The fundamental physical principle underlying diagnostic ultrasound as used in a number of medical disciplines is the generation of sound waves at frequencies above the range of human hearing (greater than 20,000 Hz or 20 KHz) by the vibration of a thin crystal stimulated by pulses of electric current. The waves of sound then propagate through a medium and are reflected by tissue surfaces back to the resting crystal that is then made to vibrate, generating electrical impulses that are amplified and processed to show a pattern on an oscilloscope screen.

The following images were created in the 1970s using miles movie film and then condensed into a film of only a few minutes (Figs. 1 and 2). Pulsed sound is what is used in ophthalmology because the transducer not only sends out a pulse of focused sound, it also waits and listens for the returned echo signal, hence, the name pulser–receiver system. Each time the pulse of sound strikes an interface, some is reflected back to be displayed and some goes on to deeper tissues, but with slightly less energy. These reflections can also reverberate in between various structures and be changed by the surface shape and texture. The eye contains both flat sheetlike structures such as membranes as well as curved ones such as the cornea, lens, and the globe itself. Some tissues are smooth which will better reflect echoes than those with a rough texture, like pigment cells on an anterior lens capsule, for example.

The history of ultrasound in ophthalmology is a relatively recent one. The principles of ultrasound were understood in the late 1800s and were utilized to develop sonar for submarine warfare in World Wars I and II. During this time, industry adapted the technology for the detection of flaws in materi-
The first paper describing the ocular use of the “reflectoscope” by Mundt and Hughes appeared in the ophthalmic literature in 1956 [11]. They basically described the use of the A-scan to image various ocular structures and abnormalities. An adaptation of the instrument was also used about this time to image gallstones in a patient with cholelithiasis.

Diagnostic echography now has widespread application in medicine, mainly in the specialties of obstetrics and gynecology, cardiovascular disease, peripheral vascular disease, gastroenterology, neurology, and urology. The frequencies used for non-ophthalmic organ systems usually are in the range of 3–5 MHz to allow deep penetration into such areas of the body as the abdomen. Higher frequencies than this provide better resolution but poor penetration into the depths required for the examination of most organ systems. The resolution possible in the examination of the eye is much higher than in other parts of the body. The globe is mostly a fluid-filled structure that is ideal for the propagation of ultrasound. The 8–10-MHz frequencies used mostly for the examination of the posterior segment resolves structures as small as 0.10 mm. The 50-MHz ultrasound biomicroscope (UBM) probe used for anterior segment scans enables resolution on the micron scale (less than 40 μm). Such imaging capability allows the diagnosis of lesions on almost a histopathologic level and is reflected in the 99.7% diagnostic accuracy for choroidal melanoma as reported in the Collaborative Ocular Melanoma Study (COMS).

Ophthalmic echography has advantages over other imaging techniques in the clinical practice of ophthalmology. An instrument that is readily available, portable, and cost-effective and provides rapid and accurate diagnosis of intraocular and orbital pathology can be an invaluable aid to the practicing clinician.

The diagnostic A-scan probe (Fig. 3) has a wafer-thin ceramic crystal near the tip that is stimulated by bursts of electric current to vibrate at a frequency of 8 MHz (eight million cycles per second). The crystal converts this electrical energy into sound energy, and then the same crystal receives the reflected sound waves. Its mechanical vibrations are converted to an electric current. This is called the piezoelectric effect, where the same crystal acts as sender and receiver of sound. The transducer transmits sound waves for about 4% of the time. Its vibrations are then damped, and it receives the reflected sound waves for the remaining 96% of the time. The returning sound wave is amplified and displayed on a screen as vertical lines of various heights. The amplitude of each spike is related to the strength of the reflection from tissue interfaces from which it is reflected.

The B-scan probe (Fig. 4) uses a transducer similar to that of an A probe, but it sweeps back and forth at a rate of 10–25 oscillations per second. It generates sound waves at a frequency of from 10 to 20 MHz (10–20 million cycles per second). The returning echoes are processed to display bright dots on a screen which are combined to generate an image. This generates a series of echoes that are processed like pixels on a computer screen to generate an image. The brightness of the image is correlated to the strength of the sound reflection corresponding to the height of the vertical spike.
on the A-scan image. Current generation B-scan probes are sealed and oil filled, unlike previous versions that had to be injected with distilled water before each use.

Most ophthalmologic ultrasound units are sold primarily for the B-scan capability. Practitioners are generally most comfortable with B-scan images because of the recognizable topography displayed on the screen, as opposed to the unfamiliar vertical spikes of the A-scan. This is especially true for a generation familiar with the imaging capabilities of CT and MRI scans. These modalities “cut” radiologic sections through structures, and the medically trained mind is comfortable mentally reconstructing the entire lesion from a compilation of these slices. Three-dimensional (3D) imaging is evolving that does such reconstruction with computer graphics, but most CT scans are currently displayed as a series of tissue slices. The ultrasound B-scan is based on the same principle of image processing, although by acoustic instead of radiologic sectioning. An A-scan acts more like penetrating tissue with a needle to take a “core” sample for biopsy versus “slicing” sections of the tissue with the B-scan.

An example of the A- versus B-scan dichotomy is the familiar mushroom shape of a choroidal melanoma as it breaks through Bruch’s membrane that is immediately evident to the untrained eye on the B-scan but displays only a series of vertical internal spikes on the A-scan (Fig. 5). However, the diagnostic information contained in all of those “dancing” lines on the A-scan is the major reason for the 99.7% accuracy of the diagnosis of melanomas reported in the recently completed COMS study.

Karl Ossoinig pioneered the concept of standardized echography and much of his work concentrated on the A-scan. His criteria for the characterization of numerous intraocular and orbital lesions are based on the use of a standardized A-scan technique, including an S-shaped amplifier in the unit that combines features of linear and logarithmic amplifiers. An examiner cannot take the criteria he developed and use them successfully to diagnose pathology unless an A-scan is used based on these principles. There are several units produced that utilize separate A- and B-scan probes that can be reliably used to evaluate lesions based on the criteria of Ossoinig. Several companies produce excellent ophthalmic ultrasound units that are modular in design with the option to add features to the basic unit as need and budgets allow. It is highly advantageous to have separate diagnostic A- and B-scan probes with individual signal processors.

The A-scan displays the reflected signals as vertical lines. It is like freezing the B-scan transducer so it does not oscillate and recoding the signals from that point as a line instead of a grayscale dot. The height of the vertical line is a function of the reflectivity of the interface as is the brightness of the B-scan dot. The physical basis for the intensity of the reflected signal is impedance. The equation $Z = \text{sound velocity} \times \text{tissue density}$ describes the physical basis for ultrasound reflection from the interface between tissues. The greater the difference in impedance between two different media, the higher the A-scan spike or the brighter the B-scan dot. The result of this principle is that there is greater reflection of sound waves when they are travelling through tissue at a
specific velocity and then spread through a different tissue at a different velocity unique to that tissue. This change in velocity results in sound reflection from the interface between the two tissues; the greater the change in velocity, the stronger the reflection. Figure 6 illustrates various degrees of B-scan brightness as the sound beam is reflected from different tissue interfaces.

The interface between the vitreous (sound velocity 1,532 m/s) and a densely cellular tumor, such as malignant melanoma (1,550 m/s), with a relatively smooth surface results in strong sound reflection. When the sound beam is directed perpendicular to the tumor, it is reflected back directly into the probe. A large percentage of the returning sound energy is then amplified to give a steeply rising echo spike. When the beam is angled more obliquely to the surface, some energy is lost due to reflection away from the probe, and the echo spikes are lower in amplitude and less steeply rising (Fig. 7). This effect is based on Snell’s law of reflection, which he derived for light rays but is equally applicable to sound. His equation stating that the angle of incidence equals the angle of reflection gives the result of maximal reflection from the surface reflecting the wave. The oblique sound beam direction results in an erroneous characterization of the internal reflectivity pattern.

