Ultrasound Biometry

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Maya C. Shammas and H. John Shammas

Ultrasound biometry measures the axial length (AL) with an A-scan biometer. In the 1970s, 1980s, and 1990s, A-scan biometry was widely used to measure the AL [1–3]. Although modern biometry has evolved with the introduction of optical biometry in 1999 and swept-source optical coherence tomography in 2016, the acquisition rate never reached 100% of the cataractous eyes. In these eyes with advanced cataracts, A-scan biometry is still being used to acquire the AL.

During biometry, the ultrasound beam is aligned with the optical axis of the eye (Fig. 9.1). The emitted sound beam will meet multiple interfaces. At each interface, part of the sound beam is reflected toward the probe and the remainder of the sound beam keeps propagating deeper into the tissues. This process will generate echospikes from the different interfaces that have been intersected: the anterior surface of the cornea, posterior surface of the cornea, anterior surface of the lens, posterior surface of the lens, anterior surface of the retina, and the anterior surface of the sclera. When the ultrasound beam reaches the orbital tissues, it is attenuated until it loses all its energy. The reflected sound beam returns to the transducer that also acts as a receiver. The pulses are then processed within the biometer to display "echo signals" on the screen.

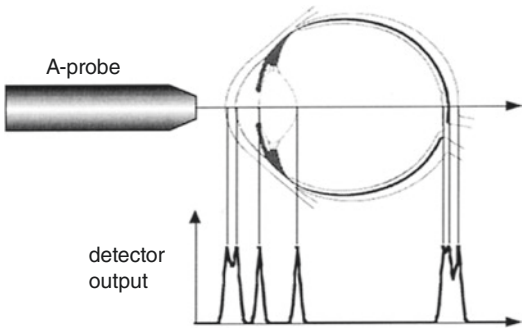

Fig. 9.1 The ultrasound beam is perpendicular to the cornea, the anterior and posterior lens surfaces, and to the retina. Please note the peaks generated when the beam intersects the anterior corneal surface, the posterior corneal surface, the anterior lens surface, the posterior lens surface, and the retina. Extra spikes are generated behind the retinal one by the sclera and the orbital tissues

Basic Principles of A-Scan Echography

In A-scan echography, an electro-acoustic device called a *transducer* is used as both a source and detector of sound. The transducer is typically mounted at the tip of a handheld probe. In an ideal world, the sound produced by the transducer would be an *impulse*. Each time this sound

M. C. Shammas
Shammas Eye Center, Lynwood, CA, USA

H. John Shammas (✉)
The Keck School of Medicine of USC,
Los Angeles, CA, USA

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impulse crosses an interface, a similar "echo" impulse would be reflected back and detected by the transducer. For a variety of reasons, no real-world transducer can produce an ideal impulse. What we get instead is a sound pulse of finite duration, whose sound-pressure graph is like that shown in Fig. 9.2.

To turn these into a nice echo graph, something like that of Fig. 9.1, an electronic circuit called an *envelope detector* is used. Given the pulse shown in Fig. 9.3 as input, this circuit will output a voltage signal corresponding to the instantaneous intensity of the echo, as shown in Fig. 9.4.

The width or "thickness" of the detector output pulse determines how well the A-scan system can distinguish closely spaced interfaces—its *axial resolution*. Many factors combine to determine this pulse width, one of the most important being the *bandwidth* of the system electronics. An A-scan system with a large bandwidth will produce narrower echospikes—hence higher resolution—than the one with a smaller bandwidth.

During A-scan biometry, alignment of the ultrasound beam is extremely important. To display the highest spikes possible, the ultrasound beam must stay perpendicular to the smooth and regular surfaces it intersects, whether it is the anterior and posterior corneal surfaces, the anterior and posterior lens surfaces, or most importantly the retinal surface, forming an incidence angle of 90° with each of these surfaces. If the ultrasound beam is aimed tangentially at any of the surfaces, the related echospike will be displayed much smaller or not at all (Fig. 9.4). Small echospikes can also be displayed if the surface in question is irregular due to scattering of the ultrasound beam when it intersects the irregular surface (Fig. 9.5).

In the displayed echograph (Fig. 9.1), the time axis of the graph indicates the "time-of-flight" of the impulse—the total time it takes for the impulse to travel from the transducer to a given

