CHAPTER 1

Sonography—a window into the human body

OUTLINE

Learning objectives

After reading this chapter, the student should be able to do the following:

- Explain the pulse-echo principle used in sonographic imaging.
- List the differences between operating Principles 1 and 2.
- Describe the image formats used in sonography.
- Explain how the Doppler effect is applied in sonography.
- List the ways in which Doppler information is presented.

KEY TERMS

Color-Doppler display
Doppler effect
Gray-scale image
Image

Linear image

Operating Principle 1

Operating Principle 2

Pulse-echo technique

Scan line

Sector image

Sonography

Spectral-Doppler display

Transducer

Ultrasound

Volume imaging

Bats, dolphins, and other animals used **ultrasound** long before humans adopted it for their needs. These animals use ultrasound to detect, locate, determine the motion of, and capture prey; to avoid obstacles; to detect and avoid predators; and to court their mates. One way humans have applied ultrasound techniques is by using **sonography** in diagnostic medicine. Sonography is the use of ultrasound in medical anatomic and flow imaging. Diagnostic ultrasound encompasses sonography and Doppler ultrasound. Doppler ultrasound includes the detection, quantization, and evaluation of tissue motion and blood flow by using the **Doppler effect** with ultrasound. This chapter presents an overview of the principles of sonography and Doppler ultrasound. Here, we are skiing over the principles. In subsequent chapters, we will dive into the details.

Sonography—two principles of operation

The word *sonography* comes from the Latin *sonus* (sound) and the Greek *graphein* (to write). Diagnostic sonography is medical two-dimensional (2D) and three-dimensional (3D) anatomic and flow imaging with the use of ultrasound. *Utra* is a prefix that means *beyond.* Ultrasound is sound that is higher in pitch than the range of human hearing. Ultrasound imaging is not a passive push-button activity; rather, it is an interactive process that involves a patient, a sonographer (an allied health professional who acquires the images), ultrasound, a **transducer** (also called a probe), an instrument (also called a system), and a sonologist (a physician who interprets the images). Understanding and application of the underlying physical and electronic principles presented in this book strengthen the expertise of the sonographer and the sonologist and improve the quality of medical care involving diagnostic sonography that patients receive.

> Medical imaging with ultrasound is called *sonography.*

An **image** (from the Latin term for *imitate*) is a reproduction, representation, or imitation of the physical form of a person or object. An ultrasound image is the visible counterpart of an invisible object, produced in an electronic instrument by the interaction of ultrasound with the object. Ultrasound provides a noninvasive way of looking inside the human body (Figure 1.1) to image otherwise hidden anatomy. Anatomic imaging with ultrasound is accomplished with a **pulse-echo technique**. Pulses of ultrasound generated by a transducer are sent into the patient (Figure 1.2), where they produce echoes at organ boundaries and within biological tissues. These echoes return to the transducer, where they are detected and presented on the display of a sonographic instrument. A transducer (Figure 1.3) generates the ultrasound pulses and receives the returning echoes. Sonography requires knowledge of the location of origin of each echo and its strength as it returns from the patient. An ultrasound instrument (Figure 1.4) 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 echo strength, producing what is known as a **gray-scale image**. The location of each dot corresponds to the anatomic location of the echo-generating structure.

