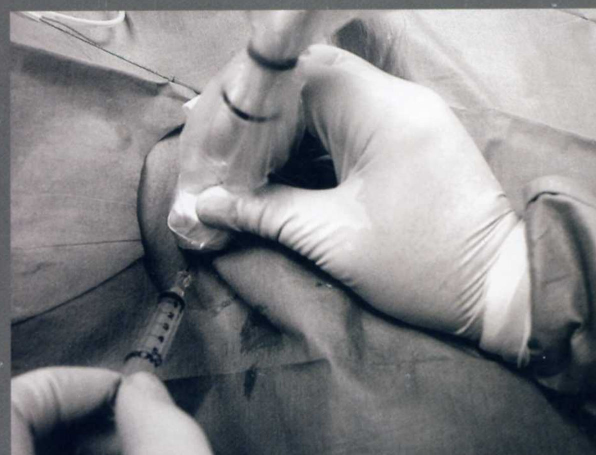

The Handbook of *Ultrasound* in Trauma and Critical Illness

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CHAPTER TWO

INSTRUMENTATION

INTRODUCTION

Ultrasound waves are commonly found in nature. However, to capture this energy form and put it into a form of usable technology, certain assumptions need to exist:[1]

1. The speed of sound in human tissues is constant at 1540m/s

2. The reflectors that result in echoes lie along the transmitted beam axis

Despite its complexity, an ultrasound scanner can be broken down to the following key components: transducer, beam former, transmitter, receiver, scan converter and image display. This chapter highlights the key points of transducer properties and of instrumentation.

TRANSDUCERS

The term transducer is used to refer to any device that converts signals or energy from one form to another. Ultrasound transducers convert electrical signals to acoustic energy and vice versa, while employing the piezoelectric effect. This is caused by the crystals in the transducer changing shape when in an electrical field or when mechanically stressed, so that an electrical impulse can generate a sound wave or vice versa.

Early on, the crystals used in diagnostic medical sonography were made of either quartz or tourmaline. Today, most ultrasound transducers are comprised of a ceramic-epoxy composite. The most common composite mixture is lead zirconate titanate (PZT) combined with epoxy. This composite transducer element is advantageous because it has a lower acoustic impedance and a very wide frequency bandwidth. A wide frequency bandwidth will allow the same transducer to operate at variable frequencies or be made to emit pulses that have a very short duration. This is significant since the shorter the pulse duration, the better the spatial resolution.

The basic components of a transducer include: a metal shield, a plastic case, a tuning coil, the piezoelectric element, matching layers, and a backing material. The backing material acts to shorten the duration of vibration of the piezoelectric element. A short pulse duration enhances the axial resolving capabilities of the transducer and produces a better image. The impedance-matching layers improve transmission of the sound waves into the body by reducing reflections at the transducer-tissue interface.

Ultrasound transducers can utilize a pulsed-echo or continuous-echo mode. Continuous-echo transducers employ separate crystals to send signals and to listen for returning sound waves, while pulsed-echo transducers employ the same crystals to both send signals and to listen for returning sound waves. Using the same crystals to perform both functions limits the information provided since the instrument will not be able to provide any information about echo depth. A common example of a continuous-echo instrument is the hand-held Doppler stethoscope used in the ED. This instrument provides information about the presence or absence of flow but does not provide any information about echo location.

The ability of an ultrasound transducer to separately identify two closely positioned reflectors is an important factor in medical imaging and is closely related to ultrasound frequency. Transducers today are commonly multi-frequency. It is a trade-off for the sonographer since higher frequency means better resolution but poorer penetration.

Resolution can be broken down into axial and lateral resolution. Axial resolution refers to the minimum reflector interval along the axis of an ultrasound beam that results in separate echoes being displayed. Lateral resolution refers to the minimum reflector interval perpendicular to the axis of an ultrasound beam that results in separate echoes being displayed. Axial resolution is most closely linked to transducer frequency while lateral resolution is most closely linked to transducer beam width. A higher frequency transducer will result in better axial resolution and a narrower transducer beam width will result in better lateral resolution.