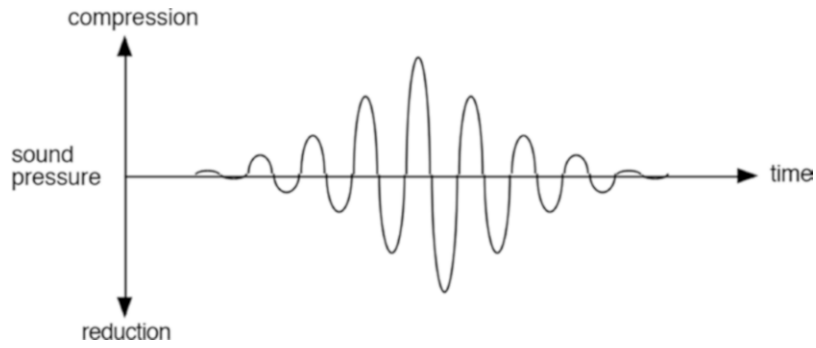

Fig. 9.2 A sound-pressure graph of a realistic A-scan pulse

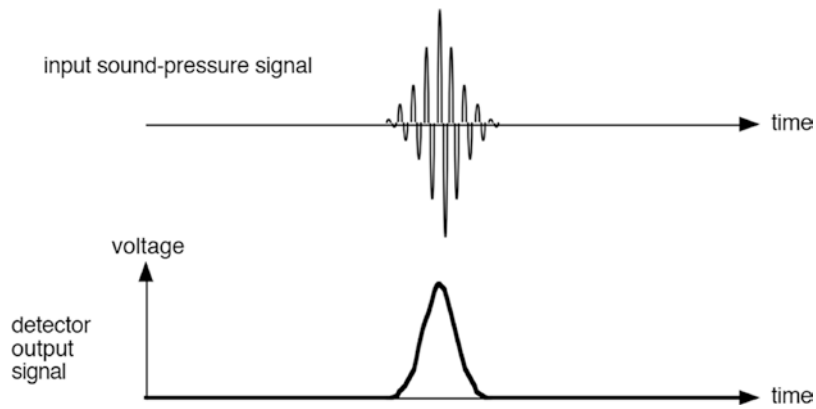

Fig. 9.3 An envelope-detector response to a realistic A-scan pulse

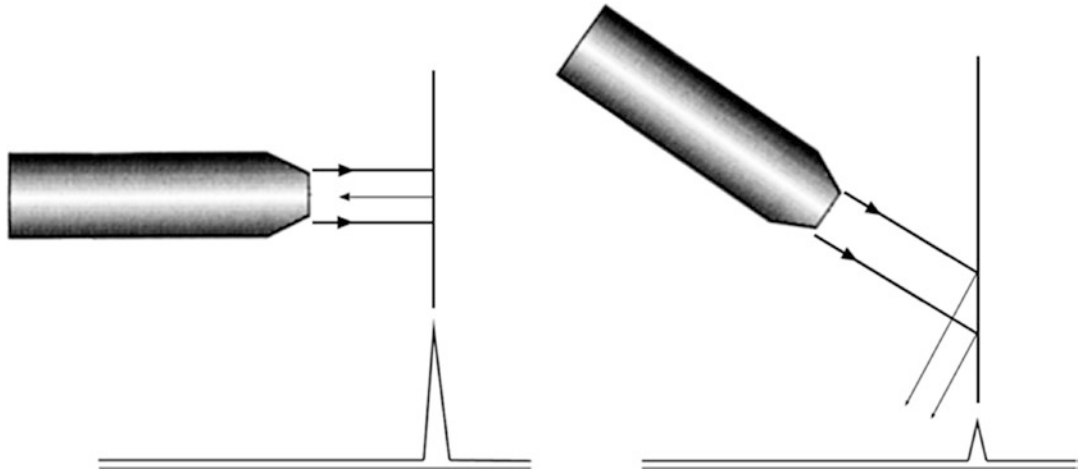

Fig. 9.4 A sharp and tall echospike is displayed when the ultrasound beam is kept perpendicular to the surface under study. A smaller echospike is displayed when the ultrasound beam is tangential to the same surface

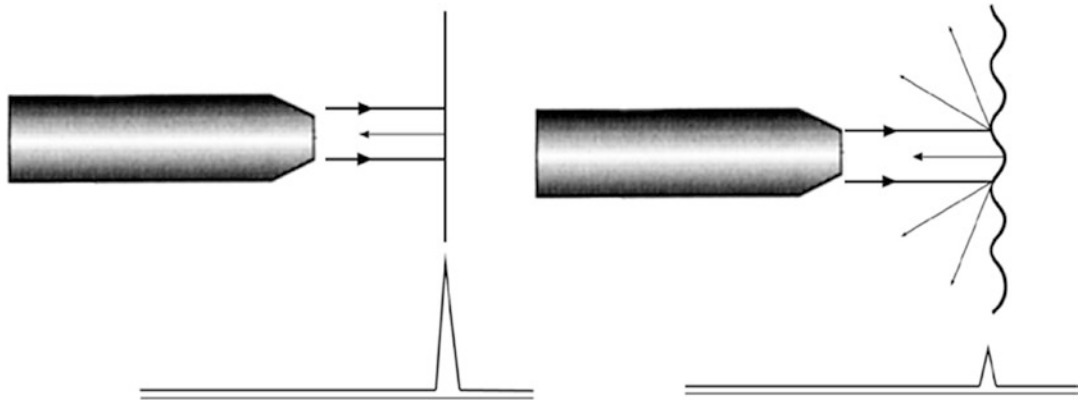

Fig. 9.5 A smaller echospike is displayed when the ultrasound beam encounters an irregular surface. Note the scattering of the beam when it intersects the irregular surface

interface and back to the transducer. The times at which echo impulses are received can be used to compute the distances between the corresponding interfaces, provided we know the sound velocity. The formula is:

$$d = tv / 2,$$

where d is distance, t is echospike time (taken from the horizontal axis of the echo graph in Fig. 9.1), and v is sound velocity. The factor of 2 occurs because the echospike time t is a time-of-flight measurement of the time required for the sound to travel the distance d twice (outward from the transducer, then back).