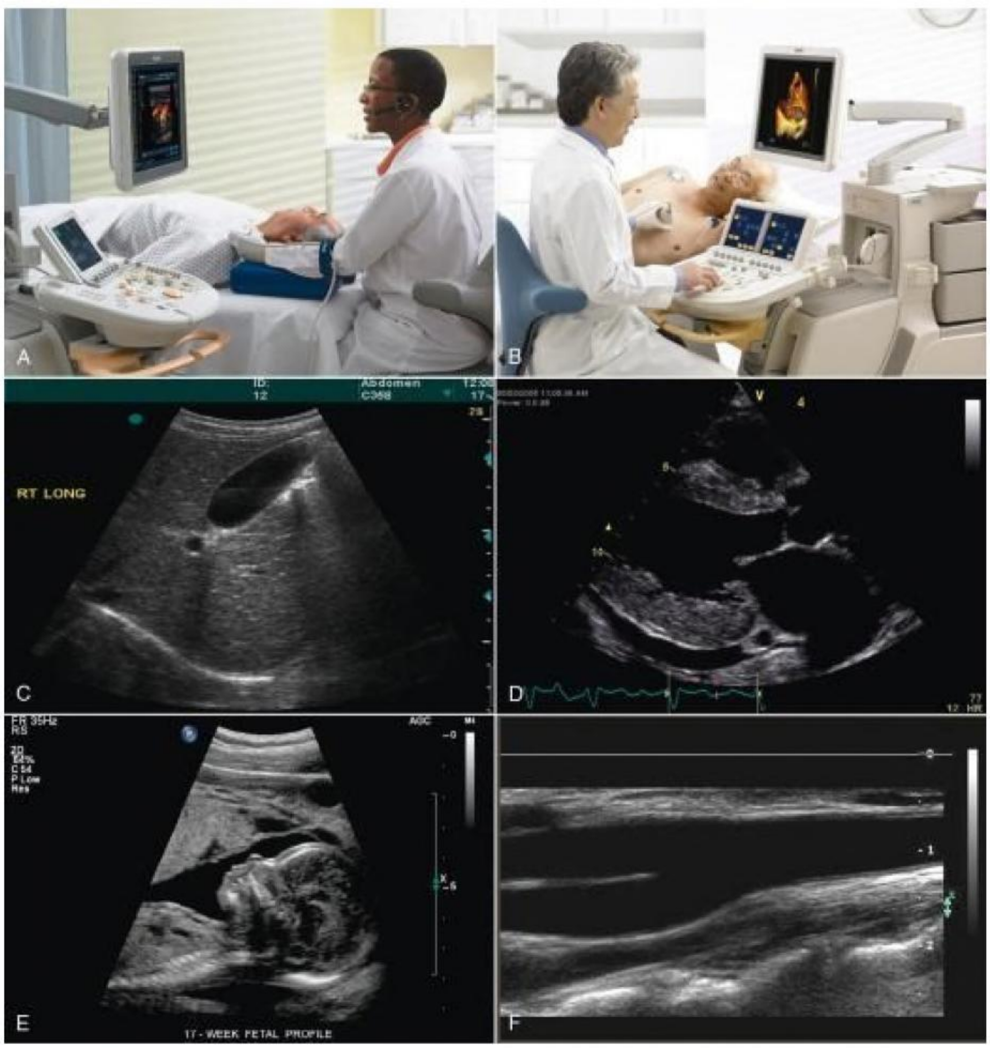

FIGURE 1.1 Ultrasound provides a window into the human body, allowing us to see what would otherwise be hidden from view **(A–B)**. Images shown are as follows: **C,** abdominal; **D,** cardiac; **E,** obstetric; and **F,** vascular.