Ultrasound transducers can be either mechanical or electronic. Mechanical transducers contain a single element that oscillates back and forth within the transducer head. Advantages include lower cost and a small footprint (the portion of the transducer in contact with the patient) which allows for intercostal scanning. Mechanical transducers can be used for the intra-abdominal and intra-thoracic applications in this handbook. The mechanical sector scanner will produce a pie-shaped image.

The electrical transducers have up to 256 small individual crystals arranged in a variety of configurations (called arrays) in the transducer head. Linear array transducers are commonly used for imaging superficial structures and have crystals in a linear sequence in the transducer head. The footprint of the transducer is variable and most companies will make multiple similar frequency linear array transducers with different footprints in order to accommodate different scanning needs. The image produced by a linear array transducer is rectangular (Figures 3A and 3B). As with all electronic transducers, the multiple elements can be fired in different sequences resulting in focal points at different depths.

Figure 3A. Linear array transducer.

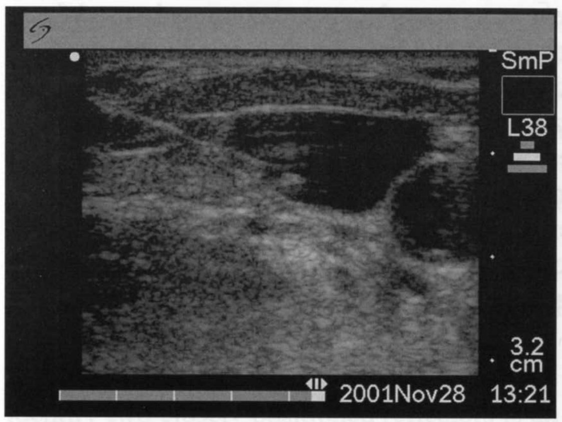

Figure 3B. Image obtained with linear array transducer.

A curvilinear (curved) array transducer has the crystals arranged in a curvilinear fashion in the transducer head. Each of the crystals fires in a straight line so the image produced is a pie-shaped image (Figures 4A and 4B). Large-footprinted curved array transducers are commonly used in obstetrical and abdominal applications, while small-footprinted curved array transducers (high-frequency) are used in transvaginal, transrectal, and pediatric applications.

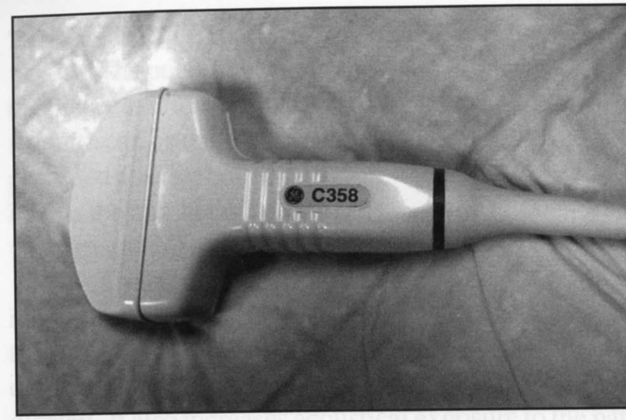

Figure 4A. Curvilinear array transducer.

Figure 4B. Image obtained with a curvilinear array transducer.

A phased array transducer contains elements in the transducer head that are pulsed as a complete group with a slight time delay or phasing. The phasing is changed with each successive repetition so the beam direction continually changes resulting in a sweeping of the beam which produces a pie-shaped image (Figures 5A and 5B). This phasing allows the fabrication of transducers with relatively small-footprints but with large pie-shape (sector) fields of view. These transducers are most useful for intercostal scanning where access is limited.

