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Ultrasound Biomicroscopy

By Charles J. Pavlin, MD

Ultrasound is an indispensable tool in medical imaging and plays an important role in ophthalmologic diagnoses. Conventional B-scan examination produces 2-dimensional cross-sectional views of the eye and orbit. This method of imaging is the most important examination technique for intraocular lesions, particularly in the presence of anterior segment opacities. There are, however, limitations to conventional ultrasound, particularly in the area of resolution. In our attempts to gain a greater understanding of the mechanisms of ocular disease, there is a never-ending need for higher resolution. In the same way that optical microscopy has improved our understanding of basic processes, improved imaging resolution allows us to see and understand that which has not been seen before. The basic physics and techniques of using higher frequency ultrasound to image living structures were developed in the laboratories of Stuart Foster at the University of Toronto. We subsequently applied these techniques to ocular imaging and named this process "ultrasound biomicroscopy (UBM),"[1-3] ie, the imaging of living structures at microscopic resolution. This issue of *Ophthalmology Rounds* discusses the foundations of this method of imaging and illustrates how the ablility to use microscopic resolution to see below the surface has allowed improved diagnoses and clarified mechanisms of ocular disease that had only been speculated on previously.

Theoretical considerations

Mechanical waves and vibrations occur over a wide range of frequencies called the acoustic spectrum. This spectrum extends from the audible range (10 to 20,000 Hz), with which we are all familiar, to the range of phonons (>1012 Hz) that comprise the vibrational states of matter.

Higher frequency ultrasound provides higher resolution on the order of 20-40 µm, but the penalty is a loss of penetration. All human tissues exhibit ultrasound attenuation co-efficients that increase with frequency. The maximum penetration that can be achieved for a 10 MHz system is approximately 50 mm. For a 60 MHz system, the penetration is only 5 mm. This penetration limit prevents imaging of the posterior pole with high frequency ultrasound, but is sufficient to gain valuable information on events in the anterior segment.

Clinical use of ultrasound biomicroscopy

In the laboratory, we use instruments with frequencies between 40 and 100 MHz; the most commonly used commercial instrument is a 50 MHz transducer, which is a good compromise between resolution and penetration. Various instruments are currently available with frequencies between 20 and 50 MHz.

Technique

The technique for using UBM when examining the eye is similar to examining the anterior segment using conventional B-scan. A fluid immersion technique is required to provide an adequate stand-off from the structures being examined. This is necessary to avoid distortion of the image close to the transducer and to prevent contact between the

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transducer and the eye. We have designed a series of eye cups that hold the eyelids open and allow more rapid patient preparation. These eye cups resemble those used in conventional ultrasound biometry and have a lip that slides under the eyelids and holds the cup in place. They differ from biometry eye cups in being shallower and having a distinct flair that allows a good view of precisely where the scanning head is being placed. 1% methyl cellulose is used as a coupling medium.

Unlike the conventional 10 MHz B-scan, high frequency transducers are generally not covered by a membrane since a membrane would provide excessive sound attenuation and defeat the purpose of doing examinations at this frequency. Since the transducer is moving, any contact with the eye and resultant corneal abrasion must be carefully avoided.

Any part of the eye that can be approached directly over the surface can be examined. The cornea and anterior segment structures are easily examined in any meridian. The conjunctiva, underlying sclera, and peripheral retina can be examined by rotating the eye as far as possible away from the region being examined. Any adnexal structures that can have their surfaces exposed can be examined.

Measuring ocular structures

UBM expands our ability to accurately measure ocular structures. Measurement accuracy is improved by ultrasound biomicroscopy, which has an axial resolution 5-10 times that of conventional 10 MHz ultrasound. Measuring a structure accurately with ultrasound requires a knowledge of the speed of sound in the structure being examined. We have used a speed of sound of 1540 m/s to make the majority of measurements. This speed is used in conventional ultrasound scanning to measure distances in most tissue.

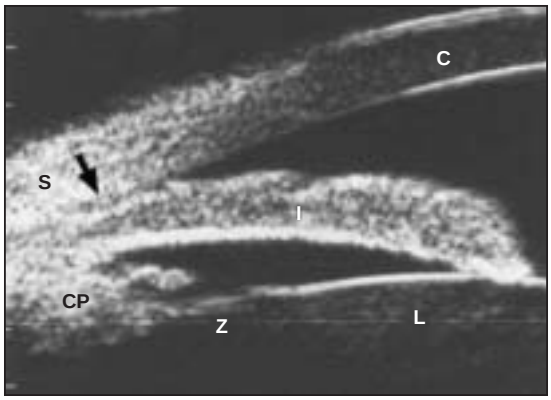
UBM in ocular disease

Since UBM is a non-specific imaging tool, it is suitable for examining a large range of diseases that fall within the penetration limits of this technique. It is particularly useful in those conditions in which structural abnormalities are present, ie, those conditions that produce rearrangement of normal anatomy.