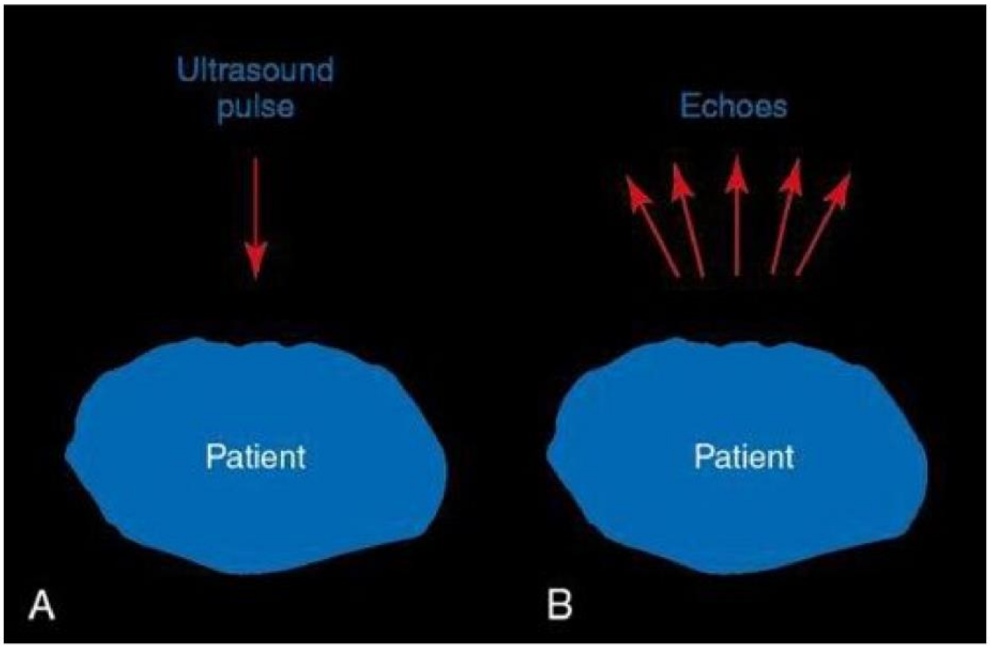

FIGURE 1.2 Pulse-echo technique. **A,** In diagnostic ultrasound, ultrasound pulses are sent into the tissues to interact with them and to obtain information about them. **B,** Echoes return from the tissues, providing information that enables anatomic imaging and observation of motion and flow, thus contributing to diagnosis.

FIGURE 1.3 A–C, Transducers.

FIGURE 1.4 Sonographic instruments by: **A** and **D,** GE Healthcare; **B,** Philips Healthcare; and **C,** Sonosite, Inc.

Previously, there has been but one underlying operating principle for all systems throughout the 50-year history of changing technology in sonography. Now there are *two* operating principles with significant differences between them, not only in the underlying principle of operation but in the implications for various characteristics and features of these systems. Therefore for the first time in this edition of the book, a parallel approach is necessitated to recognize and illuminate these differences. This will be necessary as long as there are two operating principles, a period of years, the length of which no one knows.

In **Operating Principle 1**, positional information is determined by knowledge of the direction of the pulse when it enters the patient and by measurement of the time it takes for each echo to return to the transducer. The proper location to present the echo can then be determined from a starting point on the display (usually at the top). With knowledge of the sound speed, the instrument uses the echo arrival time to determine the depth of the structure that produced that echo.

Sonography is accomplished with a pulse-echo technique.

Echoes from anatomic structures represent these structures in a sonographic image.

If one pulse of ultrasound is sent into tissue, a series of dots (one line of echo information, specifically, an echo line, data line, or **scan line**) is displayed (Figure 1.5). Not all of the ultrasound pulse is reflected back from any structure. Rather, most of the original pulse continues on to be reflected back from deeper structures. The echoes from one pulse appear as one scan line (see Figure 1.5, E–F). If the process is repeated, but with different starting points for each subsequent pulse, a cross-sectional image of the anatomy is constructed (Figure 1.6). Pulses travel in the same direction from different points and yield vertical parallel scan lines and a rectangular image, as shown in Figure 1.7. These cross-sectional images are produced with vertical parallel scan lines that are so close together that they cannot be identified individually. The rectangular display resulting from this procedure is often called *a linear scan,* or **linear image**, referring to the linear-array transducer that is used to produce it. A second approach to sending ultrasound pulses through the anatomy to be imaged is shown in Figure 1.8. With this method, each pulse originates from the same starting point, but subsequent pulses go out in slightly different directions. This approach results in a sector scan, or **sector image**, which has a shape similar to a slice of pie (Figure 1.9). Figure 1.10 shows a format that is a combination of the two just described; that is, pulses (and scan lines) originate from different starting points (as in a linear image), but each pulse (and scan line) travels in a slightly different direction from that of the previous one (as in a sector image). In this example, the starting points form a curved line across the top of the scan, rather than a straight line, as in the linear scans shown in Figure 1.7.

