Ophthalmic Ultrasonography: Theoretic and Practical Considerations

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KEYWORDS

- Ophthalmic ultrasound • B-scan • A-scan
- Ultrasound biomicroscopy

Ophthalmic ultrasonography is the main diagnostic imaging modality of the eye. It is a safe, noninvasive diagnostic tool that provides instant feedback for the evaluation of various ophthalmic disorders. Diagnostic ophthalmic ultrasonography is most useful in the presence of opaque ocular media caused by corneal opacities, anterior chamber opacities, cataracts, vitreous hemorrhage, or inflammatory opacities. Ophthalmic ultrasonography is also valuable in the presence of clear media and for evaluation of the iris, lens, ciliary body, and orbital structures. Intraocular tumors are routinely documented, measured, and differentiated by ultrasonographic techniques (see the article by Fu and colleagues, elsewhere in this issue). This article provides a brief overview of the basic physics of ultrasound, instrumentation, and special examination techniques used in ophthalmic ultrasonography.

BASIC PHYSICS

Acoustic Wave

Ultrasound is an acoustic wave with a frequency above the audible range of 20 KHz. Echoes are produced when ultrasound waves encounter an interface in which two different materials have different acoustic impedances. Ultrasound machines in use in medicine produce high-frequency waves and then detect, process, and amplify the returning echoes. A short acoustic pulse is generated mechanically by a piezoelectric crystal, which acts as a transducer to convert electric energy into ultrasound. At every acoustic interface, some of the echoes are reflected back to the transducer, indicating a change in tissue density. The echoes returned to the probe are converted back into an electrical signal and processed. Based on the parameters and design of the specific ultrasound receiver, processing can include amplification, compensation, compression, demodulation, and rejection. Although amplification curves are preset on ultrasound machines, they also can be adjusted manually by the examiner. The gain, measured in decibels, is the measurement of relative amplification.

Laws of Acoustic Energy

The use of ultrasound in medicine depends on the physical laws of acoustic energy, reflection, refraction, and absorption.[1] The angle of incidence is an important factor in the strength of the returning echoes. To accurately access structures based on the intensity of the returning echoes, the sound beam needs to be directed perpendicular to the desired structure. Sound beams directed at an oblique angle toward an interface result in the reflection of some of the sound beams away from the probe, which causes a weaker signal. Variations in the shape and size of the acoustic interface also can result in scattering of some of the sound beams. Ultrasound directed at a coarse, irregular

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surface results in significant loss of echo strength because of diversion of reflected echoes.

Frequency and Resolution

Frequencies currently used in ophthalmic ultrasound machines range from 8 to 80 MHz, compared with 2 to 6 MHz typically used in other fields of diagnostic ultrasound. The use of higher frequencies allows for increased resolution, which is essential in the evaluation of small ophthalmic structures. The superficial location of the eye and the low absorptive properties of its primarily aqueous based structures make the use of high frequencies practical.[2] The high frequencies are achieved with mechanical scanning by single-element focused transducers. Electronically scanned arrays are not usually found in ophthalmic imaging devices because it is difficult to assemble array elements with the necessary half-wavelength spacing.[3] The unique anatomy of the ocular structures allows the sound beam in ophthalmic devices to reach all areas of the eye in a close to optimal perpendicular orientation by movement of the eye and positioning of the transducer.

INSTRUMENTATION

In 1956, Mundt and Hughes[4] published the first report of in vivo A-scan ultrasonography of intraocular tumors. Other clinical applications were published soon after.[5] Techniques for B-scan ophthalmic examination and ultrasonographic features of specific ocular diseases and tumors were described within 2 years of the initial publication.[6] Since then, many investigators have aided in the design and improvement of ophthalmic ultrasound instrumentation and expanded on the diagnostic techniques. The most frequently used ophthalmic ultrasound instrumentation includes A-scan, B-scan, and ultrasound biomicroscopy. Color Doppler ultrasonography and three-dimensional ultrasonography has limited ophthalmic applications.

A-scan

A-scan is a one-dimensional display of echo strength over time. Vertical spikes correspond to echo intensity and are shown on the horizontal axis as a function of time. Two primary types of A-scan are used in ophthalmic ultrasonography: biometric A-scan and standardized diagnostic A-scan.[7] Each has slightly different operating frequencies and amplification algorithms.

Biometric A-scan

Biometric A-scan is optimized for axial eye length measurements. It uses a probe with an operating frequency of 10 to 12 MHz and a linear amplification curve.[8] The sound velocity in ocular structures along the visual axis at physiologic temperatures is well established, resulting in highly accurate measurements.[9–11] The primary function of biometric A-scan in ophthalmology is to determine the axial eye lengths for patients undergoing cataract surgery so that the dioptric power of the intraocular lens to be implanted can be determined accurately (see the article by Maia Rocha and Krueger, elsewhere in this issue).

Standardized A-scan

Standardized A-scan is a special diagnostic instrument developed by Ossoinig.[12,13] It uses a probe with an operating frequency of 8 MHz and an S-shaped amplification curve. The S-shaped curve provides the benefit of the wide range of logarithmic amplification and the high sensitivity of linear amplification. The primary feature of standardized A-scan is the tissue sensitivity or standardized decibel setting used for the detection and differentiation of abnormal intraocular tissues. Standardized A-scan is designed to display an echo spike for retina that is 100% on the echo intensity scale when the sound beam is directed perpendicular to the retina (**Fig. 1**). Highly dense ocular structures, including choroid and sclera, also produce 100% echo spikes. All intraocular structures that have a density lower than retina, including vitreous opacities and membranes, produce echoes of less than 100% intensity. The reflectivity of the A-scan spike also allows intraocular and orbital tumor cell structure to be evaluated

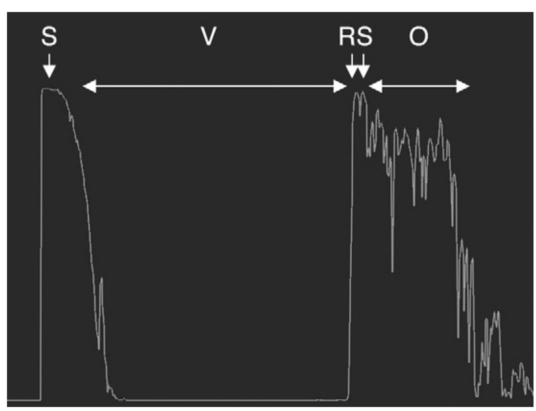

Fig. 1. Standardized A-scan in a normal eye. Echo shows transscleral A-scan produced by placing the probe against the sclera and directing the sound beam perpendicular to the retina. S, sclera; V, vitreous; R, retina; O, orbital tissue.