A little careful analysis reveals that this formula can be slightly modified to compute distances *between* adjacent interfaces, based on the time *difference* between the corresponding echospikes, using the specific velocity for the intervening medium. For example, the first two echospikes in the graph shown in Fig. 9.1 correspond, as shown, to the anterior and posterior surfaces of the cornea. The velocity of sound in the corneal tissue has been measured experimentally to be 1641 m/s. So, if the anterior and posterior corneal echospikes occur at points t_{C1} and t_{C2}, respectively, on the echo graph time axis, the corneal thickness, T_C can be computed as.

$$T_C = \left[\left(t_{C2} - t_{C1}\right) \times 1641\right] / 2.$$

Similarly, the anterior chamber depth can be computed from the time between the posterior cornea and anterior lens echospikes using the velocity 1532 m/s for aqueous; the lens depth can be computed from the time between the anterior and posterior lens spikes using the velocity 1641 m/s for the natural lens, and the vitreous cavity depth can be computed from the time between the posterior lens and retina spikes using the velocity 1532 m/s for vitreous. Moreover, we can correct for other media by using the proper velocities, for example, 980 m/s for silicone IOLs, 2718 m/s for PMMA IOLs, and so on. Modern A-scan biometers perform such calculations automatically.

Measurement Technique

Immersion Technique

The immersion technique is the preferred examination method [4] because it eliminates any corneal compression during the exam:

- The patient is placed in a supine position on a flat examination table or in a reclining examination chair, and a drop of local anesthetic is instilled in both eyes.
- A scleral shell is applied to the eye. The most used scleral shells are the Hansen shell, the Prager shell, and the Kohn shell (Fig. 9.6). The Hansen shells are available in 16-, 18-, 20-, 22-, and 24-mm diameter. Other types of scleral shells are also available from different manufacturers.
- The flared edges of the scleral shell are placed between the lids, making sure that the cup is stable on the eye (Fig. 9.7).
- The Hansen shell is filled with gonioscopic solution (Fig. 9.8). Methylcellulose 1% is preferred over the 2.5% concentration (too thick) and over saline solutions (too liquid). The solution should be free of air bubbles; the presence of bubbles causes variations in the speed of sound and is responsible for noise formation within the ultrasound pattern. The easiest way to avoid bubbles is to remove the bottle's nipple and pour the solution into the cup. If bubbles do form within the solution, they are removed with a syringe, and, if unsuccessful, the cup must be emptied, cleaned, repositioned, and refilled with gonioscopic solution.
- The ultrasound probe is immersed in the solution keeping it 5–10 mm away from the cornea (Fig. 9.9). The patient is asked to look, with the fellow eye, at a fixation point placed at the

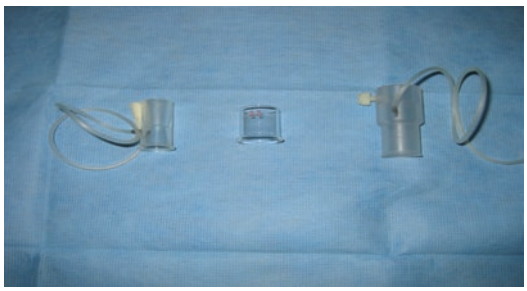

Fig. 9.6 Popular shells used for immersion biometry. From left to right, the Kohn shell, the Hansen shell, and the Praeger shell

Fig. 9.7 Immersion A-scan biometry. The Hansen shell with its flared edges is placed between the lids

Fig. 9.8 Immersion A-scan biometry. The Hansen shell is filled with gonioscopic solution

Fig. 9.9 Immersion A-scan biometry. The ultrasound probe is immersed in the solution, keeping it 5–10 mm away from the cornea

ceiling. Attention is then focused on the screen. The probe is gently moved until it is properly aligned with the optical axis of the eye and an acceptable A-scan echogram is displayed on the screen. A printout is obtained.

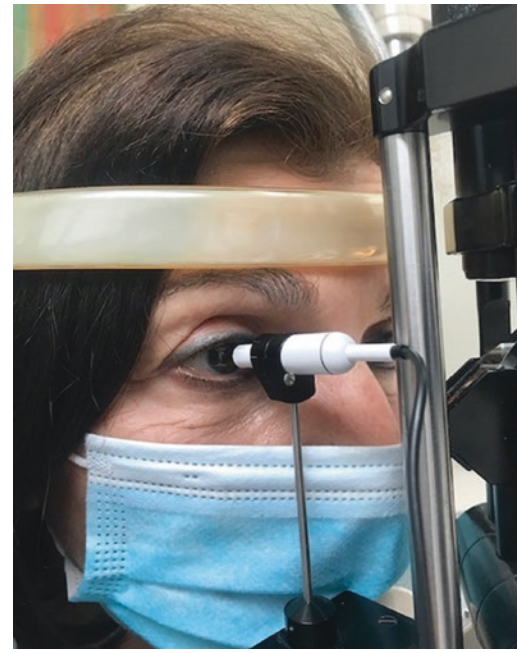

Fig. 9.10 Contact A-scan biometry. The patient is examined in the seated position. The technician uses the joystick to align the probe with the eye to be measured

Contact Technique

The contact technique was popularized in the 1980s [5–7]. The probe is brought forward to gently touch the cornea without indenting it (Fig. 9.10). In a prospective study on 180 eyes performed by the author [6], axial length measurements were obtained on each eye with both contact and immersion techniques. Axial length measurements obtained with the contact technique were shorter than those obtained with the immersion technique by an average of 0.24 mm.

