CHAPTER

8 Artifacts

LEARNING OBJECTIVES

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

- List reasons why sonographic gray-scale images can present anatomic structures incorrectly.
- List reasons why spectral and color Doppler displays can present motion and flow information incorrectly.
- Describe how specific artifacts can be recognized.
- Explain how artifacts should be handled to avoid the pitfalls and misdiagnoses that they can cause.

KEY TERMS

The following terms are introduced in this chapter:

Aliasing
Anechoic
Baseline shift
Comet tail
Cross-talk
Enhancement
Hypoechoic
Mirror image
Multiple reflection
Nyquist limit
Range ambiguity
Resonance
Reverberation
Ring-down artifact
Section thickness
Shadowing
Speckle
Speed error

In imaging, an artifact is anything that is not properly indicative of the structures or motion imaged. An artifact is caused by some problematic aspect of the imaging technique. In addition to helpful artifacts, there are several that hinder proper interpretation and diagnosis. One must avoid these artifacts or handle them properly when encountered.

Artifacts are incorrect representations of anatomy or motion.

Artifacts in sonography occur as apparent structures that are one of the following:

1. Not real
2. Missing
3. Improperly located
4. Of improper brightness, shape, or size

Some artifacts are produced by improper equipment operation or settings (e.g., incorrect gain and compensation settings). Other artifacts are inherent in the sonographic and Doppler methods and can occur even with proper equipment and technique. Artifacts that occur in sonography[51,52] are listed in Box 8-1, where they are grouped as they are considered in the following sections.

The assumptions in the design of sonographic instruments are that sound travels in straight lines, that echoes originate only from objects located on the beam axis, that the amplitude of returning echoes is related directly to the reflecting or scattering properties of distant objects, and that the distance to reflecting or scattering objects is proportional to the round-trip travel time (13 μs/cm of depth). If any of these assumptions is violated, an artifact occurs.

Several artifacts are encountered in Doppler ultrasound,[53] including incorrect presentations of Doppler flow information, either in spectral or in color Doppler form. The most common of these is **aliasing.** Others include **range ambiguity,** spectrum mirror image, location mirror image, and **speckle.**

BOX 8-1 Sonographic Artifacts

PROPAGATION GROUP
- Axial resolution
- Comet tail
- Grating lobe
- Lateral resolution
- Mirror image
- Range ambiguity
- Refraction
- Reverberation
- Ring-down
- Section thickness
- Speckle
- Speed error

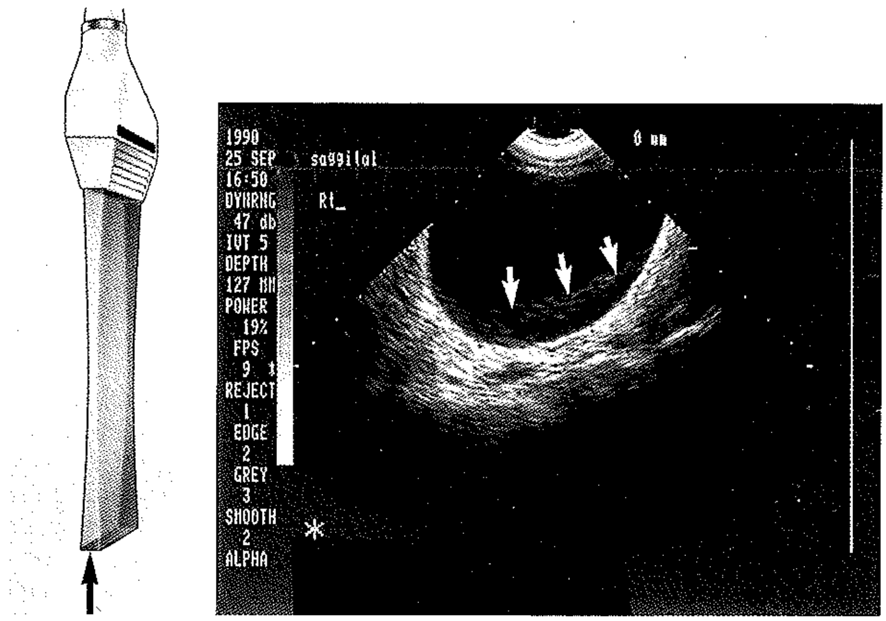
ATTENUATION GROUP
- Enhancement
- Focal enhancement
- Refraction (edge) shadowing
- Shadowing

PROPAGATION

Section Thickness

Axial and lateral resolution are artifactual because a failure to resolve means a loss of detail, and two adjacent structures may be visualized as one. The beam width perpendicular to the scan plane (the third dimension; Figure 8-1, *A*) results in **section thickness** artifacts; for example, the appearance of false debris in echo-free areas (Figure 8-1, *B*). These artifacts occur because the interrogating beam has finite thickness as it scans through the patient. Echoes are received that originate not only from the center of the beam but also from off-center. These echoes are all collapsed into a thin (zero-thickness) two-dimensional image that is composed of echoes that have come from a not-so-thin tissue volume scanned by the beam. Section thickness artifact is also called partial-volume artifact.

