The A-Scan Biometer

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A-scan ultrasonography has been used for diagnostic purposes since the 1960s. Biometry was then limited to measuring eyes with deformities affecting the axial length (AL), i.e., congenital glaucoma, axial myopia, and phthisis bulbi. Around the mid-1970s, the use of intraocular lenses during cataract surgery gained in popularity and many intraocular lens (IOL) theoretical formulas were published to determine the IOL power. All these formulas required an AL measurement, and A-scan biometry was the only way to accomplish the task. The original units required manual measurement of the ultrasound travel time with a caliper from a Polaroid picture of the A-scan and converting it to millimeters. The measurement was then entered into a calculator to obtain the IOL power needed for emmetropia. Through the years, the ultrasound biometer evolved with the introduction of electronic gates, automatic calibration, and computerized capabilities. Most available A-scan biometers are now compact, efficient, computerized, and complete with IOL power calculation capabilities.

Routine use of A-scan ultrasound biometry has been largely replaced by the more accurate, precise, and reproducible optical biometry. However, the use of optical biometry is limited when measuring eyes with a mature cataract or other vitreoretinal pathology. A-scan biometry is needed in these cases. A-scan biometry can be achieved by contact or immersion techniques. The contact technique applanates the probe against the cornea to obtain the measurements; errors can occur with axial length measurements from excessive indentation of the probe against the cornea. With the immersion technique, the probe is immersed in a gonioscopic solution or balanced salt solution (BSS) contained within a scleral shell; because it does not cause indentation of the cornea, the results are more reliable and therefore the preferred method whenever possible.

Basic Technology

An ultrasound unit is composed of four basic elements: *the pulser*, *the receiver*, and *the display screen* all contained within the same chassis and connected to *the transducer*, located at the tip of the probe by an electrically shielded cable (Fig. 16.1a). The pulser produces electrical pulses at a rate of 1000 pulses/s. Each pulse will excite the electrodes of the piezo-electric crystal of the transducer, generating sound waves. The returning echoes are received by the transducer and transformed into electrical signals. These signals are processed in the receiver and demodulator and then displayed on the screen.

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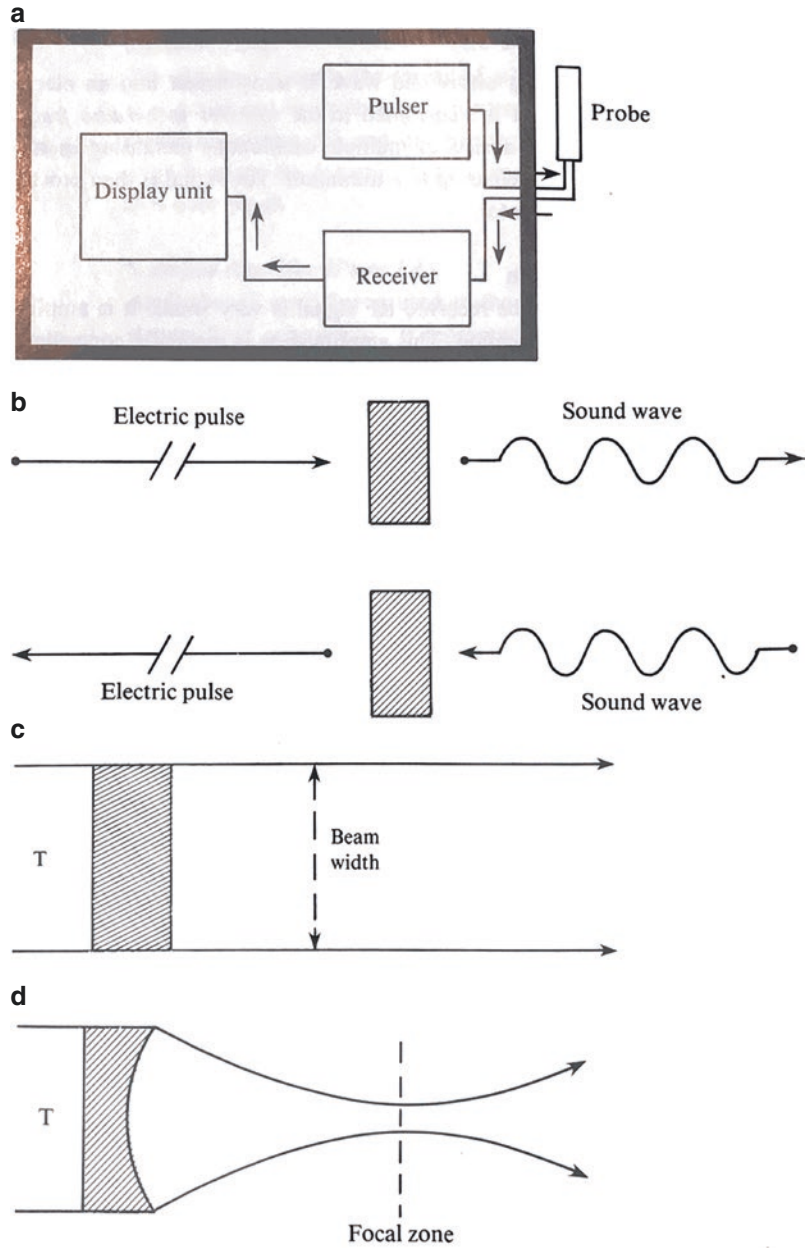

