Echocardiography is sonography of the heart. **Sonography** comes from the Latin *sonus* (sound) and the Greek *graphein* (to write). Diagnostic sonography is medical real-time, two-dimensional (2D) and three-dimensional (3D) anatomic and flow imaging using ultrasound. Ultrasound is sound of frequency higher than what humans can hear. Frequencies used in echocardiography range from about 2 MHz for adult transthoracic studies to about 7 MHz for higher-frequency applications such as harmonic imaging and pediatric and transesophageal studies. Ultrasound provides a non-invasive view of the heart. Echocardiography is accomplished with a pulse-echo technique. Pulses of ultrasound, two to three cycles long, are generated by a transducer (Fig. 1.1) and directed into the patient, where they produce echoes at organ boundaries and within tissues. These echoes then return to the transducer, where they are detected and presented on the display of a sonographic instrument (Fig. 1.2). The ultrasound instrument processes the echoes and presents them as visible dots, which form the anatomic image on the display. The brightness of each dot corresponds to the strength (amplitude) of each echo voltage. The location of each dot corresponds to the anatomic location of the echo-generating object. Positional information is determined by knowing the path of the pulse as it travels and measuring the time it takes for each echo to return to the transducer. From a starting point at the top of the display, the proper location for presenting each echo is determined. Because the speed of the sound wave is known, the echo arrival time can be used to determine the depth of the object that produced the echo.

When a pulse of ultrasound is sent into tissue, a series of dots (one scan line, data line, or echo line) is displayed. Not all of the ultrasound pulse is reflected from any single interface. Rather, most of the original pulse continues into the tissue and is reflected from deeper interfaces. The echoes from one pulse appear as one scan line. Subsequent pulses go out in slightly different directions from the same origin. The result is a sector scan (sector image), which is shaped like a slice of pie (Fig. 1.3). The resulting cross-sectional image is composed of many (typically 96 to 256) of these scan lines. For decades, sonography was limited to 2D cross-sectional scans (or slices) through anatomy such as that in Figure 1.3. 2D imaging has been extended into 3D scanning and imaging, also called volume imaging, as described in Chapter 2. This requires scanning the ultrasound through many adjacent 2D tissue cross sections to build up a 3D volume of echo information, like a loaf of sliced bread (Fig. 1.4). In addition to anatomic grayscale imaging, stationary beam, M-mode presentations provide depth versus time recordings of moving objects (Fig. 1.5).

**TRANSUDER**

The transducer used in echocardiography is a phased array that electronically steers the ultrasound beam in the sector format. It is energized by an electrical voltage from the instrument that produces the outgoing ultrasound pulse. The returning echo stream is received by the transducer and converted to an echo voltage stream that is sent to the instrument, ultimately appearing on the display as a scan line. This process occurs a few thousand times per second (called the **pulse repetition frequency** [PRF]). A coupling gel is used between the transducer and the skin to eliminate the air that would block the passage of ultrasound across that boundary. Transducers are designed for transthoracic and for transesophageal imaging (see Fig. 1.1). The latter provides a shorter acoustic path (with less attenuation, allowing higher frequency and improved resolution) to the heart that avoids intervening lung and ribs.

**INSTRUMENT**

An echocardiographic instrument has a functional block diagram as shown in Figure 1.6. The beam former drives the transducer and receives the returning echo streams, amplifying (this is called **gain**) and digitizing them. Attenuation compensation occurs in the reception side of the beam former. The signal processor, among other functions, detects the strength (amplitude) of each echo voltage. Echo amplitudes are stored as numbers in the image memory, which is part of the image processor. Upon completion of a single scan (one frame of a real-time presentation), the stored image is sent to the display. The display is a flat-panel screen, now common in computer monitors and television sets. The echo information is sent into the image memory in ultrasound scan lines in sector format, but it is read out and sent to the display in horizontal display line format, with each horizontal line on the display corresponding to a row of echo data in the image memory.

**ARTIFACTS**

In imaging, an artifact is anything that does not correctly display the structures or functions (tissue motion and blood flow) imaged. An artifact is caused by some problematic aspect of the imaging technique. They can hinder correct interpretation and diagnosis. These artifacts must be prevented or handled properly when encountered.