It is common for ophthalmic ultrasound equipment to have a vector A-scan superimposed on the screen with the B-scan image. The same probe is utilized for both and the signal is processed by the same unit to display the B-scan in the center of the screen and a small A-scan tracing at the bottom. The A-scan tracing is derived from the B-scan vector envelope and is not a stand-alone signal. A vector (line) can be displayed to cut through a given section of the B-scan image and the corresponding A-scan display can theoretically be analyzed for internal frequency characteristics. This seems advantageous in principle, but in practice the quality of the A-scan is such that meaningful information about the internal characteristics of any lesion is suboptimal. Figure 8 illustrates the difference in diagnostic usefulness between a dedicated A-scan image and one derived from an A/B vector. This type of A-scan is not useful in evaluation of the orbit.

It is a common misconception worldwide that adding a simultaneous “cross-vector” A-scan to a posterior B-scan will produce diagnostically useful information. Standardized diagnostic A-scan is a completely different type of exam using an 8-MHz unfocused A-scan probe, a unique amplification system, and a precise level of gain called tissue
sensitivity used for each and every patient to ensure consistency. Therefore, the vector A-scan produced from a 10 to 12-MHz focused posterior B-scan probe is not considered diagnostic (Fig. 9). The incorrect belief is that an unknown membrane (e.g., posterior hyaloid with adherent blood cells or a retinal detachment) may be evaluated by adding the vector A-scan. The thought is that seeing a tall echo indicates a retinal detachment. Unfortunately, this is not the case. Inconsistent gain levels can make a PVD with hemorrhage appear as bright as a retina, especially posteriorly. Similarly, high gain can make a melanoma’s vector A-scan have high internal reflectivity and look like a hemangioma, whereas low gain could make a hemangioma have low internal reflectivity and look like a melanoma. Cross-vector A-scan should not be used for tissue characterization. That is the realm of standardized diagnostic A-scan.

One possible exception to the disadvantage of a superimposed vector A-scan is its use in measuring the axial length of an eye with a posterior staphyloma. It is difficult to be certain that the sound beam of an A-scan biometer is congruent with the fovea on the sloping side of a staphyloma. However, with a combined A- and B-scan unit, the B-scan can be used to image the macula and then the vector A-scan superimposed on it (Fig. 10). Roldivar states that the accuracy of this technique is questionable as the fovea’s location in the depths of the staphyloma is difficult to determine exactly [12]. Experienced echographers feel that by aligning the beam with the double-peaked cornea, anterior and posterior lens, and retina spikes, a reasonable estimate of the anatomic axial length can be obtained. In addition, many A-scan biometry probes have a fixation light in the tip that enables the measurement of the true visual axis in those patients capable of fixation on the light.

A-scan biometry units utilize probes optimally focused for measuring from the anterior corneal surface to the retinal surface. Such a probe could detect an abnormality such as a tumor only if a systematic examination of the eye was performed. The standard axial measurement of the globe could only display a lesion such as a tumor if it were large and in the area of the macula. Such pathology would usually result in difficulty in obtaining axial measurements and not be diagnostic of a tumor.
Diagnostic A- or B-scan would be required to characterize the lesion. There are a number of reported cases of intraocular tumors that were not detected until after the removal of a cataract. Preoperative biometry failed to alert the examiner to the presence of the lesion [13].

The axial length of the eye is most accurately measured when the sound beam is directed perpendicular to the corneal surface. The screen displays a double-peaked corneal spike, steeply rising and highly reflective anterior and posterior lens spikes, and a steeply rising maximally high retinal spike (Fig. 11). Measurements of any ocular or orbital structure are most accurate when the sound beam is maximally perpendicular to the surface. This is theoretically possible in the orbit because of sound beam refraction even though the probe applied to the globe must be angled obliquely to the optic nerve or extraocular muscles. Refraction of the sound beam by orbital tissue bends it in a direction that is perpendicular to the structure being examined, such as the optic nerve sheath [14].

Technique

Most ocular and orbital pathology is optimally evaluated by A- and B-scan during the same patient encounter. The preferred approach is to use the B-scan to detect abnormalities and obtain a gestalt of the general shape and structural relationships. In the examination of the globe, the vitreous cavity is observed for sound reflections above the baseline while simultaneously watching the fundus for irregularities of the normal smooth convex shape. Any abnormalities detected during the initial screening are then studied in greater detail using longitudinal and transverse B-scan positions. The A-scan is then applied to the eye, and a brief screening scan may be performed in the eight meridians as a double check on anything that may have been missed on the B-scan. This step is not essential, however, and it is usually sufficient to direct the A probe to the abnormality detected on the B-scan examination. It is very important to maximize perpendicularity to the lesion with the A-scan, and adequate time and effort should be expended until this is accomplished.

The most important goal of any scanning technique is to perform examinations in a consistent manner. This ensures a thorough and accurate observation of all parts of the globe and orbit. There are many different ways to approach this challenge, and presented here is one reliable method. Clinics throughout the world use a wide variety of exam protocols. If you choose a different method, be certain that it is both systematic and includes all components of a complete exam.

The fear of missing pathology is a valid one to have. Knowing and routinely using a systematic protocol ensures a proficient and complete evaluation of the patient. There is no such thing as a “quick B-scan,” as all patients deserve a thorough exam. When presented with a particularly challenging case, consult someone with more ultrasound experience for his or her input.
When available, attend B-scan courses and lectures, and watch training videos on the Internet to find new ideas and learn from interesting case studies such as are found in this book. Lastly, whenever possible, examine patients with clear media known pathology, such as PVD, RD, PFV, tear, hemorrhage, asteroid hyalosis, and elevated nevus. Start with a visual knowledge of pathology and its location. Then develop a plan for which probe positions and eye movements are needed to produce diagnostically useful images.

Technology continues to evolve in this important medical field with improvements in transducer design, image quality, and software that require ongoing education. There is no end to learning about ultrasound imaging; even after decades, we often see something new and always learn from the experience.

Some basic principles of ultrasound imaging include the following:

Ultrasound Does Not Travel Through Air

Air is a 100% reflector of sound. No image is produced at all if an obstructing bubble is large enough. Small bubbles or poor probe contact with the eye will affect a portion of an image. Interference from air is most likely when a bubble is inside the probe. This could occur if the probe tip membrane has been damaged, allowing fluid around the transducer to leak out. A second source of air in the sound’s pathway is the coupling medium between probe and globe surface or skin of the eyelids in special cases of recent surgery or trauma. Artificial tear gel is the preferred coupling medium and is applied to the probe tip prior to exam and added as needed. Do not use abdominal ultrasound gel because it is toxic to the eye. Thirdly, there could be air inside an eye, as in the case of a pneumatic retinopexy. An ultrasound exam in these cases is severely limited. In a penetrating trauma, a small air bubble may be misinterpreted as a foreign body due to its strong reflectivity, producing a bright white dot on B-scan (Fig. 12).

Echoes Are Produced when Sound Beams Cross a Tissue Interface

When the sound beam is perpendicular to an interface between two different tissues, a reflection of sound will be produced. The “B” in B-scan stands for brightness because echoes are displayed as dots on a screen with intensities varying from black to white. Images, whether white, black, or some level of gray, contain maximum clinical data when the sound beam is perpendicular to an interface between two different tissues. An oblique beam will produce a less clear, therefore less diagnostic image, and in some cases render the tissue invisible. The “A” in A-scan stands for amplitude because echoes are displayed as tall, short, and of various heights.

When a gray membranous structure is seen, ask two questions: is it gray because the tissue is really a low-reflective PVD, or is it gray because it is really an RD and the sound beam is not perpendicular? When the membrane is bright white ask: is it white because it really is a highly reflective retinal detachment, or is it white because it is a PVD with adherent blood cells and the gain is high?