Fig. 16.1 (**a**) An ultrasound unit is composed of four basic elements: the pulser, the receiver, and the display screen all contained within the same chassis and connected to the transducer, located at the tip of the probe by an electrically shielded cable. (**b**) The piezo-electric principle: changes in the polarity of an electric current passing through a quartz crystal will cause changes in the shape and size of the crystal, and vice versa. This in turn will transform the electrical energy into mechanical energy in the form of sound waves. When the sound waves return to the probe, the mechanical energy will modify the thickness of the crystal and produce electrical energy. (**c**) A crystal with a flat surface emits a non-focused beam, essential for biometry. (**d**) A crystal with a concave surface emits a focused beam essential for B-scan echography

This process is based on the piezo-electric principle (Fig. 16.1b); changes in the polarity of an electric current passing through a quartz crystal will cause changes in the shape and size of the crystal, and vice versa. This in turn will transform the electrical energy into mechanical energy in the form of sound waves. When the sound waves return to the probe, the mechanical energy will modify the thickness of the crystal and produce electrical energy. The performance of the crystal depends mainly on its shape and thickness. A flat surface emits a non-focused beam (Fig. 16.1c) essential for biometry; a concave surface emits a focused beam essential for B-scan echography (Fig. 16.1d).

Physical Principles of A-Scan Ultrasound

Ultrasound refers to sound waves beyond the range of human hearing. In order to make this definition more precise and to explain the properties of ultrasound, we must first explain *sound*. Consider knocking on a door. When the knuckles of the hand strike the door's surface, the molecules of which the door is made are temporarily forced closer together. The compression or "mechanical disturbance" has thus *moved* or "propagated" deeper into the "medium" which is the material of the door. Disturbances which propagate in this way are generally called *waves*; hence, we speak of "sound waves."

A *point source* of sound creates a spherical wavefront, with sound propagating in all directions away from the source. A piston-like sound source creates a quasi-planar wavefront, with sound propagating mostly in a single direction, as shown in Fig. 16.2.

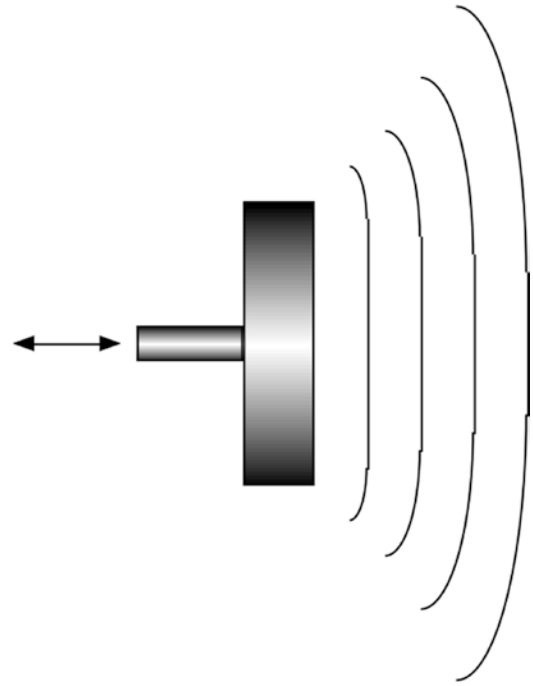

Fig. 16.2 Quasi-planar wavefronts created by a broad, flat sound source (piston)