The two methods of examination differ in the patient's position and the possible corneal applanation by the ultrasound probe. The patient is conventionally examined in the seated position with the contact technique, and the probe is brought forward to touch the cornea.

The patient is conventionally examined in the supine position with the immersion technique, and the solid probe is kept 5–10 mm away from the cornea. These differences in the methods of examination, mainly the corneal indentation and the subsequent shallowing of the anterior cham-

ber, are responsible for the shorter measurement obtained with the contact technique.

A-Scan Pattern of the Phakic Eye

Identifying the Echospikes

The A-scan pattern of a normal phakic eye examined with an immersion technique (Fig. 9.11) displays the following echospikes from left to right [8, 9]:

IS: The initial spike (IS) is produced at the tip of the probe. It has no clinical significance. Many units will allow the technician to move the whole A-scan pattern to the left and remove the IS from the picture.

C: The corneal spike (C) is double-peaked representing the anterior and posterior surfaces of the cornea.

L1: The anterior lens spike (L1) is generated from the anterior surface of the lens.

L2: The posterior lens spike (L2) is generated from the posterior surface of the lens and is usually smaller than L1.

R: The retinal spike (R) is generated from the anterior surface of the retina. This surface is highly reflective resulting in a straight, high-reflective, and tall echospike whenever the ultrasound beam is perpendicular to the retina, as it should be during axial length measurement. The scleral spike is another high-reflective spike generated from the scleral surface, right behind the retinal spike, and should not be confused with it. The orbital spikes are low reflective behind the scleral spike.

With a contact technique, the probe touches the cornea, and the initial spike merges with the anterior corneal echospike forming an overloaded first echospike that appears wider and truncated at the top (Fig. 9.12). The remainder of the echospikes are displayed the same as in the immersion technique.

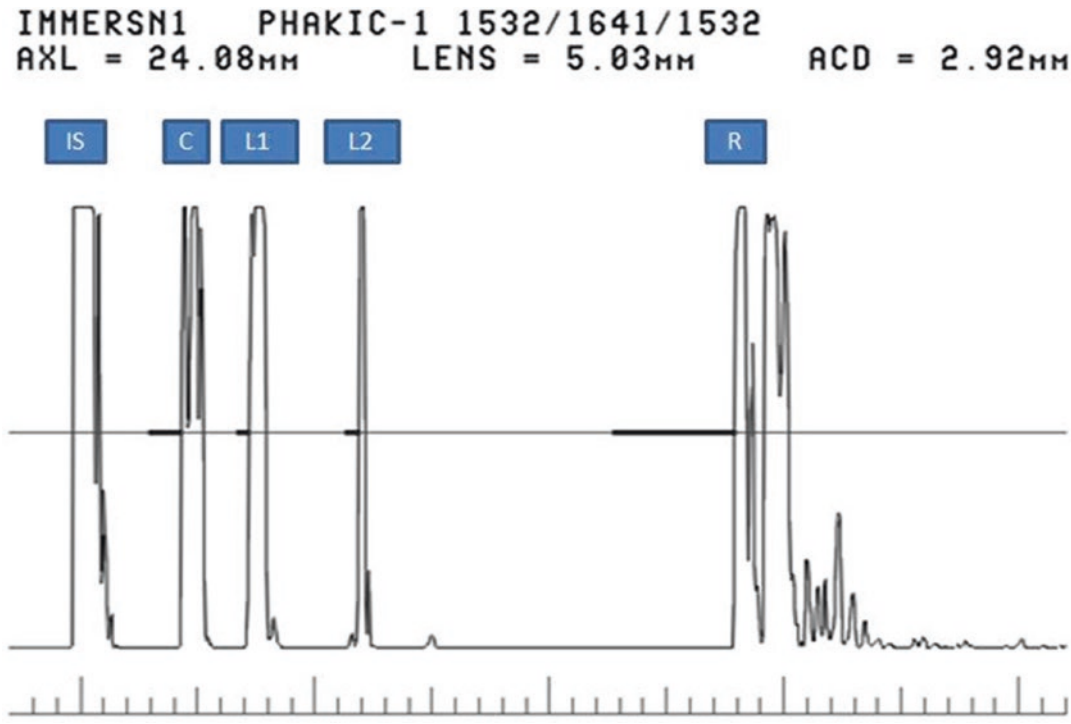

Fig. 9.11 An A-scan display of a phakic eye during immersion A-scan biometry, identifying the initial spike (IS), the cornea (C), the anterior lens surface (L1), the posterior lens surface (L2), and the retina (R)