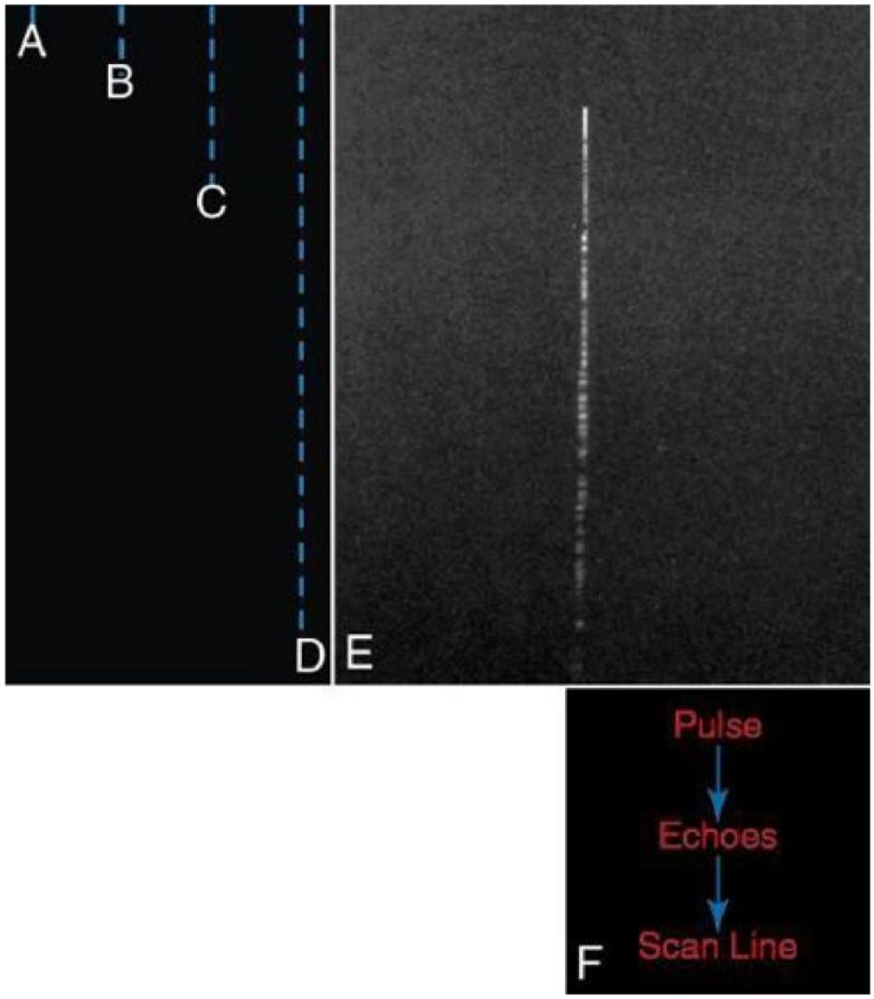

FIGURE 1.5 One pulse of ultrasound generates a single scan line (series of echoes) as it travels through tissue. Echoes are presented in sequence on a scan line while they return from tissue during pulse travel. **A,** The first echo is displayed. **B,** The second echo is added. **C,** Three more echoes are added. **D,** All the echoes from a single pulse have been received and displayed as a completed scan line. **E,** A complete scan line results from one emitted pulse. In practice, this is accomplished in less than one one-thousandth of a second. **F,** According to the pulse-echo imaging principle, one pulse traveling through tissues produces a stream of echoes that become one scan line on the display.