Beam width perpendicular to the scan plane causes section thickness artifact.



A B

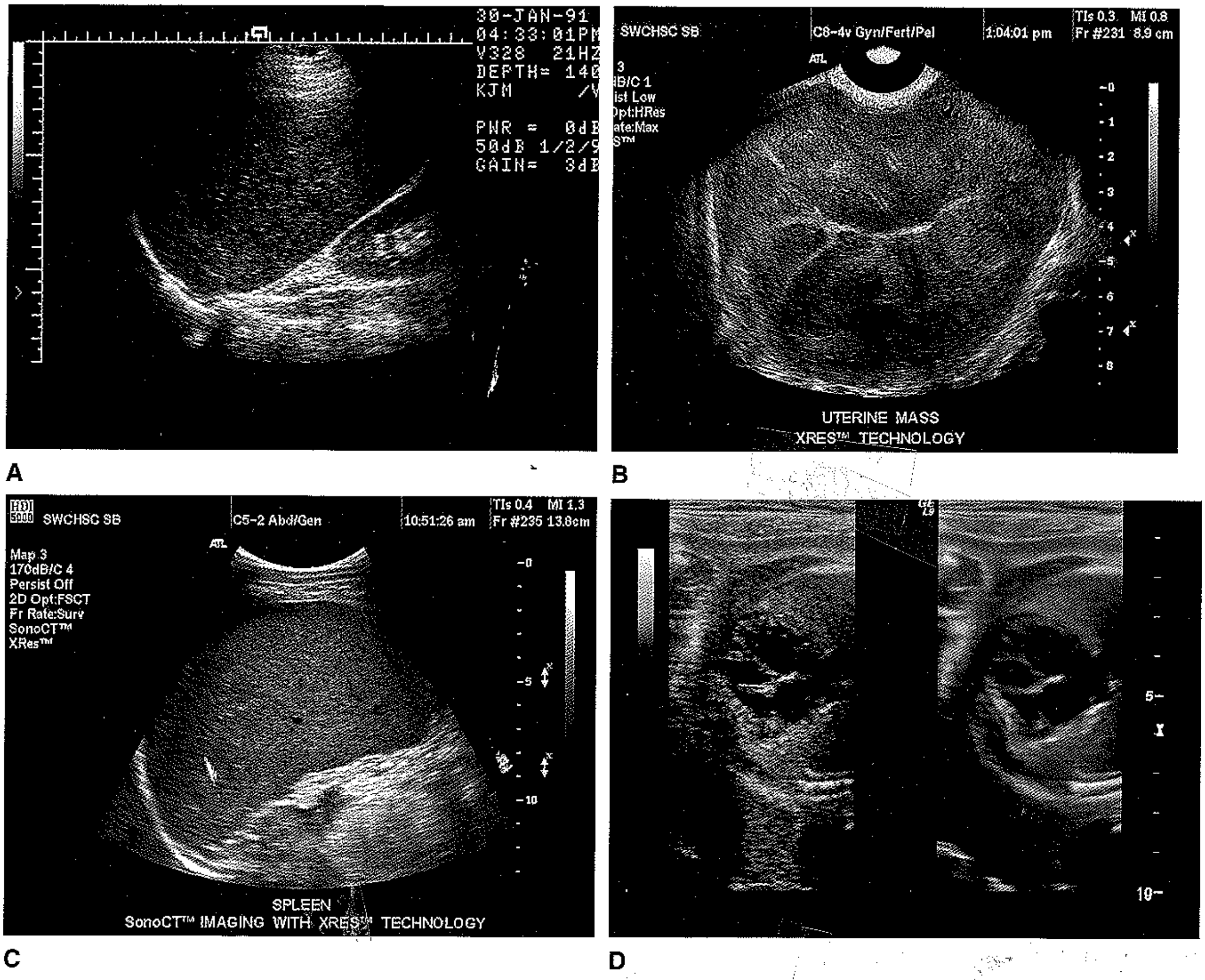
■ **FIGURE 8-1** **A,** The scan "plane" through the tissue is really a three-dimensional volume. Two dimensions (axial and lateral) are in the scan plane, but there is a third dimension (called section thickness or slice thickness). The third dimension *(arrow)* is collapsed to zero thickness when the image is displayed in two-dimensional format. **B,** An ovarian cyst that should be echo-free has an echogenic region *(arrows)*. These off-axis echoes are a result of scan-plane section thickness.