Glaucoma

Several types of glaucoma are caused by structural abnormalities of the anterior segment of the globe. This is particularly true of angle closure glaucoma and infantile glaucoma. The ability of UBM to image structural abnormalities on a much finer scale than was previously possible provides a quantitative new tool for research and clinical assessment of glaucomatous disease.

Figure 1: In pupillary block, the iris shows anterior bowing narrowing the angle (arrow) and a small iris lens contact.



S = sclera, C = cornea, I = iris, CP= ciliary processes, z = zonule, L = lens.

Pupillary block

In pupillary block, the iris assumes a convex profile due to the pressure differential between the posterior and anterior chambers (Figure 1). Following iridotomy, the profile changes to a much straighter configuration. Of interest is the fact that the degree of iris-lens contact is relatively small in pupillary block, as the iris is lifted off the lens. The block is thus not related to the area of contact. The area of iris-lens contact becomes even smaller when the pupil dilates. Anatomical angle closure in the dark in pupillary block occurs rapidly and relates to increased iris thickness and increased anterior bowing as the iris tip moves towards the iris root.[4] A darkroom provocative test can be done utilizing UBM that detects whether appositional angle closure occurs in the dark.[5]

A very common reason for referral for UBM is the patient in whom the angle does not open completely post-iridotomy. The usual cause is an imperforate iridotomy, anterior synechiae, or plateau iris, all of which can be detected by a UBM examination..

Anterior synechiae

Angle closure by synechiae is illustrated in Figure 2 The iris takes an angular form as opposed to the smooth curve of pupillary block. The state of the angle behind the synechia can be defined by ultrasound biomicroscopy

Plateau iris syndrome

UBM has been used to elucidate the etiology of plateau iris syndrome.[6] In plateau iris syndrome, the ciliary processes are anatomically anteriorly located, closing the ciliary sulcus and providing structural support behind the peripheral iris (Figure 3). This prevents this portion of the iris from falling away from

Figure 2: Anterior synechiae show an angled appearance of the iris with attachment to the trabecular meshwork (arrow).

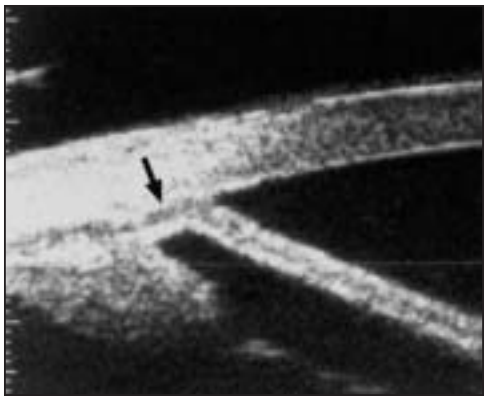
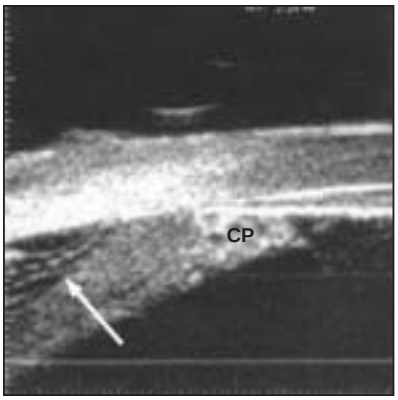


Figure 4: In malignant glaucoma, a supraciliary effusion is present (arrow) with anterior rotation of the ciliary processes (CP) and iris.

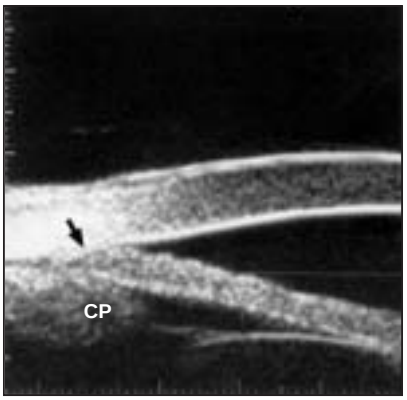


the trabecular meshwork following iridectomy. In studies of plateau iris in the dark and after pilocarpine administration, we demonstrated that the distance between the ciliary processes and trabecular meshwork remained constant with the only variable contributing to angle narrowing being iris thickness.[7] We have recently shown that the axial anterior chamber is shallower in plateau iris than pupillary block.[8] The false sense of a deeper chamber likely relates to the deeper peripheral chamber that occurs when the iris flattens following iridotomy. Pupillary block and plateau iris frequently co-exist.