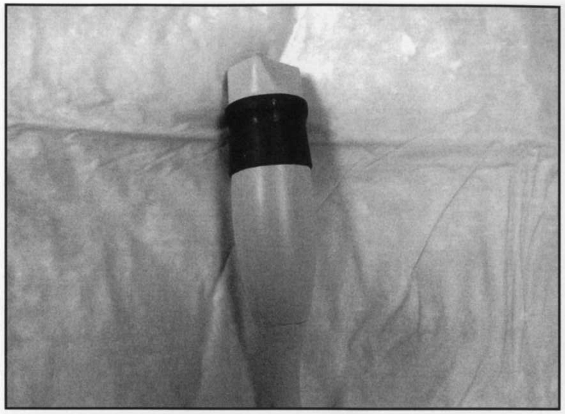

Figure 5A. Phased array transducer.

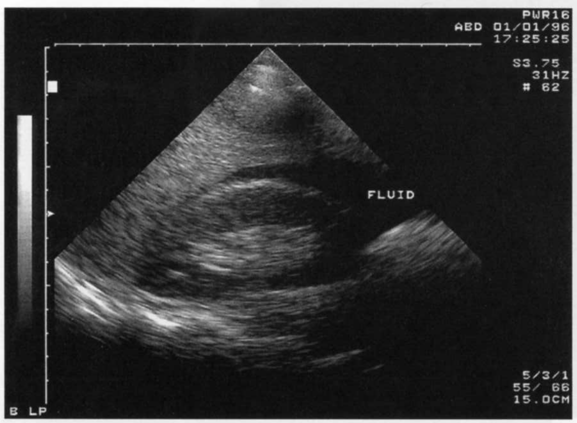

Figure 5B. Image obtained with a phased array transducer.

An annular array transducer has multiple concentric elements in the transducer head and produces a pie-shaped image. Unlike the previously mentioned electronic transducers, annular array transducers are steered mechanically, not electronically. A particular advantage of this type of transducer is that the beams can be focused in both the axial and lateral planes.

TRANSMITTER

The pulse transmitter provides the electrical signals that excite the piezoelectric elements. Both the frequency of the signals and their strength can be controlled by the sonographer. The pulsing signals are provided at a rate called the pulse-repetition frequency (PRF). The PRF is the number of acoustical pulses transmitted per second and will vary depending on the operating mode and settings used.

The strength of the electrical signal can be adjusted by either increasing or decreasing the output power. Increasing the output power to the transducer will produce higher-intensity ultrasound pulses capable of allowing the echoes from weaker reflectors to be visualized on the display. It also increases acoustical exposure to the patient.

BEAM FORMER

The beam former provides the pulse-delay sequences applied to individual elements to achieve transmit focusing, controls the dynamic focusing of the received echoes, and controls the beam direction for electronically scanned arrays. More and more ultrasound companies are integrating digital beam formers into their machines and are moving away from analog beam formers.

RECEIVER

The echo signals detected by the transducer are sent to the receiver, where they are processed for image display. In general, the amplitudes of the echo signals at the transducer levels are too low to allow visualization on a display. Therefore, the echo signals are amplified at this level and the degree of amplification is called the gain of the receiver. Gain is defined as the ratio of the output signal amplitude to the input signal amplitude and is usually expressed in decibels (dB). The gain can be controlled on most machines through an overall gain control that increases or decreases amplification at all depths and a time gain compensation (TGC) control that allows selective increases or decreases in amplification at various levels. The TGC is used to compensate for the attenuation that occurs in the human body.

SCAN CONVERTER

The role of the scan converter is to store images during scan build-up to be used for viewing/recording and to perform scan conversion which will allow image data to be viewed on the video monitor. In simple terms, it accepts, formats, stores, and reads out the echo signal data onto the video monitor. Current machines utilize digital scan converters rather than analog scan converters since the former provides better images.

IMAGE DISPLAY

In the early days of ultrasound, oscilloscopes were used for displaying image data. Today TV (video) monitors are used since they provide excellent resolution of the gray scale images.

Image recording can be done through laser images, color thermal prints, video thermal prints, and videotape recording.

REFERENCE

1. Zagzebski JA. Pulse-Echo Ultrasound Instrumentation. *Essentials of Ultrasound Physics*. St. Louis: Mosby, 1996;46-68.