Ultrasound Beams Must Be Perpendicular to Tissue for Maximum Reflection

Similar to light reflection, when sound encounters tissue in a perpendicular direction, the maximum reflection of sound will be produced. The “B” in B-scan stands for brightness because echoes are displayed as dots on a screen with intensities varying from black to white. Images, whether white, black, or some level of gray, contain maximum clinical data when the sound beam is perpendicular to an interface between two different tissues. An oblique beam will produce a less clear, therefore less diagnostic image, and in some cases render the tissue invisible. The “A” in A-scan stands for amplitude because echoes are displayed as tall, short, and of various heights.

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Gain and Sensitivity

Gain is often called the volume control on an ultrasound instrument. High gain is used to image small differences in tissues at an interface like fresh blood, inflammatory cells, and floaters. Gain is also called sensitivity as in the tissue sensitivity, a specific gain value used for standardized diagnostic A-scan exams. Turning down the gain will increase resolution as smaller echoes disappear. Low gain is useful in determining maculopathy and produces a clearer image of vitreoretinal traction and lesions. Lowering the gain will also improve imaging of foreign bodies and calcification (Fig. 13). In evaluating papilledema, low gain makes optic nerve drusen stand out as a bright white spot. Adjust the gain throughout every exam as different areas and tissues are examined. Turning the gain up or down does not change the amount of sound entering the eye; it only changes what strength of echo you choose to display at the moment.

Velocities and Measurements

Ultrasound travels at different speeds through different tissues. Standard ocular velocities used to generate measurements in most instruments are:

<table>
<thead>
<tr>
<th>Speed (m/s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.550 m/s</td>
<td>Average “soft tissue” (tumor measurements)</td>
</tr>
<tr>
<td>1.532 m/s</td>
<td>Aqueous and vitreous</td>
</tr>
<tr>
<td>1.641 m/s</td>
<td>Crystalline lens</td>
</tr>
<tr>
<td>1,000 m/s</td>
<td>Average silicone oil (ranges from 986 to 1,040 depending upon viscosity)</td>
</tr>
</tbody>
</table>

The correct velocity must be used to obtain accurate measurements. Axial measurements are in the same direction as the sound beam, like the height of a tumor or an eye length. They are fundamentally based on a probe’s frequency and the electronic measurement tolerance of an instrument. However, lateral measurements, as in the base of a tumor, are inherently less accurate. This is because they are most directly affected by mechanical probe design as well as the electronic measurement tolerance of the instrument (Fig. 14).

There is one more very important factor that influences accuracy. That is the examiner’s proficiency in placing each caliper. Particularly in B-scan,
caliper position is subjective. Lowering gain and magnifying the image can help determine optimum caliper position. When following a lesion, always review scans from prior visits to confirm caliper position and measurements to ensure consistency.

Also remember that there is a difference between precision and accuracy. Precision simply refers to obtaining the same value more than once. Accuracy is obtaining the correct value. A low standard deviation does not assure accuracy. Accuracy is only obtained as a result of measuring with optimal echo patterns, correct velocities, and correct caliper positions.

Artifacts Are Created by a Variety of Sources

Artifacts used to be called unwanted signals, but they are an excellent source of information. Shadowing is a complete absence of echoes behind a total reflector of sound such as calcium, foreign body, or air. Different types of reverberation echoes can indicate what may have caused the extra echoes. For example, spherical and small foreign bodies create a comet’s tail reverberation artifact and are seen when imaging an IOL loop haptic in cross section.

Unique artifacts are seen when scanning a patient with silicone oil as a vitreous substitute. The retina is displayed far to the right making the eye appear extremely myopic. Also the globe shape is unusually flat. These two artifacts are caused by velocity and refraction. The velocity of sound through oil is 2/3 slower than vitreous, so the retina appears farther away. This is because our instruments use 1,550 m/s to generate an anatomically correct image of a normal eye and to calibrate the millimeter ruler often seen on a display.

Silicone oil also refracts sound, causing an additional distortion in globe shape. Another challenge with scanning these patients is when the oil has emulsified. This makes imaging nearly impossible. The patient’s head position must also be considered because a small amount of sub-oil aqueous will be present. Since oil floats, a supine patient will demonstrate a very bright curved echo that may be misinterpreted as retina. This strong echo is produced from the interface between the bottom of the bubble and the sub-oil aqueous (Fig. 15). Retina and orbital signals are dim, even at high gain, due to oil’s absorption of sound. Even if the eye is able to produce an image that shows an attached retina, there is no guarantee that it would not re-detach once oil is removed. Axial eye length measurements, to calculate IOL power once a cataract has formed, are also challenging. It is recommended to perform these scans in the older, contact method with the patient seated. This allows the oil to be against the macula and sub-oil aqueous to shift inferiorly and out of the way of the A-scan beam (Fig. 16). Eye length in these patients should be automatically measured after oil has been placed in order to be prepared when a cataract develops.

Transducer Frequency and Focusing Determine Image Depth and Resolution

The goal is to select the most appropriate probe for the tissue being imaged. To do this, the relationship between frequency, resolution, and image depth must be considered. As the probe’s transducer frequency increases, so does the resolution. But depth of penetration will decrease. Therefore, high frequencies produce higher resolution images than
low frequencies. But high frequencies have more shallow imaging depth than low frequencies.

Posterior B-scan probes use a 10–12 MHz range for general globe/orbit imaging, whereas 20 MHz is used for retinal surface imaging. In the 10–12 MHz range, B-scan systems can image to a depth of about 45 mm. A posterior 20 MHz probe will have better resolution but a more shallow depth of penetration where limited orbital echoes are seen (Figs. 17 and 18).

Probes for anterior segment B-scan, also called UBM for ultrasound biomicroscopy, range from 35 MHz to 70 MHz and higher. A 35 MHz probe can routinely see the posterior lens capsule. A 50 MHz can often image the back of the lens, but since sound is absorbed by cataractous changes, it may be difficult to observe in some cases. 50 MHz is excellent for analysis of IOL position, iridocorneal angle, ciliary body, etc. Using a very high frequency (VHF) such as 70 MHz will produce excellent images of the iris and cornea but is too high to adequately and routinely visualize the ciliary body.
Nearly all transducers in ultrasound imaging have a focusing lens placed on their surface. They are designed to create a Focal Zone that will be the segment of the sound beam where maximum resolution is seen. Posterior probes image deeply and have a long area of focus, generally the center 1/3 of each image. The first 1/3, from tip to 15 mm, is called the “near field,” and ultrasound images are blurry and out of focus here. The last 1/3 of an image, from 30 to 45 mm, is called the “far field,” and images are out of focus here as well. The center of the image, from 15 to 30 mm, will have the best image quality. Therefore, it is the examiner’s job to place the tissue of interest into the Focal Zone of the transducer being used.

A high-frequency probe with a shallow image depth will also have a shorter Focal Zone. In the case of 50 MHz UBM, for example, image depth is about 10 mm with only a 2 mm zone of focus in the center of the display. It is critical to position the tissue of interest in the Focal Zone of each transducer to obtain diagnostically useful scans (Figs. 19 and 20).

The technique for examination of the globe with the B-scan is demonstrated in video segment 1 and is described as follows.

**Exam Techniques and Labeling**

- Posterior B-scan
- Anterior B-scan UBM
- Biometric A-scan
- Diagnostic A-scan

**Patient Positioning for All Types of Scans**

Position examiner, patient, and instrument display monitor so that only the examiner’s eyes move from patient to display. Small body movements will interfere with obtaining desired scans and make micro-probe adjustments more difficult. Keep one foot on the pedal so that scans may be quickly frozen. If movie mode is available, freeze the image after several good scans have been observed. Individual scans from the movie may then be adjusted, measured, and saved.