When the piston is moving repetitively back and forth at a constant *frequency,* we can plot a graph of the piston's position against time and we would obtain a curve as shown in Fig. 16.3. Such a curve is called *periodic* because it repeats itself continuously. The smallest repeated portion is called a *cycle*, and the length of time required for one cycle is called the *period*. The study of periodic sound provides the theoretical basis of ophthalmic ultrasound. Frequency is measured in cycles per second, also called *Hertz* (after Heinrich Hertz, a German physicist who studied wave phenomena at the end of the nineteenth century), which is abbreviated Hz. One *kilohertz*, abbreviated kHz, equals 1000 cycles/s. One *megahertz*, abbreviated MHz, equals 1,000,000 cycles/s. The healthy human ear can detect sound frequencies in a range of about 20 Hz to as much as 20 kHz. *Ultrasound* is sound at frequencies well above the 20 kHz.

Real-world ultrasound equipment generates sound pulses whose energy is confined to a limited range or *band* of frequencies. The size of the range is called the *bandwidth*. The midpoint of the range is called the *center frequency*. Both are typically measured in MHz. A typical A-scan biometry system, for example, might have a center frequency of 10 MHz and a bandwidth of 4–6 MHz.

The amount of distance corresponding to one cycle (Fig. 16.4) is called the *wavelength*, and it depends on both the *frequency* of the sound and the speed or *velocity* at which it propagates through the medium, according to the formula:

$$\lambda = v / f$$

where "λ" represents wavelength, "v" represents velocity, and "f" represents frequency. Most ocular ultrasound images work at frequencies of 8–10 MHz. The average velocity of sound in human tissue is about 1550 m/s. 10 MHz sound in human tissue has a wavelength of 155 μm (millionths of a meter).

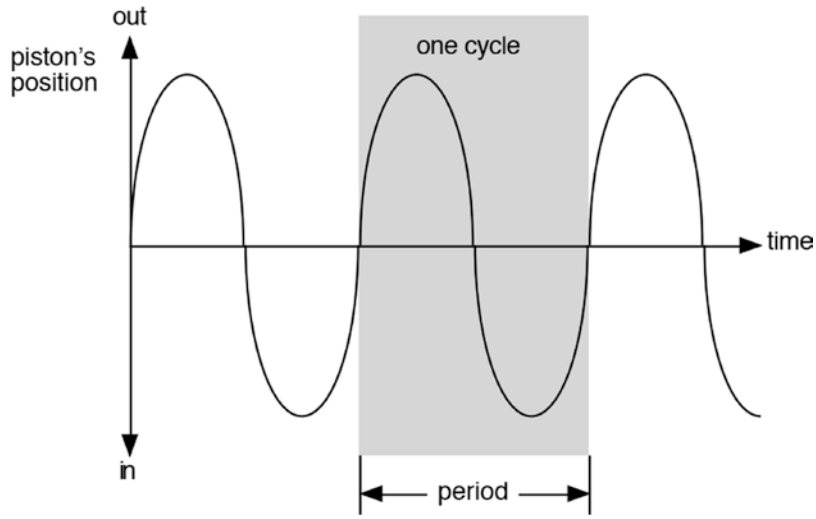

Fig. 16.3 Piston's position plotted against time

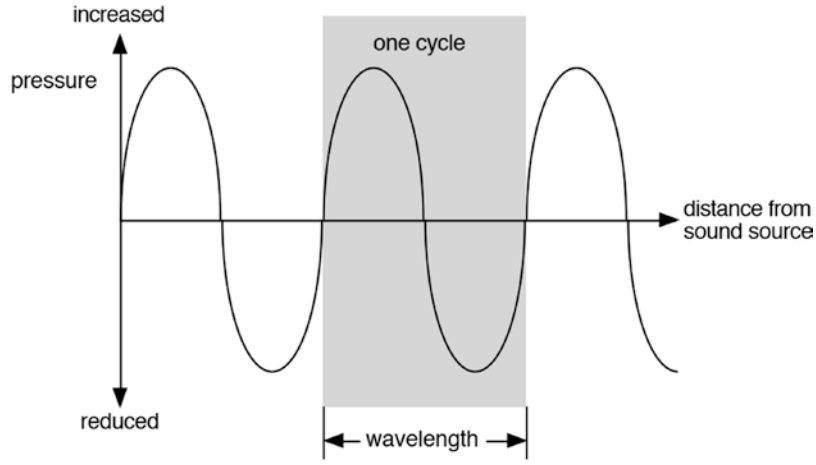

Fig. 16.4 Plot of sound pressure vs. distance along sound beam, at a single instant

Major Components of a Biometer

Four different components are herein discussed including the probe and its transducer, the sensitivity setting, the velocity setting, and data analysis with IOL calculation.