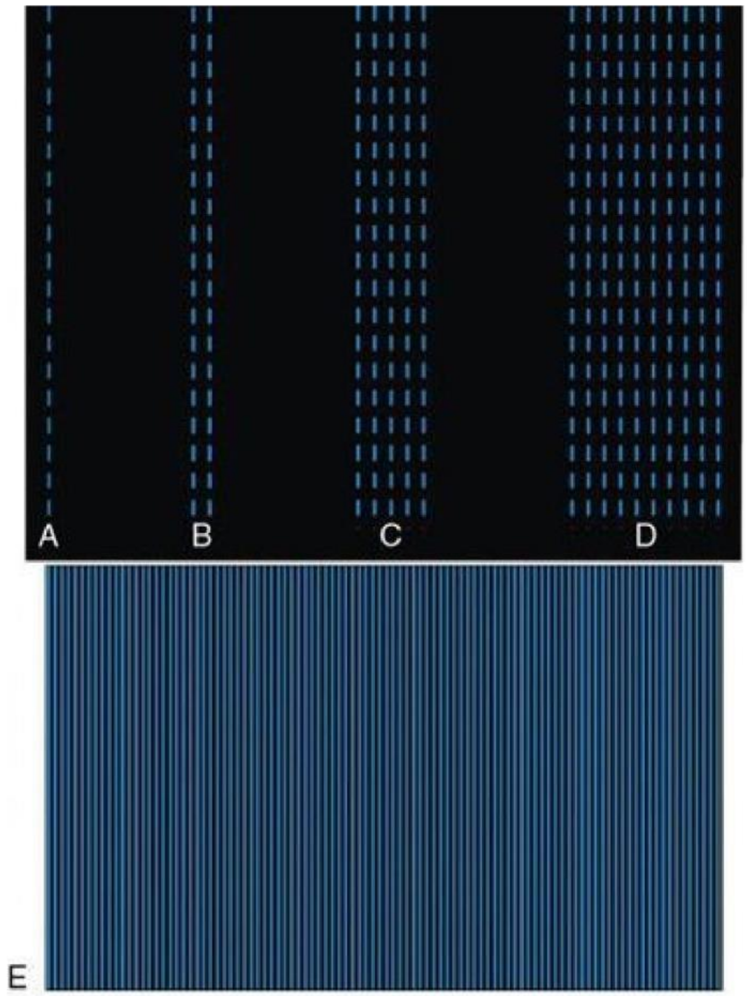

FIGURE 1.6 A single rectangular image or scan (also called a *frame*) is composed of many vertical parallel scan lines. Each scan line represents a series of echoes returning from a pulse traveling through the tissues. **A,** One scan line from one pulse, as generated in Figure 1.5. **B,** A second scan line is added. **C–D,** Five and ten scan lines, respectively. **E,** A complete frame consisting of (in this example) 100 scan lines.