Use a finger of the other hand to stabilize the probe. Hold the probe as close to the tip as possible to prevent excessive globe pressure. Instruct the patient to report if pressure is too great or if there is any discomfort.

**Probe Orientation Determines Area Being Scanned and Labeled**

Scans are labeled to indicate the section and primary clock hour displayed. A marker near the probe tip determines image orientation. The B-scan transducer moves towards and away from this mark producing a slice of sound very similar to a slit beam. Think of the B-scan probe as a handheld slit lamp, where an acoustic section may be directed towards any area of interest.
In posterior B-scan, the probe marker indicates the top of the display (Fig. 21). In anterior B-scan UBM, it usually indicates the left of the display but in some instruments may indicate the right. It is critical to know where the mark on each probe is oriented. To confirm, gently touch the probe membrane on the edge nearest the marker with a wet fingertip or small bead of tear gel. Observe movement on the top of display in posterior scans. Gently sliding a fingertip from the mark to the opposite side will display movement from top to bottom of the display.

For UBM probes that use a fluid-filled bag, perform an orientation test by touching the membrane on the same side as the marker (Fig. 22). Observe where on the display movement is seen. Most instruments orient the probe mark to the left side of the display, but some orient to the right. If using a scleral shell for exams, test orientation by filling a container with water, and then image a submerged fingertip or other small object to determine which side of the screen relates to the probe marker (Fig. 23).

**Exam Techniques and Labeling**
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Posterior B-Scan

Components of a thorough exam:
- Patient eye stationary, probe moves
- Patient eye moves, probe stationary
- Patient eye and probe both stationary
- Systematic protocol and labeling for OD and OS

Patient Eye Stationary, Probe Moves

Begin each scan plane having the patient fixate in a certain direction while the probe is moved to sweep the acoustic section through each aspect of the globe. Images that best represent normal structures or pathology are labeled and saved.

Patient Eye Moves, Probe Stationary

When a structure is identified that may be mobile, hold the probe still and ask the patient to direct their gaze in a very specific way as outlined in the protocol described in section Exam techniques and labeling.

Patient Eye and Probe Both Stationary

When both patient and probe are stationary, it allows observation of blood flow in a tumor, detached choroid, or edematous macula. Convection currents from sub-hyaloid heme, post-vitrectomy heme, or inflammatory cells are also observed.

Systematic Protocol and Labeling for OD and OS

A systematic protocol is a series of scans performed on each and every patient, with additional scans added as the pathology or special circumstances indicate. This ensures a complete exam of the globe and orbit. The original method of performing this protocol is as follows; however, some examiners perform scans in a different order. It is important only to be certain that all aspects of the globe and orbit are examined by performing a minimum number of scans in a systematic way.

Holding the probe in certain ways allows three types of B-scan images to be produced (Figs. 24, 25, 26, 27, 28, and 29):
1. Axial, a specific type of transverse
2. Transverse
3. Longitudinal (radial)

Transverse and longitudinal scans are used to obtain diagnostically useful images. Directing the sound beam around a crystalline lens is how most scans are performed. In this way, artifact echoes created by refractive properties of a lens are avoided. Sound and light waves are both affected by lenses. Only in axial scans is the sound purposely directed through the lens. Determination of retinal lesions in an axial scan is questionable due to peripheral pseudo-elevations, called Baum’s bumps, caused by the lens.

Transverse scans image more than one clock hour. They are labeled with the center clock hour followed by a notation of whether the scan was from near the optic nerve (P), between nerve and equator (PE), from the equator (E), or from anterior (A) with additional position indicators as needed.

Longitudinal scans image one clock hour at a time, from optic nerve, through equator, to ciliary body. Longitudinal is the most useful scan plane for documenting maculopathy, retinal tear, and the anterior-posterior extent of a lesion or membrane.

Fig. 23 Scleral shells of various diameters are filled with saline and used to perform UBM exams. They are also helpful when a posterior probe is used to examine the anterior segment.
Systematic Protocol and Labeling for OD

Probe Position # 1 (OD) Horizontal Transverse of Superior Aspect with Probe Marker Nasal

- Patient looks superiorly and holds gaze.
- The farther away from the probe the patient looks, the more anterior periphery is imaged.
Probe is initially placed at 6:00 limbus directed posteriorly.
Image the optic nerve shadow as starting place of every transverse scan.
Probe is shifted on sclera in an arc inferiorly towards fornix maintaining globe contact.
Sound beam is shifted from optic nerve then superiorly to the periphery.

Top of screen is nasal, bottom of screen is temporal, and center of screen is 12:00.
Scans are labeled 12P (posterior/optic nerve), 12E (equator), and 12A (anterior), with other notations made for positions such as 12 PE (closer to the optic nerve than to the equator) and 12 EP (closer to the equator than to the optic nerve).
To observe movement, ask patient to look up and left as well as up and right.

Probe Position # 2 (OD) Vertical Transverse of Nasal Aspect with Probe Marker Superior

- Patient looks nasally and holds gaze.
The farther away from the probe the patient looks, the more anterior periphery is imaged.
Probe is initially placed at 9:00 limbus and directed posteriorly.
Image the optic nerve shadow as starting place of every transverse scan.
Probe is shifted on sclera in an arc temporally towards lateral canthus maintaining globe contact.
Sound beam is shifted from optic nerve then nasally to the periphery.
Top of screen is superior, bottom of screen is inferior, and center of screen is 3:00.
Scans are labeled 3P (posterior/optic nerve), 3E (equator), and 3A (anterior), with other notations made for positions such as 3PE (closer to the optic nerve than to the equator) and 3EP (closer to the equator than to the optic nerve).
To observe movement, ask patient to look up and left as well as down and left.

Probe Position # 3 (OD) Horizontal Transverse of Inferior Aspect with Probe Marker Nasal

- Patient looks down and holds gaze.
The farther away from the probe the patient looks, the more anterior periphery is imaged.
Probe is initially placed at 12:00 limbus directed posteriorly.
Image the optic nerve shadow as starting place of every transverse scan.
Probe is shifted on sclera in an arc superiorly towards fornix maintaining globe contact.
Sound beam is shifted from optic nerve then inferiorly to the periphery.

Fig. 28 Longitudinal B-scan images one clock hour from posterior to anterior. In this example, probe is placed temporally with marker directed towards 3:00. This position produces an image from optic nerve displayed at bottom, through equator, to anterior periphery/ciliary body of 3:00. Image is labeled L3 (Photo courtesy of Byrne and Green [18])

Fig. 29 Plane of fundus imaged with longitudinal of 3:00 probe orientation (Photo courtesy of Byrne and Green [18])

- Probe is initially placed at 6:00 limbus directed posteriorly.
- Image the optic nerve shadow as starting place of every transverse scan.
- Probe is shifted on sclera in an arc inferiorly towards fornix maintaining globe contact.
- Sound beam is shifted from optic nerve then superiorly to the periphery.
• Top of screen is nasal, bottom of screen is temporal, and center of screen is 6:00.
• Scans are labeled 6P (posterior/optic nerve), 6E (equator), and 6A (anterior), with other notations made for positions such as 6PE (closer to the optic nerve than to the equator) and 6EP (closer to the equator than to the optic nerve).
• To observe movement, ask patient to look down and left as well as down and right.

_Probe Position # 4 (OD) Vertical Transverse of Temporal Aspect with Probe Marker Superior_

• Patient looks temporally and holds gaze.
• The farther away from the probe the patient looks, the more anterior periphery is imaged.
• Probe is initially placed at 3:00 limbus and directed posteriorly.
• In this gaze, patient’s optic nerve is shifted more nasally than normal, so move probe slightly over cornea in order to locate nerve shadow.
• Image the optic nerve shadow as starting place of every transverse scan.
• Probe is shifted on sclera in an arc nasally towards medial canthus maintaining globe contact.
• Sound beam is shifted from optic nerve through macula, then temporally to the periphery.
• Top of screen is superior, bottom of screen is inferior, and center of screen is 9:00.
• Scans are labeled 9P (posterior/optic nerve), 9E (equator), and 9A (anterior), with other notations made for positions such as 9PE (closer to the optic nerve than to the equator) and 9EP (closer to the equator than to the optic nerve).
• To observe movement, ask patient to look up and right as well as up and right.