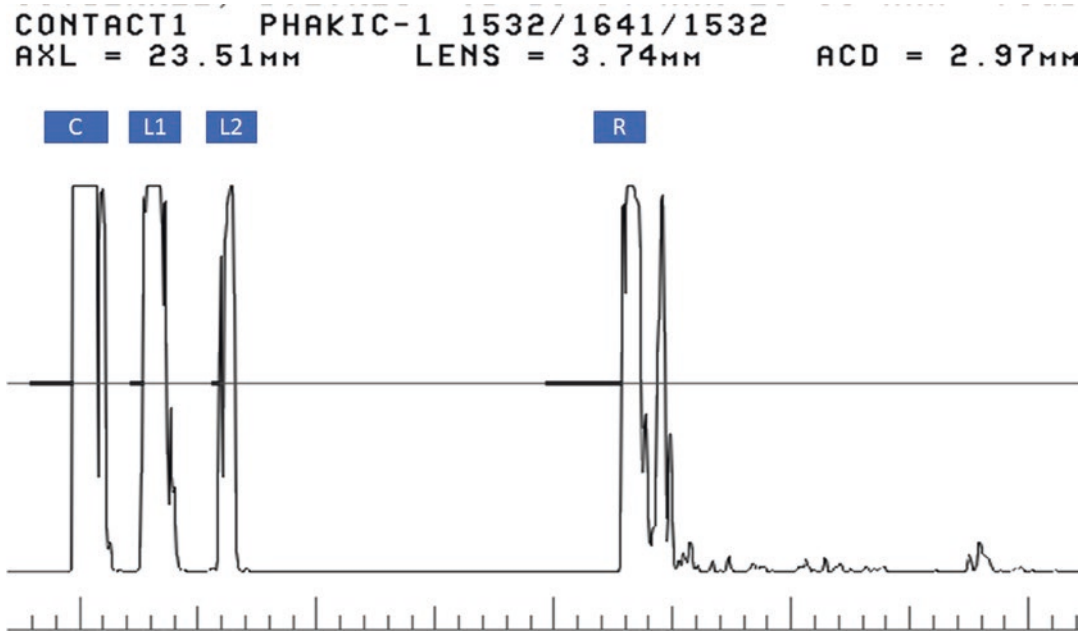

Fig. 9.12 An A-scan display of a phakic eye during contact A-scan biometry, identifying the cornea (C), the anterior lens surface (L1), the posterior lens surface (L2), and the retina (R)

Setting the Appropriate Velocities

Most modern biometers use separate sound velocities for the different eye components to obtain the total axial length [10–14]. The eye is divided ultrasonically into four compartments:

- The corneal thickness is measured between the anterior and posterior surfaces of the cornea using a velocity of 1620 m/s.
- The aqueous depth is measured between the posterior corneal surface and the anterior lens surface using a velocity of 1532 m/s. The anterior chamber depth, usually displayed on the screen, is the sum of the corneal thickness and aqueous depth.
- The lens thickness is measured between the anterior and the posterior lens surfaces, using a velocity of 1641 m/s. The sound velocity in cataractous eyes varies from 1588 to 1622 m/s with a slower velocity (average 1590 m/s) in the intumescent cataracts due to their high water content, and a higher velocity in the posterior capsular cataracts.
- The vitreous cavity's depth is measured between the posterior lens surface (L2) and the anterior surface of the retina (R) using a velocity of 1532 m/s.

Although it is best to measure the different ocular compartments at their specific sound velocities, the use of an average sound velocity of 1553 m/s yields clinically insignificant errors in the average 23.5-mm eye. However, it can yield around a 0.05-mm longer measurement in the long eye and around a 0.07-mm shorter measurement in the short eye.

In the presence of an intumescent cataract, the lens increases its water content and becomes thicker (over 5.0 mm). Concomitantly, the sound velocity decreases to around 1590 m/s from the usual 1641 m/s. Many biometers do an internal adjustment for an intumescent cataract; however, the erroneous use of a 1641-m/s sound lens velocity will yield a 0.10–0.15-mm longer measurement, calling for a weaker IOL and resulting in a slightly more hyperopic final refraction.

Errors in Axial Length Measurement and the Final Refraction

Variations in axial length measurement affect the final refraction differently in the average, long, and short eyes [4]. In an average 23.5-mm eye, a 0.1-mm difference in AL measurement affects the final postoperative refraction by 0.25 D. In a long 26.0-mm eye, a 0.1-mm difference in the AL measurement affects the final postoperative refraction by only 0.20 D. In the short 2 l.0-mm eye, a 0.1-mm difference in the AL measurement affects the final postoperative refraction by 0.31 D.

Axial Length Measurement of the Challenging Eye

Aphakic eyes, pseudophakic eyes, and eyes with a posterior pole staphyloma or filled with silicone-filled vitreous are best measured with optical biometry or swept-source optical coherence tomography. Measuring these eyes with ultrasound can be challenging.

The Aphakic Eye

In the aphakic eye, a medium reflective echospike from the anterior vitreous face replaces the two lens peaks of the phakic eye.