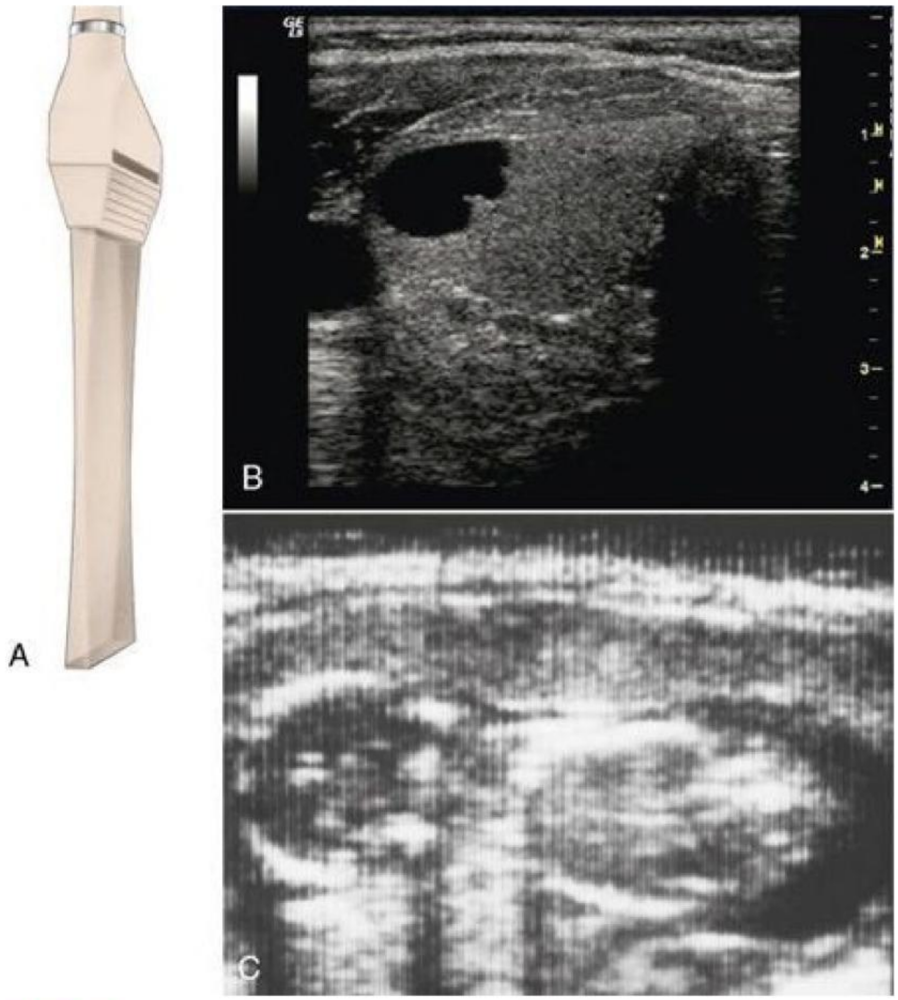

FIGURE 1.7 **A,** Ultrasound sent through a thin rectangular volume of tissue produces a rectangular image, commonly called a *linear image* or *linear scan.* **B,** Clinical linear (rectangular) scan. **C,** Poor-quality (by current standards) fetal image from the late 1970s, revealing the 120 vertical parallel scan lines of which it is composed.

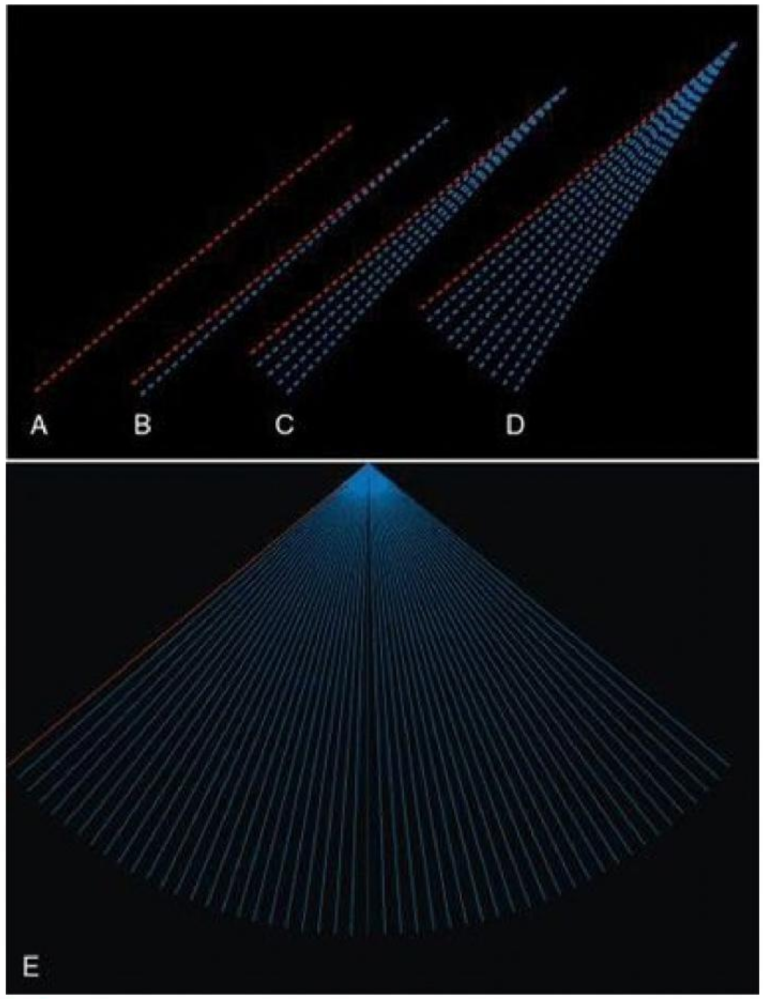

FIGURE 1.8 A single sector frame is progressively built up with 1 **(A),** 2 **(B),** 5 **(C),** 10 **(D),** and 100 **(E)** scan lines in sequence. All originate from a common origin and travel out in different directions.