_Probe Position # 5 (OD) Longitudinal Macula_

• A macula scan does not require such extreme gaze and is best imaged with the patient in a slightly temporal gaze.
• Turn probe 90°, marker pointed towards 9:00, and keep probe close to limbus.
• Image of optic nerve near bottom of screen and inserting tendon of lateral rectus muscle anterior to equator with macula centered in display.
• Top of screen is anterior periphery of 9:00; bottom of screen is the optic nerve with macula located just above the optic nerve shadow on display.
• Scan is labeled L9 MAC.
• To observe movement, ask patient to look in primary gaze then back to the right.

_Systematic Protocol and Labeling for OS_

_Probe Position # 1 (OS) Horizontal Transverse of Superior Aspect with Probe Marker Nasal_

• Patient looks superiorly and holds gaze.
• The farther away from the probe the patient looks, the more anterior periphery is imaged.
• Probe is initially placed at 6:00 limbus directed posteriorly.
• Image the optic nerve shadow as starting place of every transverse scan.
• Probe is shifted on sclera in an arc inferiorly towards fornix to maintain contact with globe.
• Sound beam is shifted from optic nerve then superiorly to the periphery.
• Top of screen is nasal, bottom of screen is temporal, and center of screen is 12:00.
• Scans are labeled 12P (posterior/optic nerve), 12E (equator), and 12A (anterior), with other notations made for positions such as 12 PE (closer to the optic nerve than to the equator) and 12 EP (closer to the equator than to the optic nerve).
• To observe movement, ask patient to look up and left as well as up and right.

_Probe Position # 2 (OS) Vertical Transverse of Nasal Aspect with Probe Marker Superior_

• Patient looks nasally and holds gaze.
• The farther away from the probe the patient looks, the more anterior periphery is imaged.
• Probe is initially placed at 3:00 limbus directed posteriorly.
• Image the optic nerve shadow as starting place of every transverse scan.
• Probe is shifted on sclera in an arc temporally towards lateral canthus maintaining globe contact.
Sound beam is shifted from optic nerve then nasally to the periphery.

Top of screen is superior, bottom of screen is inferior, and center of screen is 9:00.

Scans are labeled 9P (posterior/optic nerve), 9E (equator), and 9A (anterior), with other notations made for positions such as 9PE (closer to the optic nerve than to the equator) and 9EP (closer to the equator than to the optic nerve).

To observe movement, ask patient to look up and left as well as down and left.

**Probe Position # 3 (OS) Horizontal Transverse of Inferior Aspect with Probe Marker Nasal**

- Patient looks down and holds gaze.
- The farther away from the probe the patient looks, the more anterior periphery is imaged.
- Probe is initially placed at 12:00 limbus directed posteriorly.
- Image the optic nerve shadow as starting place of every transverse scan.
- Probe is shifted on sclera in an arc superiorly towards fornix maintaining globe contact.
- Sound beam is shifted from optic nerve through macula, then inferiorly to the periphery.
- Top of screen is nasal, bottom of screen is temporal, and center of screen is 6:00.
- Scans are labeled 6P (posterior/optic nerve), 6E (equator), and 6A (anterior), with other notations made for positions such as 6PE (closer to the optic nerve than to the equator) and 6EP (closer to the equator than to the optic nerve).
- To observe movement, ask patient to look down and left as well as down and right.

**Probe Position # 5 (OS) Longitudinal Macula**

- A macula scan does not require such extreme gaze and is best imaged with the patient in a slightly temporal gaze.
- Turn probe 90°, marker pointed towards 3:00, and keep probe close to limbus.
- Image of optic nerve near bottom of screen and inserting tendon of lateral rectus muscle anterior to equator with macula centered in display.
- Top of screen is anterior periphery of 9:00; bottom of screen is the optic nerve with macula located just above the optic nerve shadow on display.
- Scan is labeled L3 MAC.
- To observe movement, ask patient to look in primary gaze then back to the left.

**Systematic Protocol and Labeling for Axial and Oblique Transverse Scans**

**Transverse Axial Scans with Probe Marker Nasal**

An axial B-scan is performed with copious coupling gel between probe tip and corneal apex. Image will show a short double line representing anterior–posterior cornea, centered posterior lens capsule, and optic nerve shadow in one view. Standard positions are horizontal (HAX) and vertical (VAX). Because the probe marker is directed nasally in an HAX view, the macula will be just below the optic nerve shadow. Shift the probe in an
arc to the left and right in order to position the optic nerve shadow above center. The macula will then be centered in the scan.

In a VAX scan, the macula is not imaged. Oblique axial scans are used to document the relationship of pathology to the posterior lens capsule and optic nerve. These are labeled with the clock hour where the probe marker is directed. For example, a lesion is located at the 1:30 equator. With marker directed at 1:30, an axial scan is obtained and labeled 1:30 AX. The lesion will appear on the top half of the display. For lesions from 3:00 through 6:00 to 9:00, the probe marker is positioned as far up as possible. For example, for a lesion at 7:30, the probe marker is also at 1:30, and the pathology will appear on the bottom half of the display with lens and optic nerve centered. This scan is also labeled 1:30 AX.

Transverse Oblique Scans

When pathology extends through several clock hours, an oblique transverse is often needed to completely document lesion borders. For a lesion at 1:30 equator, place probe at the 7:30 limbus with marker as up as possible, in this case towards 11:30, and sweep from optic nerve to anterior to locate maximum lesion elevation. The lesion should be centered in the display that spans from 11:30 at top of screen to 3:30 at bottom of screen. Scan is labeled 1:30 E. As with axial scans, the probe marker is positioned as far up as possible, but no lens is seen. For a lesion at 7:30 equator, the probe is placed at 1:30 with marker at 9:30. Scan will image from 9:30 inferiorly to 5:30.

Many echographers also include four oblique transverse scans to their systematic protocol. The four oblique scans image superonasal, superotemporal, inferonasal, and inferotemporal quadrants.

Systematic Protocol and Labeling for Longitudinal Scans

Longitudinal Scans for Membranes and Retinal Tears

This is the most powerful scan position for finding and documenting the anterior–posterior extent of membranes. Longitudinal scans demonstrate posterior attachment or detachment of a membrane, and follows it to the anterior periphery. This significantly helps to differentiate posterior hyaloid with blood from retinal detachment. Choroidal detachments are clearly seen inserting at the vascular arcades, not all the way back to the optic nerve as is seen with many retinal detachments. A PVD with heme will be brighter and thicker posteriorly where it attaches near the nerve but will be thinner and grayer out at the periphery where fewer cells are adherent to the hyaloid.

To create a longitudinal scan, have the patient look at the clock hour to be imaged, direct the probe marker towards that same clock hour, and place the probe on the opposite sclera near the limbus. Moving the probe in an arc closer to and farther from the cornea will center pathology in the display. In order to observe membrane movement, have the patient look in primary gaze and then back to the clock hour of interest.

This is the only scan plane that permits visualization of peripheral retinal tears, often with vitreous seen attached to the flap. It is also extremely valuable to evaluate vitreoretinal traction. A complete screening for tears and traction includes a minimum of 8 positions—L12:00, L1:30, L3:00, L4:30, L6:00, L7:30, L9:00, and L10:30. Examine all 12 clock hours if needed.