The axial length is measured between the anterior corneal surface and the anterior retinal surface using an average sound velocity of 1.532 mm/μs (1532 m/s), which is the velocity in aqueous and vitreous. Certain units use a slightly higher sound velocity of 1534 m/s to account for the faster speed of sound within the cornea. If the ultrasound unit uses only fixed 1550 m/s velocity and does not allow the use of 1534 m/s velocity, the axial length of the aphakic eye can then be calculated as follows:

$$\text{APHAKIC AL} = (1534/1550) \times \text{AL measured with } 1550\,\text{m/s}.$$

The Pseudophakic Eye

In a pseudophakic eye (Fig. 9.13), a high reflective spike from the anterior surface of the pseudophakic lens is visualized following the corneal spikes. It is usually followed by multiple smaller echospikes (arrows) that represent reverberations of the ultrasound beam between the anterior and posterior surfaces of the implant. The operator must remember to lower the beam's amplification to better differentiate the different peaks and to reduce artifacts.

In pseudophakic eyes, most biometers make an internal adjustment and the operator can choose the "pseudophakic mode" and the IOL material. The average sound velocity (V_L) and central thickness (T_L) of each IOL vary according to the IOL material (Table 9.1).

It is best to measure the AL at the velocity of 1532 m/s as if it is an aphakic eye and then add or subtract a corrected axial length factor (F):

$$\text{PAL} = \text{AL}_{1532} + F$$

$$\text{and } F = T_L \times (1 - 1532/V_L)$$

where

- PAL is the true axial length of the pseudophakic eye.
- F is the corrected axial length factor.
- AL_{1532} is the axial length measured at the velocity of 1532 m/s.
- T_L is the central IOL thickness.
- V_L is the average sound velocity within the IOL.

If the measurement of the AL is taken at a velocity of 1550 m/s (AL_{1550}) like measuring a phakic eye with an average velocity of 1550 m/s, the measurement can be converted to an aphakic measurement (AL_{1532}) where:

$$\text{AL}_{1532} = (1532/1550) \times \text{AL}_{1550}.$$

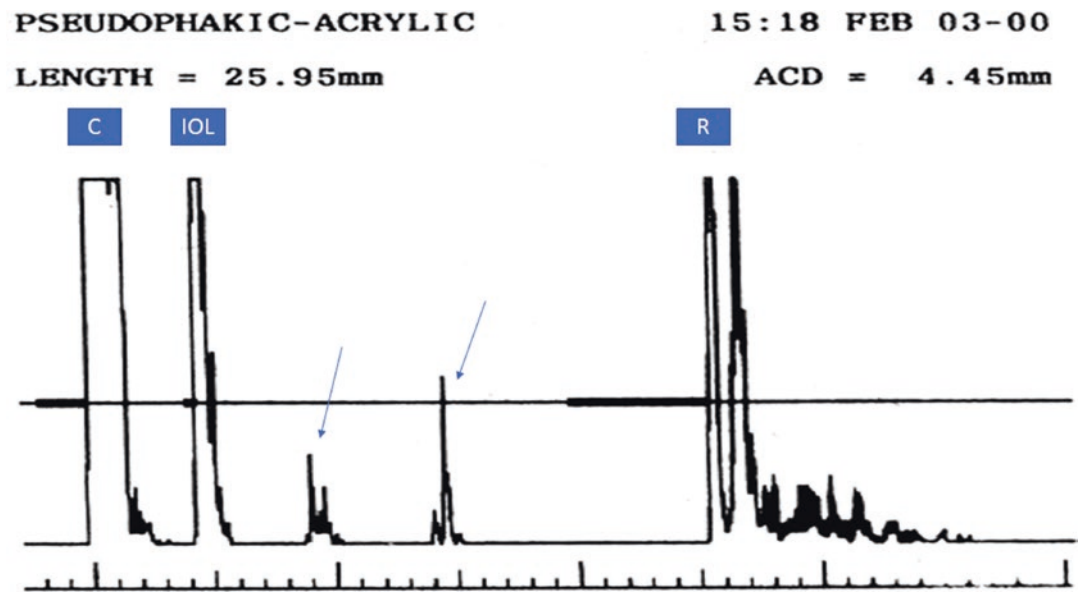

Fig. 9.13 An A-scan display of a pseudophakic eye. Note the presence of reverberation spikes (arrows) behind the intraocular lens (IOL)

Table 9.1 Average sound velocity and central thickness of different intraocular lens materials

Implant	Sound velocity (m/s)	Central thickness (mm)
PMMA	2660	0.6–0.8
Silicone	980	1.2–1.5
Glass	6040	0.3–0.4
Acrylic	2200	0.7–0.9

– The average correction factor (*F*) is "+0.4 mm" for the PMMA IOL, "+0.2 mm" for the acrylic IOL, and "−0.6 mm" for the silicone IOL.

The following table details the correction factors according to the IOL power (Table 9.2):

If the eye is to be measured with an average sound velocity instead of using preceding formulas, the following velocities are recommended:

– 1555 m/s for an eye with PMMA IOL
– 1476 m/s for an eye with a silicone IOL
– 1549 m/s for an eye with a glass IOL
– 1554 m/s for an eye with an acrylic IOL

If a pseudophakic eye is measured at the phakic average velocity of 1550 m/s, the error is <0.1 mm for the eye with a PMMA, glass, or acrylic IOL. However, this error exceeds 1.0 mm for the eye with a silicone IOL.