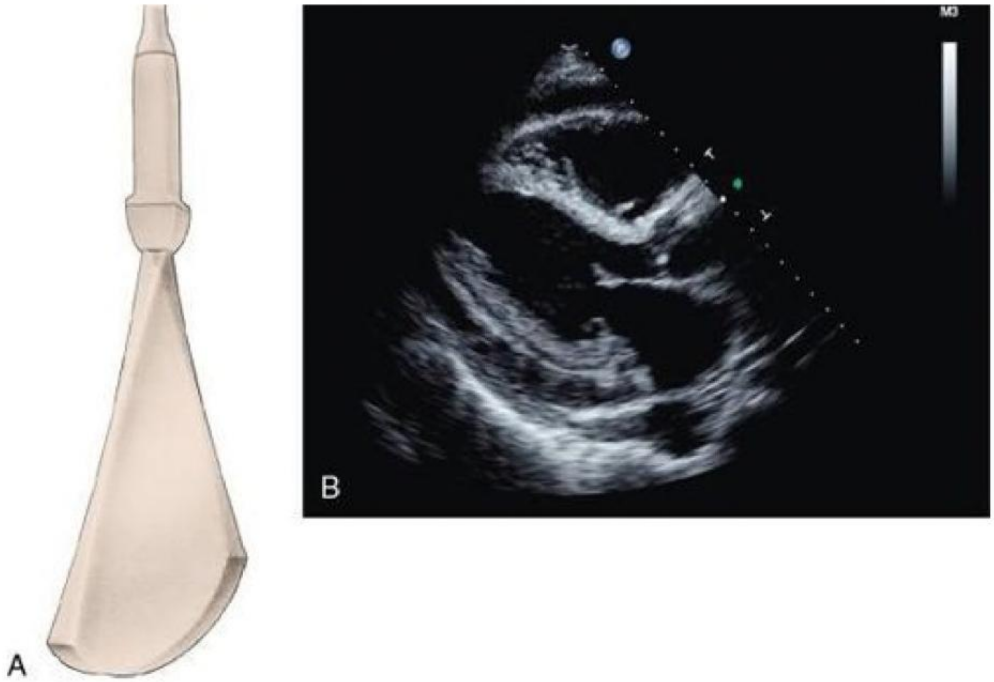

FIGURE 1.9 **A,** Ultrasound sent through a thin pie-slice–shaped volume of tissue produces an image commonly called a *sector image* or *sector scan*. **B,** Sector scan of adult heart.

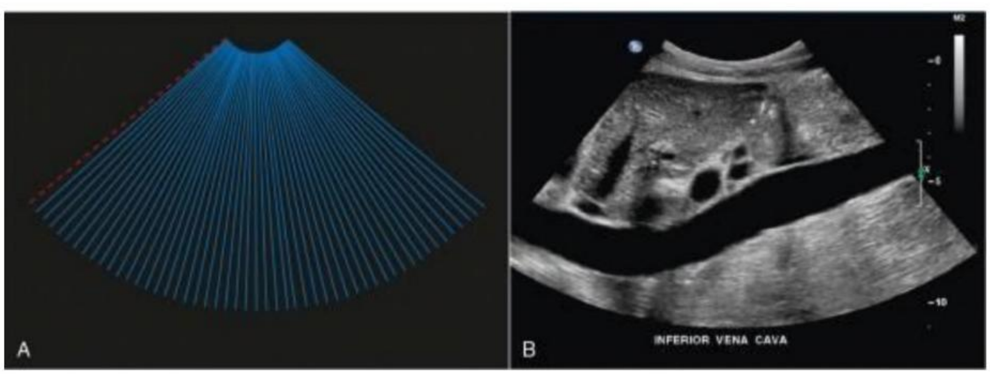

FIGURE 1.10 **A,** A modified form of a sector scan is produced when pulses and scan lines originate from different points across the curved top of a sector display. **B,** Abdominal scan using the scan format shown in **A**.

Sonographic images are composed of many scan lines.