Longitudinal Scans for Lesions

This scan position documents the anterior–posterior extent of a lesion. From the earlier example of a lesion near the equator at 1:30, the transverse scan showed how many clock hours are involved. A longitudinal scan will demonstrate the anterior–posterior dimension of pathology. It shows how close the posterior aspect of the lesion is to the optic nerve and how close the anterior aspect of the lesion is to the ciliary body. To create an L1:30 scan, have the patient look at 1:30, direct the probe marker towards 1:30, and place probe on opposite sclera near limbus at 7:30. Moving the probe in an arc closer to and farther from the cornea will center pathology in the display for best resolution and measurements. Lower gain will reduce vitreous echoes, increase resolution, and raise confidence in caliper positioning.

Globe Versus Through-the-Lid Exams

Due to many factors, results from an exam with the probe placed on a closed upper lid will be compromised. There are times where through-the-lid exams are required, such as recent surgery or a challenging patient, but that is an exception. Closed lids prevent knowing direction of patient gaze. Patients already have difficulty looking where needed with open
eyes, for example. It is exceptionally difficult for a patient to properly look up and left with closed eyes. The lids, especially the upper, also attenuate an ultrasound signal reducing image quality. Also, it is impossible to image the superior periphery with a probe on the upper lid. In order to image superior peripheral retina when a through-the-lid exam is to be performed, have the patient look up with open eyes and place the probe on the lower lid.

For best image quality and assurance of a complete exam, instill topical anesthesia, place tear gel or 2.5% methylcellulose on probe tip, and apply probe directly to the sclera. Axial scans are the only time a B-scan probe is on the corneal apex. If using methylcellulose, be certain to irrigate remaining gel from the eye to reduce irritation. It is not necessary to irrigate tear gel used as coupling medium from the eye.

3-Dimensional Thinking

A three-dimensional image of pathology is envisioned from the series of two-dimensional images observed. When thinking through what is seen on an image, ask these four questions:
1. In what direction was the patient looking?
2. In what direction was the probe’s orientation marker?
3. Where on the globe was the probe placed: near limbus, fornix, or canthus?
4. Where on the fundus was the acoustic section directed: posterior, equatorial, or anterior?

Answers to these questions are the foundation for mapping intraocular and orbital structures as well as accurately labeling sonograms, also called echo-grams. There is no substitute for taking the time to logically think through each examination. Allocating the needed time to practice and learn builds confidence and diagnostic ability. Knowledge, combined with a thorough and systematic exam protocol, produces valuable information leading to earlier detections of subtle pathologies such as retinal tear, maculopathy, and minimally elevated lesions.

Anterior B-Scan (Using Posterior Probe)

The anterior segment of the eye from the pars plana forward can only be viewed echographically when some sort of immersion technique is used to move the probe away from direct contact with the eye. The initial spike on the A-scan echogram results from the reverberation of the crystal in the tip of the probe. On B-scan, it is from reverberation echoes produced by the probe tip membrane. This creates the initial spike on the echogram that obscures the 3 to 5 mm part of the globe that is in direct contact with the probe (Fig. 30). The frequency and focus of the transducer being used determines the zone. This creates an acoustic “dead zone” where information is not obtainable unless the probe is moved several millimeters back. This hidden area is “moved into the view” of the probe by the use of various immersion techniques.

Coleman described a water bath apparatus in the late 1960s where plastic drapes were positioned around the patient’s eyes, fixed to the skin with adhesive, and suspended by a metal frame [15]. This reservoir was filled with water and the tip of the probe immersed in it. This technique allowed wide-angle views of the entire globe. However, it
was logistically cumbersome, and many patients became claustrophobic during the examination. The contact B-scan pioneered by Bronson has generally replaced this method [16]. However, the water bath technique continues to be used in a few centers specializing in ocular oncology.

A modification of the water bath method has evolved with the development of various types of plastic shells. They fit between the eyelids and are filled with a conducting medium such as methylcellulose, tear gel, or saline (Fig. 31).

The probe tip is placed within the shell, and this allows scanning of anterior structures. An alternate technique is to cut off the finger of a latex examination glove and fill it with water. The B-scan probe is placed about $\frac{1}{2}$ to $\frac{2}{3}$ depth within the glove containing the liquid, and this creates an enclosed immersion chamber for examination of the anterior structures of the eye as the glove finger tip is placed in contact with the globe; because the probe itself is removed from the ocular surface, this part of the eye is moved out of the probe’s dead zone, allowing visualization of an otherwise inaccessible area. Biometric A-scan probes are built with the piezoelectric crystal directly on the tip just under the focusing lens. They may be used for both contact and immersion techniques.

Since most ophthalmic equipment was designed for adult-sized eyes, the ultrasound beams for posterior B-scan are set up to have the best image between 15 and 30 mm from the probe tip, where we expect to find an adult eye’s vitreoretinal interface and where we need the best resolution to differentiate small retinal lesions.

Since pediatric patients generally have much smaller eyes, it requires a modified exam technique. This may be easily accomplished by placing a tonometer cover or finger cot filled with bubble-free water on the probe tip creating a water balloon (see Fig. 22). Use warmed drops, water, and coupling gel on babies and children who are awake to attain the best possible diagnostic information from the exam.

The use of a bag of fluid on a probe is called a modified immersion or fluid standoff technique. It accomplishes the need to move the tissue of interest, mainly the vitreoretinal interface in a tiny eye, farther from the probe tip. This positions a pediatric retina in the Focal Zone of the transducer and will produce a useful, high-resolution image. The water-filled membrane will be seen on the screen prior to applying the probe to an eye. Fluid may be added or removed in order to accommodate the desired imaging depth.

Long before high-frequency probes were available, anterior segment imaging was performed using this type of fluid standoff or an immersion scleral shell. This allows the iris/ciliary body region to be placed far enough away from the probe, so tissue will be in the transducer’s Focal Zone. It served echographers well for two decades, but now a wide range of transducer frequencies are available to meet the ever-expanding need to know more about ocular anatomy and pathology. This technique is still used when UBM is not available.

**Anterior UBM Examination**

Components of a thorough exam:
- Patient eye stationary, probe moves
- Patient eye moves, probe stationary
- Patient eye and probe both stationary
- Systematic protocol and labeling for OD and OS

**Patient Eye Stationary, Probe Moves**

Most UBM exams are made with patient’s eye stationary, while the probe is moved in order to obtain desired images. Movements with UBM probes are far more sensitive than with posterior B-scan. Echoes are very magnified on the screen, and a steady hand is required.

**Patient Eye Moves, Probe Stationary**

In UBM exams, eye movement is usually not required in order to make a determination of pathology.
Patient Eye and Probe Both Stationary

An eye and probe stationary position is used to observe spontaneous movement such as pupil constriction and dilation. It is also helpful in analyzing accommodative IOL movement where patient fixates with the fellow eye on a near, then far target while a UBM movie is captured.

Systematic Protocol and Labeling for OD and OS

The protocol is similar to that of posterior B-scan exams with one big difference. In posterior B-scan, images are labeled opposite of probe placement because the area being examined is on the other side of the eye from the probe. In anterior B-scan, it must be noted that labeling is opposite. Scans are labeled by the clock hour where the probe is placed because images are produced from tissue directly beneath the probe. Placing a probe at 6:00 will image 6:00 and is labeled 6:00.

Longitudinal scans are obvious because the image shows the iridocorneal angle. Usually these scans are only labeled with the clock hour. Transverse UBM scans are similar to a gonio view of the angle and are useful to analyze iridociliary cysts and IOL haptic location. Horizontal axial UBM scans are used to measure the diameter of the ciliary sulcus for sizing of specialty lenses.

Biometric A-Scan

Axial eye length measurements are primarily made to calculate IOL power in a cataract patient. It is also important when calculating external beam radiation treatments of ocular tumors.