Table 9.2 IOL correction factors

IOL power	Acrylic IOL	Silicone IOL	PMMA IOL
+10.0 D	+0.18	−0.50	+0.23
+12.0 D	+0.18	−0.52	+0.25
+14.0 D	+0.18	−0.54	+0.28
+16.0 D	+0.22	−0.55	+0.30
+18.0 D	+0.23	−0.56	+0.33
+20.0 D	+0.25	−0.59	+0.36
+22.0 D	+0.26	−0.60	+0.39
+24.0 D	+0.27	−0.62	+0.41
+26.0 D	+0.29	−0.64	+0.44
+28.0 D	+0.30	−0.65	+0.46
+30.0 D	+0.31	−0.67	+0.50

The Eye with Silicone-Filled Vitreous

Silicone oil is used to fill the vitreous cavity to prevent recurrent retinal detachments in high-risk cases. Silicone oil can have varying viscosity, measured in centistokes (cSt). The commonly used 1000 centistoke oil has a velocity of 980 m/s,

whereas the 5000 centistoke oil's velocity is 1040 m/s. The low velocity within the silicone oil will cause an erroneous measurement of the vitreous cavity depth (VCD). Some biometers provide an option to measure the axial length in the presence of silicone oil. If this option is not available, the eye is measured as usual. The vitreous cavity depth measurement will need to be corrected.

The formula to correct the axial length in any silicone oil-filled vitreous is:

1. The vitreous cavity depth as measured by the biometer is calculated:

$$\mathrm{VCD}_{1532} = \mathrm{AL} - (\mathrm{ACD} + \mathrm{LENS}).$$

2. The vitreous cavity depth measurement is corrected using the correct velocity of 980 instead of 1532 m/s: $\mathrm{VCD}_{\text{corrected}} = \mathrm{VCD}_{1532} \times (1/1532) \times 980$ m/s *
   * or 1040 m/s (depending on the oil placed in the patient's eye).
3. $\mathrm{AL}_{\text{CORRECTED}} = \mathrm{VCD}_{\text{corrected}} + \mathrm{ACD} + \mathrm{LENS}$

In some cases, silicone oil must remain in the vitreous cavity for a long period. In this case, we must consider some IOL power adjustments. The additional IOL power for a silicone oil-filled vitreous is +3.0 to 3.5 D to obtain emmetropia.

In cases of eyes filled with gas or Perfluorocarbon liquid, ultrasound echoes are blocked. Measuring the AL with ultrasound becomes almost impossible.

Avoiding Errors in Axial Length Measurement

During AL measurement, the technician aligns the ultrasound beam with the optical axis of the eye by being perpendicular to the four major surfaces of the eye: the anterior surface of the cornea, the anterior surface of the lens, the posterior surface of the lens, and the anterior surface of the retina. Errors in AL measurement are due to an improper technique yielding shorter or longer measurements [1–3]. Often, manufacturers recommend using the average value of multiple measurements to improve precision and avoid errors. Although this is a good practice, one should remember that multiple readings of an erroneous measurement will still yield an erroneous average measurement.

Avoiding Shorter Axial Length Measurement

Shorter AL measurement might occur with corneal compression, off-axis measurement, and sometimes in the presence of asteroid hyalosis. Entering a shorter measurement of the AL in IOL power calculations will call for the use of a stronger IOL than is required, resulting in an induced myopia in the final postoperative refraction.

Corneal compression is the most common cause of shorter AL measurements with the "contact technique." An unskilled technician can indent the cornea with the A-scan probe more than needed, resulting in a shallower anterior chamber depth and a shorter axial length, even though an acceptable A-scan echogram has been displayed on the screen. Using an "immersion technique" will keep the probe away from the cornea and will avoid any corneal compression.

Off-axis measurement occurs when the ultrasound beam is not perpendicular to the surfaces of the eye components. A minimal off-axis scan is characterized by the absence of a posterior lens spike or the presence of an exceedingly small one (Fig. 9.14). The remainder echospikes from the cornea, the anterior surface of the lens, and the retina usually appear normal. A larger off-axis measurement occurs when the patient is not looking at the fixation light due to the presence of a dense cataract or the inability of the patient to hold the eye in a steady position. A larger off-axis scan is characterized by the absence of the poste-