The Probe and Its Transducer

The probe is connected to the main chassis of the biometry by an electronically shielded cable and contains a transducer at its tip [1–3]: The original solid probe (Fig. 16.5) has been designed for standardized A-scan echography using the Kretztechnik 7200 MA ultrasound unit. This probe can also be used to measure the axial length through an immersion technique. The newer probe (Fig. 16.6) is thinner and designed specifically for biometry.

The transducer emits the ultrasound beam. Ultrasound consists of high-frequency sound waves over 20,000 cycles/s, which is the highest frequency audible to the human ear [4]. The ultrasound beam is formed of ultrasound waves that display different characteristics depending on the ultrasound frequency, wavelength, velocity, and direction.

The *frequency* [5] is the number of hertz (Hz) or cycles per second. Higher frequencies provide

Fig. 16.5 The Kretztechnik 7200 solid probe is used for diagnostic standardized A-scanning and for biometry

Fig. 16.6 Smaller solid probe designed for biometry

a higher resolution while lower frequencies provide better penetration but a reduction in the resolution. To obtain the high resolution needed for axial length measurement, biometry units use ultrasound frequencies ranging between 8 and 25 MHz (1 MHz = 1 megahertz = 1 million cycles/s).

The *wavelength* [6] is the distance between two particles in the same phase of oscillation. Within the ocular tissues, the wavelength is approximately 0.19 mm if an 8 MHz probe is used and 0.15 mm if a 10 MHz probe is used.

The *velocity* [7] is the speed of sound propagation and is expressed in meters per second (m/s). The velocity varies according to the medium through which sound propagates; within the eye, the ultrasound velocity is 1532 m/s in aqueous and vitreous, 1640 m/s in a clear lens, and 1550 m/s in solid tissues. During an accurate measurement of the different eye components, the proper sound speed must be used for each of these entities.

The *direction* of the ultrasound beam [8, 9] affects the display of the tissues under examination. During biometry, 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 echo spikes from the different interfaces that have been intersected, i.e., 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 anterior surface of the sclera. When the ultrasound beam reaches the orbital tissues, it is attenuated until it loses all its energy. The 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.

The Sensitivity Setting

The sensitivity setting controls the height of the echo spikes displayed on the screen.

The axial length is more accurately measured at a lower system sensitivity that allows a better pattern recognition of the anterior and posterior corneal surfaces, anterior and posterior lens surfaces, and anterior retinal surface.

The Velocity Setting

The velocity setting controls the speed of sound propagation. The velocity, measured in meters per second (m/s), varies according to the medium through which sound propagates. Most units use an average velocity of 1548–1556 m/s in a cataractous eye and 1532 m/s in an aphakic eye. Newer units measure each ocular compartment at its correct velocity; the anterior chamber depth is measured with a velocity of 1532 m/s; the

cataractous lens is measured with an average velocity of 1640 m/s; the vitreous cavity's depth is measured with a velocity of 1532 m/s like the aqueous. These measurements are then computed within the instrument to display one axial length reading.

The Electronic Gates

Electronic gates allow ultrasound units to provide an electronic read-out of the axial length in millimeters. The gates will measure the travel time between the leading edges of the spikes (Fig. 16.7) or the peaks of the spikes (Fig. 16.8). Biometers are equipped with 2, 4, or 5 gates. The two main gates are the "corneal gate" placed in the region of the anterior corneal spike and the "retinal gate" placed in the region of the retinal spike. Such instruments measure the travel time between the anterior surface of the cornea and the anterior surface of the retina and use an average sound velocity for the measurement of the axial length.

Instruments equipped with four gates (Fig. 16.7) allow the positioning of these gates over the leading edges or the peaks of the echoes generated from the anterior surface of the cornea, the anterior surface of the lens, posterior surface of the cornea, the anterior surface of the lens, the posterior surface of the lens, and the anterior surface of the retina. A measurement of the anterior chamber depth, lens thickness, and the total axial length is displayed on the screen.