Some artifacts are produced by improper equipment operation or settings (e.g., incorrect gain and compensation settings). Other artifacts are inherent in the sonographic methods and can occur even with proper equipment and technique. The assumptions inherent in the design of sonographic instruments include the following:

- Sound travels in straight lines
- Echoes originate only from objects located on the beam axis
- The amplitude of returning echoes is related directly to the reflecting or scattering properties of distant objects
- The distance to reflecting or scattering objects is proportional to the round-trip travel time at a speed of 1.54 mm/µs

If any of these assumptions are violated, an artifact occurs. Figure 1.7 and Video 1.7, A to D, provide examples of cardiac artifacts.
Figure 1.1. A, Transthoracic transducer. B, Transesophageal transducer.

Figure 1.2. Echocardiographic instrument.

Figure 1.3. 2D cardiac sector image.

Figure 1.4. 3D cardiac image.

Figure 1.5. M-mode display. A (amplitude)-mode is shown on the right, and the 2D sector scan at the upper left. M (motion)-mode is depth on the vertical axis versus time on the horizontal axis.

Figure 1.6. Block diagram of echocardiographic instrument.
SAFETY

Information derived from in vitro and in vivo experimental studies has yielded no known risks in the use of echocardiography. Thermal and mechanical mechanisms have been considered but do not appear to be operating significantly at diagnostic intensities. Experimental animal data have helped to define the intensity–exposure time region in which bioeffects can occur. However, differences, physical and biological, between the two situations make it difficult to apply results from one risk assessment to the other. In the absence of known risk, it is still necessary to remember that bioeffects not yet identified could occur. Therefore, a conservative approach to the medical use of ultrasound is recommended.

Epidemiologic studies have revealed no known risk associated with the use of diagnostic ultrasound. Experimental animal studies have shown that with most equipment, bioeffects occur only at intensities higher than those expected at relevant tissue locations during ultrasound imaging and flow measurements. Thus a comparison of instrument output data adjusted for tissue attenuation with experimental bioeffects data does not indicate any risk. We must be open, however, to the possibility that unrecognized, but not zero, risk may exist. Such risk, if it does exist, may have eluded detection up to this point because it is subtle or delayed, or its incidence is close to normal values. As more sensitive end points are studied over longer periods or with larger populations, such risks may be identified. However, future studies might not reveal any detrimental effects, thus strengthening the possibility that medical ultrasound imaging is without detectable risk. In the meantime, with no known risk and with known benefit to the procedure, a conservative approach to imaging should still be used. That is, ultrasound imaging should be used when medically indicated, with minimum exposure to the patient. Exposure is limited by minimizing both instrument output and exposure time during a study.

Following is the April 1, 2012, American Institute of Ultrasound in Medicine (AIUM) Official Statement on Prudent Use and Clinical Safety:

Diagnostic ultrasound has been in use since the late 1950s. Given its known benefits and recognized efficacy for medical diagnosis, including use during human pregnancy, the American Institute of Ultrasound in Medicine herein addresses the clinical safety of such use: No independently confirmed adverse effects caused by exposure from present diagnostic ultrasound instruments have been reported in human patients in the absence of contrast agents. Biological effects (such as localized pulmonary bleeding) have been reported in mammalian systems at diagnostically relevant exposures but the clinical significance of such effects is not yet known. Ultrasound should be used by qualified health professionals to provide medical benefit to the patient. Ultrasound exposures during examinations should be as low as reasonably achievable (ALARA).

The AIUM statement provides an excellent basis for formulating a response to patient questions and concerns. Prudence in practice is exercised by minimizing exposure time and output. Display of instrument outputs in the form of thermal and mechanical indexes (TIs and MIs, respectively) facilitates such prudent use.

In decades of use, there have been no reports of injury to patients or to operators from medical ultrasound equipment. We in the ultrasound community want to maintain that level of safety. In the past, application-specific output limits and the user’s knowledge of equipment controls and patient body characteristics were the means of minimizing exposure. Now more information is available. The mechanical and thermal indexes provide users with information that can be applied specifically to formulate ALARA guidelines. Values of these indexes eliminate some of the guesswork and indicate the actual physiologic effects within the patient and what occurs when control settings are changed. These values make it possible for the user to obtain the best image possible while following the ALARA principle, thus maximizing the benefits and minimizing the risks.

Advanced features and techniques (3D echocardiography, Doppler, tissue Doppler imaging, speckle tracking echo, tissue harmonic imaging) are covered in more detail in this book. Expansion of all the topics covered in this chapter can be found elsewhere.

Please access ExpertConsult to see Video 1.7, A to D.

REFERENCE