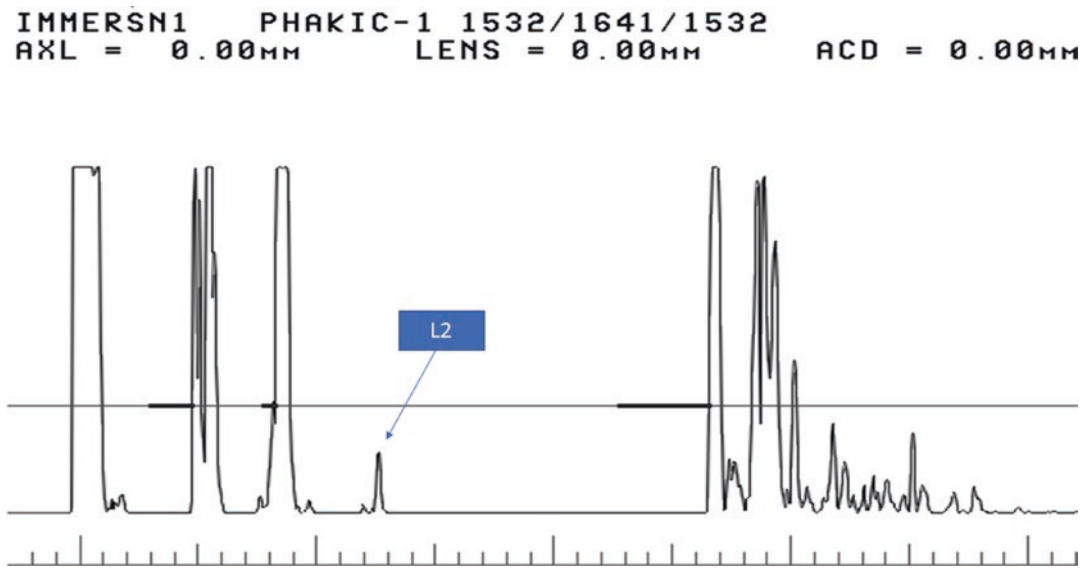

Fig. 9.14 An A-scan display of a phakic eye that is not acceptable. The unit recognizes the absence of the posterior lens spike (L2) and does not give any measurement

rior lens spike and the presence of a jagged retinal spike.

The presence of asteroid hyalosis will create echospikes within the vitreous cavity that can be confused by the biometer as the retinal surface. By decreasing the biometer's system sensitivity, the amplitude of all the echospikes will decrease to a point where the weaker vitreous spikes almost disappear. Also, when in doubt as to the nature of the vitreous pathology, a B-scan ultrasound can be helpful.

Avoiding Longer Axial Length Measurement

Longer measurements of the axial length might occur in the presence of a pre-corneal echospike, a poor retinal echospike, or the use of an inaccurate velocity. Entering a longer measurement of the AL in IOL power calculations will call for the use of a weaker IOL than is required, resulting in an induced hyperopia in the final postoperative refraction.

A pre-corneal echospike is usually generated by an air bubble within the scleral shell during an immersion technique.

A poor retinal echospike is the result of an off-axis measurement. The biometer will miss the retinal spike and read a longer measurement between the corneal and the scleral spike (Fig. 9.15).

An inaccurate velocity can be inadvertently used when measuring an aphakic eye.

Detecting Significant Intraocular Pathology

There are cases where the ultrasound pattern is difficult to interpret. In most cases, this is due to posterior pathology that cannot be visualized due to an advanced cataract. The most common cause is the presence of a staphyloma in a highly myopic eye. Other causes include a retinal detachment, macular changes, or an intraocular mass. In such cases, a B-scan will determine the correct diagnosis.

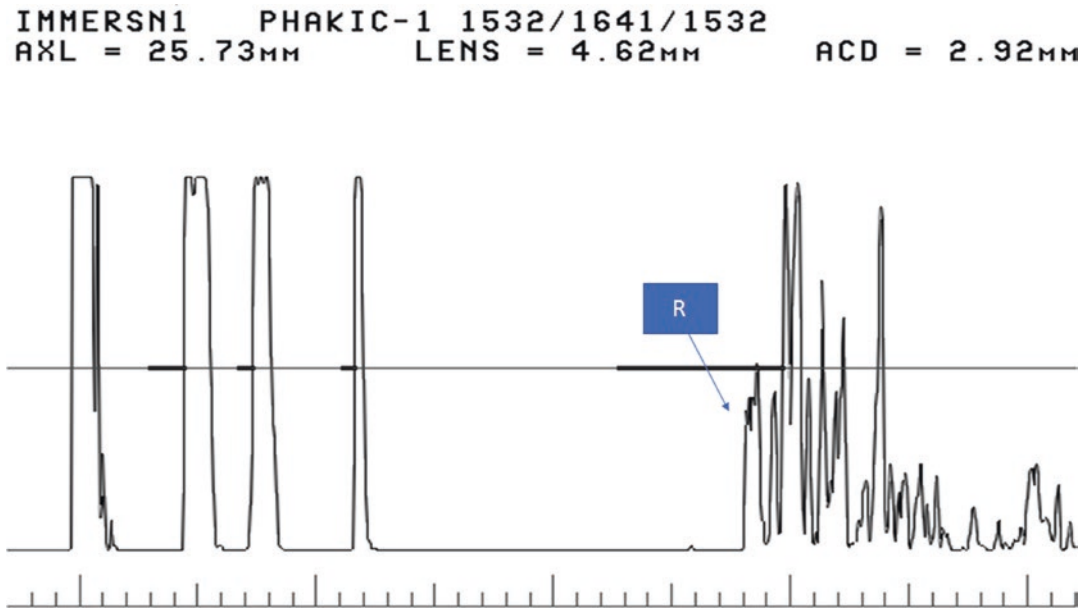

Fig. 9.15 An A-scan display of a phakic eye with a poorly defined retinal spike (R). The erroneous long measurement is taken between the cornea and the sclera (instead of the retina)

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