Instruments equipped with five gates (Fig. 16.8) will additionally locate the posterior corneal surface and include a measurement of the corneal thickness.

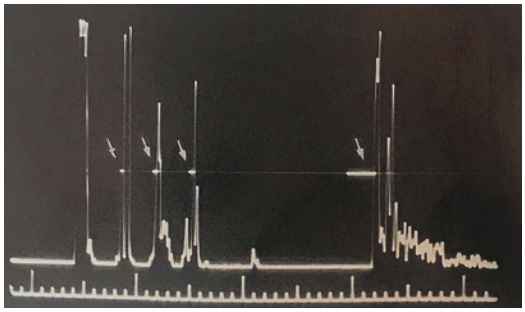

Fig. 16.7 The four gates of this horizontal caliper lights (arrows) measure the distances between the leading edges of the anterior corneal surface, anterior lens surface, posterior lens surface, and the retina

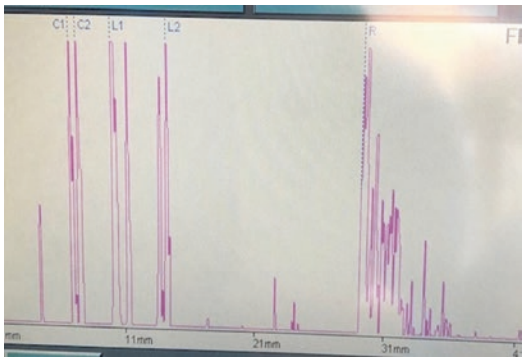

Fig. 16.8 Five vertical gates (dotted lines) measure the distances between the peaks of the anterior cornea (C_1), the posterior cornea (C_2), anterior lens surface (L_1), posterior lens surface (L_2), and retina (R)

Data Analysis and IOL Calculation

Most biometers will analyze the measurements and will display the axial length, anterior chamber depth, and lens thickness. IOL power calculations are provided using available modern formulas. Many will be able to provide a print out or connect directly to an imaging system or Electronic Medical Record. These programs are also able to store information, compare results, review data, and refine the ELP constants.

Choosing the Appropriate Ultrasound Biometer

Most biometers provide reproducible and accurate measurements and are programmed with popular formulas. However, each biometer is characterized by specific features and components that have been discussed in length in this chapter. Here are some essential features to look for in a biometer:

– A display screen that allows pattern recognition of the displayed echogram. Biometers shaped like a pen without a display unit are not advisable.
– Measurement capability of the anterior chamber depth and of the lens thickness, in addition to measuring the entire axial length. Newer formulas require these measurements.
– Measurement capability of aphakic and pseudophakic eyes.
– A freeze frame capability and a print out of the A-scan echogram for review.
– Visible electronic gates.
– IOL power calculation capability.

Some biometers are available with diagnostic B-scan, ultrasound biomicroscopy (UBM), and/or pachymetry within the same chassis. Practices that handle vitreoretinal pathology and/or perform corneal surgery will enjoy the added features in one compact unit.

Commonly Used Ultrasound Biometers

There are many excellent ultrasound machines available. Here is a list of some of the currently available machines. All the companies offer models that complete axial length measurements utilizing contact or immersion technique, measure anterior chamber depth and lens thickness, and have formulas pre-programmed in their system (Table 16.1).

Table 16.1 Commonly used ultrasound biometers

Company	Product	Additional features	Other models
Quantel Medical/Ellex	Aviso S	Pachymetry UBM B scan	Aviso Axis Nano Compact
MEDA	ODM-2200	B scan	MD-1000A
Suoer	SW-1000P	Pachymetry Tonometry	SW-1000
Keeler	Accutome A-Scan Plus Connect	Optional UBM Optional B scan	
Nidek	US-4000	Pachymetry B scan	US-500
Sonomed	MV4500 Master-Vu	Optional B scan	
DGH	Scanmate A Flex	Alignment ranking UBM B scan	Scanmate A
Ellex/Quantel	Eye Cubed	UBM B scan	
Tomey	AL-4000	Auto alignment	AL-100
SonoStar	SPA-100	Pachymetry	
Micromedical	PalmScan AP2000 Pro	Pachymetry Mobile	A2000T, AP2000T, A2000

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