To obtain accurate eye length values interpretation of four key elements is required:
1. Echo pattern
2. Eye type (velocities)
3. Caliper (gate) position
4. Correlation with patient visual history

A repeatable number with a low standard deviation may initially appear accurate, but if any one of the above 4 interpretations is not made, the patient could receive the wrong IOL and unfortunately many have. When in doubt, repeat all scans of eye length and corneal power. Remember that a 0.30-mm error in length produces approximately 1 diopter of postoperative error. Also a 1-diopter error in keratometry produces approximately 1 diopter of postoperative error. Small errors may cancel each other out but sometimes add up to create an even larger error. This is called tolerance stacking. Double- and triple-check preoperative data to ensure a predictable outcome.

Attend courses and request assistance from others, including an ultrasound manufacturer’s clinical applications specialist.

Echo Pattern

Echo pattern is the foundation of every measurement. If the echo pattern is not correct, there is no reason to even look at the measurements. An invalid pattern produces an invalid measurement. Therefore, before looking at any numbers, study and validate each echo. Anterior–posterior corneal echoes in immersion must be tall and equal in height. The anterior and posterior lens echoes should be as tall as possible, preferably 100%. Sometimes the posterior lens echo cannot reach the top of the display, so maximize it by saving scans with as tall a posterior lens echo as possible. There may be extra echoes in between that are produced from cataractous changes within the lens. Next, the retinal echo should be 100% tall and sharply rising. This means that from the bottom to the top, it is straight. Retinal echoes also should have some width and not appear as a single sharp point. Lastly, just to the right of retina must be a scleral echo to indicate that the sound beam has been directed to the macula instead of the optic nerve. Since the A-scan beam is parallel to optic nerve fibers, there will be no echo past the retina when the sound is directed to nasally toward the optic disk. Anatomically, the sclera and orbital fat are posterior to the macula. Therefore, echoes from both sclera and orbital fat are required to validate the echo pattern. Following the tall retina and scleral echoes, orbital fat echo signals quickly drop off due to sound attenuation (Fig. 32).

Eye Type

Eye type is the selection of phakic, aphakic, pseudophakic, etc. Correct selection of eye type will assure correct velocities are used for the eye being measured. It will also affect the number of calipers used.
Confirm that the proper eye type has been selected for the patient. When performing pseudophakic scans where the IOL material is not known, save one scan using each of the options offered in the instrument, and then correlate with patient’s visual history and/or fellow eye measurements to confirm. It is difficult to differentiate a silicone IOL from an acrylic IOL by their echo patterns, but PMMA lenses will produce many strong artifact echoes seen in the vitreous space and are more easily identified.

**Caliper Position**

Caliper position is critical. Validate each caliper as attached to the correct echo. Even with a perfect echo pattern, a 10-diopter error can occur if the calipers are set for contact A-scan when immersion technique is used. Another problem arises if the posterior lens caliper has mistakenly attached to an interior cataract echo or to a strong reverberation echo past the actual lens. Not only will lens thickness be incorrect, but the entire axial length is also compromised. This is because the lens has a different velocity than aqueous and vitreous, so unless each caliper is correct, the total length cannot be validated. Before saving an A-scan, first confirm correct echo pattern, caliper positions, and eye type.

**Correlation with Patient History**

Correlation with history is the final analysis. If a patient is hyperopic, and their eye measures 21 mm, that would make sense, assuming they had normal Ks. Conversely, if the eye measures 25 mm and the patient is myopic, that also makes sense. If one eye has had a scleral buckle, we expect it to be longer than the fellow eye. Therefore, look at surgical history, oldest known refraction before cataract development, and correlate eye length and keratometry values to be certain that everything makes sense for the patient (Figs. 33, 34, and 35).
When these four steps are routinely and carefully followed, the chance of a postoperative refractive error from an incorrect IOL calculation is significantly reduced.

Silicone Oil-Filled Eyes

Silicone oil-filled eyes are a challenge for ultrasound. Modern instruments have an eye-type setting for oil, but that alone is not enough to assure an accurate measurement.

Today the standard of care for performing axial length measurements is the noncontact immersion technique. However, just as seen on previous B-scans examples of an eye filled with oil, there is a large difference between a supine and seated patient. When supine, as is usually the case with immersion A-scan and with B-scan, an oil bubble floats up against posterior lens, and there are a few millimeters of sub-oil aqueous between the bottom of the bubble and the retina. Immersion A-scan instruments will choose the first tall echo in the vicinity of retina and that results in a false short value. This is because the retina caliper is attached to the bubble echo, not the actual retina that is a few mm further posterior on the scan. Often the retinal echo is short due to sound attenuation that occurs when travelling through oil. Therefore, if an immersion scan is desired, separately measure sub-oil aqueous by changing eye type to aphakic. In aphakic mode, there are only two calipers and the velocity is correctly set to 1,532 m/s. Position one caliper on the bubble echo and the other on the real retinal echo. Add this amount to the total length obtained with the eye-type set for silicone oil. On average, the amount of sub-oil aqueous is 2.0–3.0 mm.

A second somewhat easier method may be to have the patient seated with his or her back straight and perform a contact A-scan. In a seated patient, the oil bubble has again shifted up, and sub-oil aqueous will be in the inferior aspect of the globe and out of the way of the central A-scan beam. The oil bubble is against the macula, so the strong echo interface between oil and retina will produce a reasonably accurate measurement. The obvious problem of corneal compression that occurs in contact A-scan methods will cause a shortening of the globe. On average, this is 0.30 mm or about 1 diopter of error. Lastly, major consideration has to be given when calculating IOL power if oil will remain in the eye or be removed at time of cataract extraction. If oil remains in the eye, the power needed is many diopters stronger. This is due to refractive properties of silicone oil.

Special Considerations for Pediatric Patients

With axial eye length biometry, as with B-scan, care must be taken to assure proper measurements. Ultrasound instruments are designed for adult-sized eyes. In A-mode, the software will begin looking for a retinal signal about 20 mm from the cornea. Infants may have much smaller eyes, and retina caliper placement on the actual retina must be confirmed. There have been cases where an incorrect IOL power was implanted due to using an adult retinal caliper position. The caliper was then positioned in the baby’s orbital fat echoes producing a false long axial length measurement. Carefully validating every echo, and its corresponding caliper, is the only way produce an accurate result. Pediatric immersion shells with very small diameters are available to accommodate small fissures.
Standardized A-Scan Examination

All of the published A-scan ultrasound criteria for the optimal differential diagnosis of an intraocular lesion are dependent upon useful information obtained from good echographic images. It is common for beginning echographers to leap to diagnostic conclusions based on insufficient and inadequate information. The excitement of detecting a lesion and then recording A- and B-scan images of it can override the need for meticulous attention to detail. If the proper information is obtained while scanning and documenting the pathology, the differential diagnosis follows logically. Just as in clinical examination of the eye by the slit lamp or ophthalmoscope, the echographer is best advised to not jump to a diagnosis based on initial cursory impressions, but to describe what is seen. The systematic description of a lesion includes the B-scan criteria of shape, location, and relation to intraocular structures. The A-scan criteria are then added, including the characteristics of height, surface mobility, and the internal features of reflectivity including regularity, spike height, and spontaneous vascularity as described by Ossoinig [17].

It is important to examine the eye and orbit in a systematic way. It is tempting to point the probe “where the action is,” such as at an enlarged lacrimal gland or an intraocular tumor, but other pathology can be overlooked with such an approach. Both the globe and the orbit should be examined in a consistent and repetitive manner for each patient. Each examiner needs to ultimately decide which system is best for him/her, but it should be standardized for each examination setting.

The technique for the diagnostic A-scan examination is presented in video segment 2.