Supraciliary effusions and malignant glaucoma

Supraciliary effusions that cannot be detected by conventional ultrasound can be imaged by UBM. These effusions occur in a variety of conditions, including inflammatory disease, vein occlusions, and following retinal detachment surgery.[9,10] Supraciliary effusions produce rotation of the ciliary processes and iris around the scleral spur. This can result in angle closure, particularly if the angle is narrow to begin with. We have found that most cases of malignant glaucoma have supraciliary effusions and anteriorly rotated ciliary processes[11] (Figure 4). It is likely that effusions play a major role in the clinical manifestation of this condition.

Figure 3: In plateau iris the ciliary processes (CP) are forward, supporting the peripheral iris and producing peripheral angle narrowing (arrow).



Pigmentary dispersion

Pigmentary dispersion syndrome is characterized by a loss of pigment from the pigment epithelial layer of the iris and subsequent pigment deposition in the trabecular meshwork leading to glaucoma.[12] The concept of reverse pupillary block implies temporarily reversal of the pressure differential in the anterior and posterior chambers, producing posterior bowing of the iris leading to iris-zonule contact with mechanical pigment loss. UBM has shown that accommodation produces posterior iris bowing which is reversed by iridotomy[13] (Figure 5a and b). The question of whether an iridotomy is indicated in this condition has not been answered clearly, but is probably not indicated in older patients with diminished accommodation.

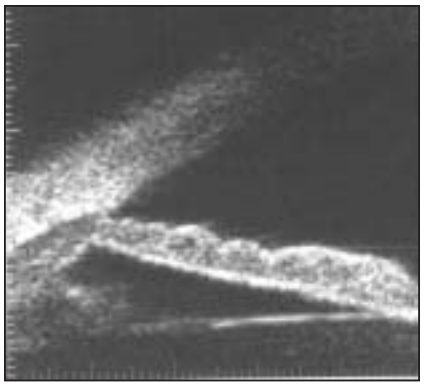
Anterior segment tumours

Iris and ciliary body tumours

UBM is a very useful adjunct in the management of anterior segment tumours,[14,15] providing a clear image of even the smallest anterior segment lesions (Figure 6). The ability to measure these lesions accurately adds the dimension of depth to our criteria for demonstrating growth. The ability to determine the underlying structure of the tumour allows improved classification and the ability to determine ciliary body involvement. When observation is selected, lesions may be followed with greater precision. Where surgical intervention is indicated, the information gained is helpful in planning the approach.

Figure 5a: Pigment dispersion – the iris profile is straight on distance fixation
Figure 5b: Pigment dispersion – The iris bows backwards on near fixation

5a



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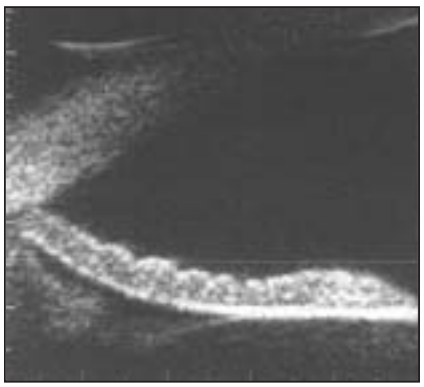


It is difficult to be too specific as to histological diagnosis with ultrasound, even with the added detail presented by UBM. Resolution is not at the level that can differentiate individual cells.

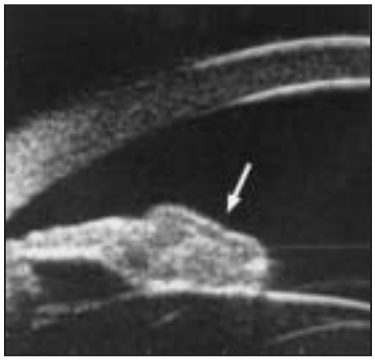
Cysts

Cysts are clearly imaged by UBM.[16,17] The usual clinical presentation of an iridociliary cyst is elevation of the peripheral iris without iris involvement. The typical ultrasound biomicroscopic appearance of a thin-walled cyst with no internal reflectivity (Figure 7) is diagnostic and essentially eliminates any question about whether the lesion is a cyst or a solid tumour. Small cysts are also occasionally found either as an isolated finding on examination for some other clinical indication or in association with solid lesions of the iris or ciliary body.

