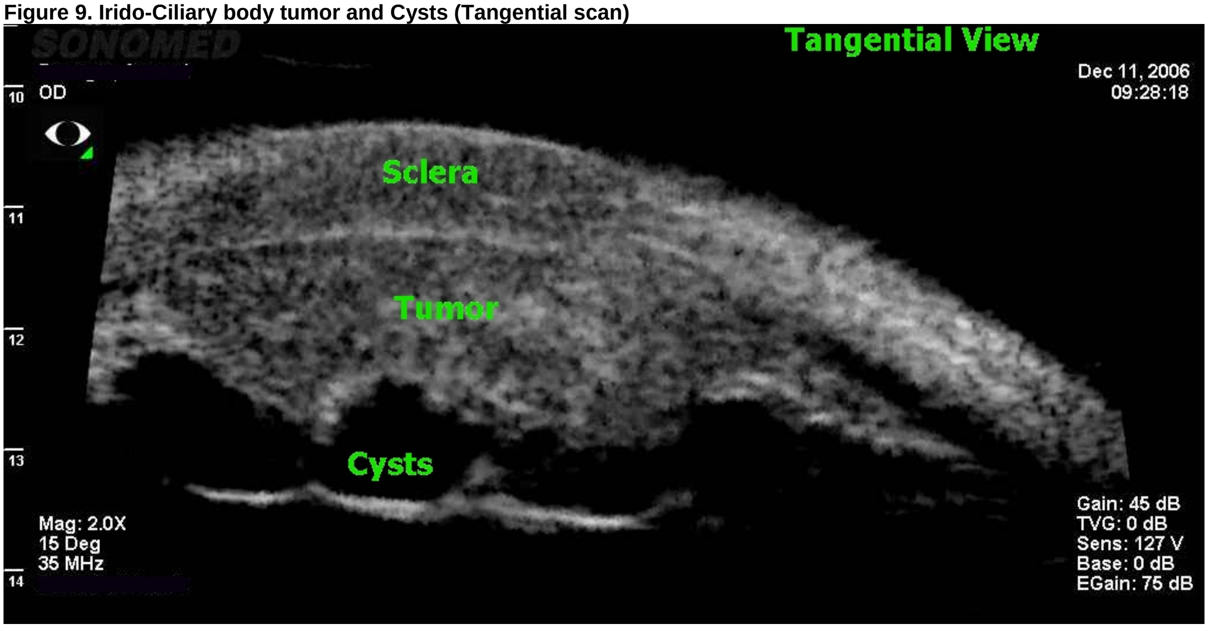


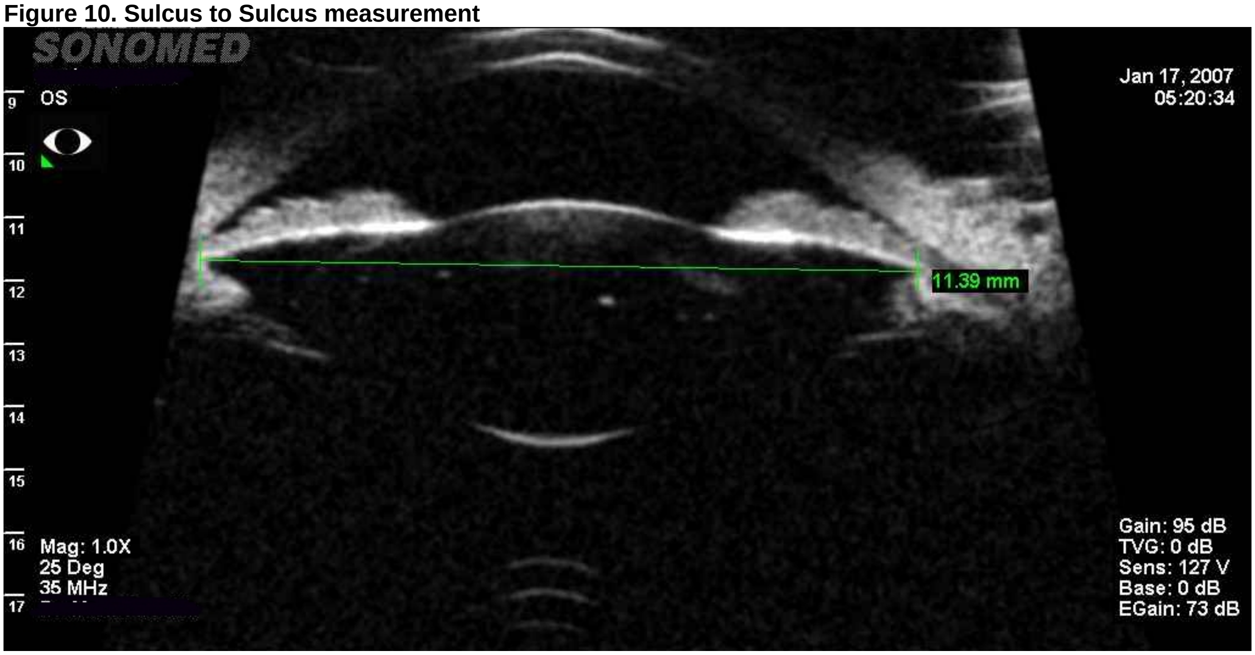
Figure 9. Irido-Ciliary body tumor and Cysts (Tangential scan)



Other applications

Ultrasound biomicroscopy can be used for evaluating various other ocular diseases involving the anterior segment. Exist a variety of UBM publications about, among others, the correlation between the thickness at the corneal apex and disease severity in eyes with keratoconus; changes on the ciliary body size and shape in uveitic eyes; measuring the height of ciliary detachment in eyes with Harada disease and recently a large amount of publications about the pre and post evaluation of the posterior chamber Phakic intraocular lens.

Figure 10. Sulcus to Sulcus measurement



The proper sizing of a phakic IOL to be implanted is the key to a successful procedure. The sulcus to sulcus (Fig. 10) measurement proved to be one of the most important factors in the pre-op evaluation. Intraocular lens-iris touch, intraocular lens-crystalline lens touch, and anterior chamber shallowing were observed after implantation using UBM technology.

When considering the ability of the VuMAX II to show motion pictures and choose the correct image to measure offers the user a wide variety of applications in the implantation of accommodative intraocular lenses.