The A-scan probe is held between the thumb and the forefinger much like a pen is held when writing. In the examination of the globe, the display on the screen is continually watched as the probe is moved in small side-to-side and back-and-forth movements to display the retinal spike as steeply rising and as high as possible. This insures perpendicularity to the retina and allows for the detection of subtle abnormalities. This technique, as with any motor skill, will improve with practice. It is advisable to start with examination of the normal eye. The probe is placed so that the sound beam is directed perpendicular to the retina and the globe is systematically scanned in eight quadrants (45° sections), which results in a complete scan of the posterior segment. The gain for the A-scan is set at tissue sensitivity. This setting is available in several models of ultrasound units. It requires the use of a “tissue model” supplied by the dealer with which to calibrate the A-scan probe for optimal sensitivity in scanning the globe for pathology. This probe calibration in combination with certain internal adjustments inside the unit before the unit leaves the factory is an important part of standardized echography as described by Ossoinig. Once a lesion is detected, the gain can be reduced for measuring purposes (Fig. 36), or it can be increased to demonstrate mild vitreous opacities, such as in early endophthalmitis (Fig. 37).

The probe at the 6:00 limbus is then slowly slid along the globe towards the inferior fornix of the lid while trying to keep it as perpendicular to the inner

![Fig. 36](image-url)  
*Left: A-scan of lesion (vertical arrows). Right: reduced gain for measuring (vertical arrows)*

Part II. Basic Principles
wall of the eye as possible. The screen is watched and slight adjustments are made with the hand to keep the retinal spike maximally high while the probe is moved posteriorly. This allows scanning of the fundus more and more anteriorly as the probe is moved. The limit of the scan is reached when the fundus signal starts to drop away and perpendicularly cannot be maintained as evidenced by a retinal spike that becomes lower in height and is jagged instead of steeply rising (Fig. 38).

This maneuver is then repeated every 1.5 clock hours around the globe. For example, it is moved from the 6:00 position to the 7:30 position on the limbus and moved posteriorly along the globe in this quadrant. It is then moved to the 9:00 position, the 10:30 position, and so on until it is back at the 6:00 position. This succession of probe positions will allow a complete scan of the globe except for its most anterior part beginning at the ciliary body.

A-scan of the orbit is performed at the orbit expansion as indicated by the designated setting on the instrument control panel. The examination of the orbit by echography is the converse of the intraocular examination. Instead of watching for reflectivity above the baseline level of the vitreous gel, the orbit is observed for reflectivity lower than the adjacent high-reflective orbital tissue. The normal orbit contains many different tissue interfaces because of the different structures present. These include orbital fat that has a septate microstructure, extraocular muscles, blood vessels, the optic nerve and its sheaths, and connective tissue. This multiplicity of tissue interfaces results in strong reflection of the sound waves so that much of the normal orbit is highly reflective with maximally high spikes on the A-scan and echodensity on the B-scan (Fig. 39).

The extraocular muscles are more homogenous in internal structure than the surrounding orbital tissue, so the echo reflectivity becomes relatively lower (Fig. 40).

These muscles are best examined sequentially by A-scan in a transocular view. Placing the probe at the 6:00 limbus and directing it towards the superior orbit image the superior rectus. It is aimed at
the 12:00 position just behind the superior orbital rim and moved side to side and back and forth in small movements. When the reflectivity begins to become lower than normal orbital tissue, the probe is kept in that same horizontal plane and angled posteriorly while attempting to display the anterior and posterior muscle sheaths by maximizing their height. The muscle is followed posteriorly until the two steeply rising maximally high spikes begin to drop off towards the apex of the orbit. The anterior tendinous part is imaged by angling the probe anteriorly towards the orbital rim and watching the space between the two muscle sheaths that become narrower and closer to the globe (Fig. 41).

It is often difficult to visualize the tendon in a normal muscle, but demonstrating it is an important differential point in distinguishing inflammatory myositis from other causes of muscle thickening, such as Graves’ disease. The tendon is usually thickened in myositis and not the other myopathies (Fig. 42).

The B-scan can be especially helpful in imaging the tendon near its attachment to the globe, whereas the tendon can “get lost” near the high reflectivity of the sclera on the A-scan. The B-scan can image the extraocular muscles both in a longitudinal (long section) and in a transverse (cross section), as seen in Fig. 43.

The gain should be reduced to increase the contrast between the lesser echodensity of the muscle
and the surrounding more echodense orbital tissue (Fig. 44).

A major advantage of the A-scan versus CT and MRI is the ability to quantitate the width of the extraocular muscles. The muscle is followed back into mid-orbit, and the two sheath spikes are maximized respecting height and smoothness of the spike. A measurement is taken at this point and recorded. It is important to take the measurement at the maximal width of the muscle both to compare it to normograms of normal extraocular muscle dimensions and for follow-up over time to document increase in width such as in Graves’ disease. There are several published tables of values for normal extraocular muscle thickness [18–20].

Figure 45 is a compilation of these reports with some modification of the values based on the author’s personal experience:

The imaging of the other extraocular muscles is continued around the globe in either a clockwise or counterclockwise direction but systematically for each eye. The superior and medial recti are usually the easiest to image with ample room to angle the probe when it is placed inferiorly for the superior rectus and laterally to view the medial rectus. The inferior and lateral recti are more difficult to image in the transocular view as a direct function of the degree of prominence of the brow or nose. Placing the probe against the eye in the inferotemporal quadrant and aiming towards the trochlea at the superior nasal orbital rim enable a view of the superior oblique tendon. The superior oblique hugs the bone as it is followed towards the apex, unlike the rectus muscles that angle away from the orbital bone towards their origin in the posterior orbit (Fig. 46).

The inferior oblique is the most difficult of the extraocular muscles to image because of its very anterior position in the orbit as it slings from the nasal to the temporal side. It can best be seen in the paraocular view if it is enlarged by infiltration, such as in inflammation or malignancy.

The probe should constantly be moved side to side incrementally as it is angled more posteriorly into the orbit. It is relatively easy to get lost in api-
cal structures, such as the superior and inferior orbital fissures, and mistake nonmuscular tissues for the muscle being followed. To reorient oneself, the probe should be angled slightly anteriorly to confirm the two high septal spikes bordering the relatively lower reflective muscle. Once this is confirmed, the probe is then directed posteriorly again while minimizing its lateral movement in an attempt to stay within the plane of the muscle.

Imaging the optic nerve requires the same constant probe “minimovements” as the nerve is followed from its exit behind the globe towards the optic foramen. The probe is first placed on the temporal globe and directed towards the medial rectus muscle and medial orbital wall. The medial rectus is used as a reference point, and the optic nerve is seen lateral to it (closer to the globe on the screen). The steeply rising twin sheath spikes of the optic nerve are detected as the probe is angled up and down and side to side (Fig. 47).

The nerve is followed posteriorly until the sheath spikes drop away near the apex. The same orientation techniques applied to the extraocular muscles are used where the probe is angled posteriorly and slightly superiorly/inferiorly to insure that the nerve is being imaged and not confused with adjacent structures. The widest dimension of the nerve is found, and this location is selected to measure the sheath-to-sheath width.

The ease of imaging the optic nerve is highly dependent on how it curves as it goes through the orbit. In some patients, the nerve is seen almost as soon as the probe is placed on the temporal globe and is easily followed along its course posteriorly towards the apex. In others, it can be very difficult no matter how the probe is manipulated. In these patients, it is advisable to try placing the probe on the nasal globe and aiming it temporally. The nerve may be more easily seen from this position. If it is still difficult to image the nerve, the patient is asked to adduct or abduct the eye a little. This maneuver will sometimes rotate the nerve into a position where it is more readily seen.

It is important to examine the eye and orbit in a systematic way. It is tempting to point the probe “where the action is,” such as at an enlarged lacrimal gland or an intraocular tumor, but other pathology can be overlooked with such an approach. Both the globe and the orbit should be examined in a consistent and repetitive manner for each patient. Each examiner needs to ultimately decide which system is best for her, but it should be standardized for each examination setting.