The zonule

The anterior zonule can be imaged clearly with UBM. We are frequently asked to determine

Figure 6: Tumor of the iris (arrow) in radial section. Tumor thickness can be measured and followed.



the state of the zonule in various disease and traumatic conditions prior to cataract surgery. The absence or irregularity of the zonule can generally be determined, and the clock hours involved reported.

Corneal and scleral disease

UBM can be helpful in patients with opaque corneas prior to transplantation.[18] Anterior segment details such as the depth of the anterior chamber, state of the angle, presence of anterior synechiae, and intraocular lens positioning can be determined pre-operatively. Intracorneal abnormalities can also be imaged. Corneal edema can be assessed and measured. An arc scanner has recently been developed that uses a transducer path that follows the corneal curvature and allows imaging of the entire cornea in one sweep. This instrumentation enables the construction of 3-dimensional depth maps of corneal thickness, epithelial thickness, and depth of intracorneal incisions[19] in refractive surgery. UBM is also

Figure 7: Irido-ciliary cyst (arrow) produces peripheral iris elevation

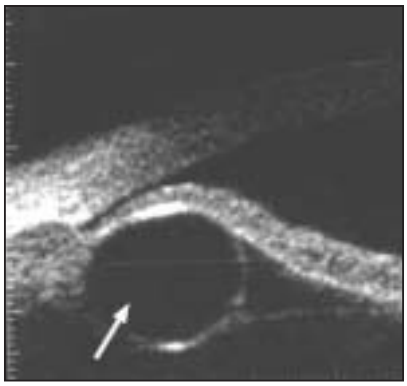


Figure 8: Intraocular lens haptic (arrow) over the pars plana

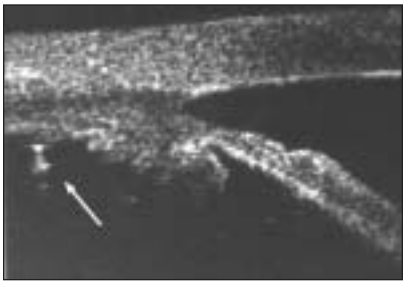
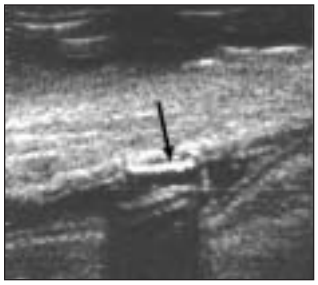


Figure 9: A punctal plug (arrow) is imaged in the canaliculus.



useful in scleritis, allowing differentiation between extra-scleral and intra-scleral disease and allowing assessment of the degree of scleral thinning.[20]

Intraocular lens complications

UBM can easily assess the position of intraocular lens haptics (Figure 8). This is very useful in assessing malpositioned lenses,[21] assessing the source of intraocular bleeding and determining haptic freedom if removal or repositioning is required.

Hypotony and trauma

UBM can image cyclodialysis clefts even when the anterior chamber is shallow and the cyclodialysis cleft is not obvious with gonioscopy.[22] There is always 360° of supraciliary fluid present in these cases. The region of the cleft is usually obvious from the displacement of the iris root from the scleral spur. Other causes of hypotony in which UBM can provide useful information include occult wound leaks and ciliary body membranes. In other trauma problems, UBM can image the state of the anterior chamber under traumatic opacities[23] and detect small foreign bodies that are difficult to image using conventional techniques.[24]

Conjunctival and adnexal disease

UBM can be used to examine any lesion that can be approached over the surface, providing valuable information in the differential diagnoses of tumours, aiding in judging the depth of conjunctival and limbal lesions, and allowing imaging of intracanalicular conditions.[25] Malpositioned punctual and canalicular plugs can also be imaged (Figure 9).[26]

Summary and future directions

UBM is a new method of imaging the anterior segment of the eye at high resolution. Its strengths lie in its ability to produce cross-sections of the living eye at microscopic resolution without violating the integrity of the globe. Although histological assessment of various disease types is sometimes available from pathology specimens, this usually occurs at a late stage in the disease and is susceptible to the inevitable distortions of the preparation process. UBM, though lacking the resolution of optical microscopy, gives us images in living eyes without affecting the internal relationships of the structures being imaged. This method has proven to be valuable in both clinical practice and ophthalmic research. New methods of using high frequency ultrasound are in development including 3-dimensional imaging, Doppler, and the use of contrast agents. These developments should extend the use of this technique to new areas.

Dr. Pavlin is a Professor at the University of Toronto and a physician on the staff of Mount Sinai Hospital, Princess Margaret Hospital and St. Michael's Hospital, Toronto.

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