Speckle

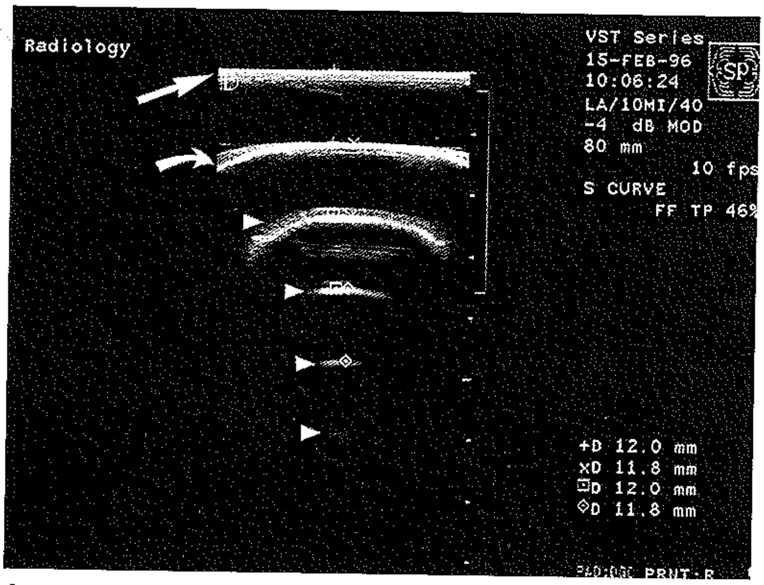
Apparent image resolution can be deceiving. The detailed echo pattern often is not related directly to the scattering properties of tissue (called tissue texture) but is a result of the interference effects of the scattered sound from the distribution of scatterers in the tissue. This phenomenon is called acoustic speckle (Figure 8-2).

Reverberation

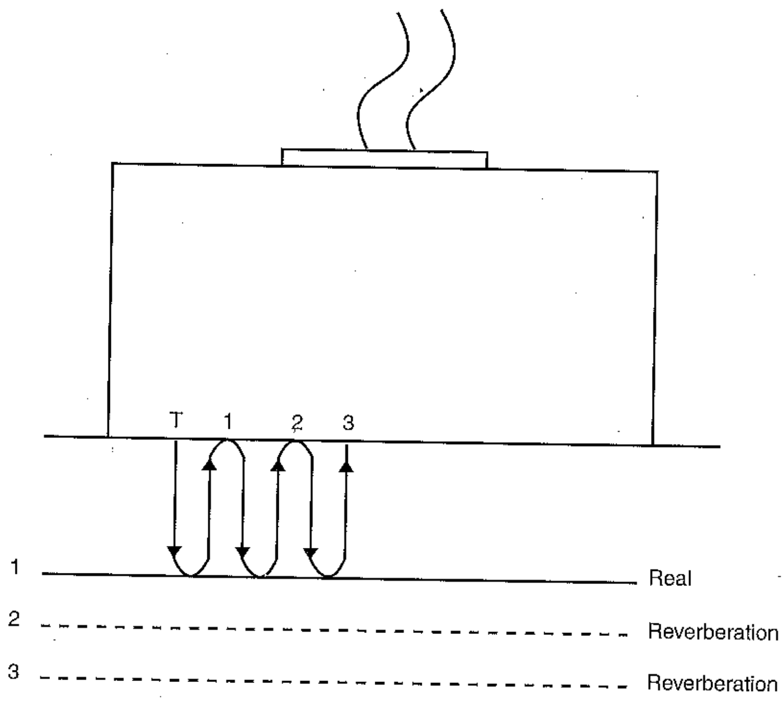
Multiple reflection (reverberation) can occur between the transducer and a strong reflector (Figure 8-3, *A*). The multiple echoes may be sufficiently strong to be detected by the instrument and to cause confusion on the display. The process by which they are produced is shown in Figure 8-3, *B*. This results in the display of additional reflectors that are not real (Figure 8-4). The multiple reflections are placed beneath the real reflector at separation intervals equal to the separation between the transducer and the real reflector. Each subsequent reflection is weaker than prior ones, but this diminution is counteracted at least partially by the attenuation compensation (TGC) function. Reverberations can originate between two anatomic reflecting surfaces also. When closely spaced, they appear in a form called **comet tail** (Figure 8-5). Comet tail, a particular form of reverberation, is a series of closely spaced, discrete echoes.



■ **FIGURE 8-2** **A** to **C**, Three examples of the typically grainy appearance of ultrasound images that is not primarily the result of detail resolution limitations but rather of speckle. Speckle is the interference pattern resulting from constructive and destructive interference of echoes returning simultaneously from many scatterers within the propagating ultrasound pulse at any instant. **D**, Approaches to speckle reduction *(right image compared with the left)* are being implemented in modern instruments.

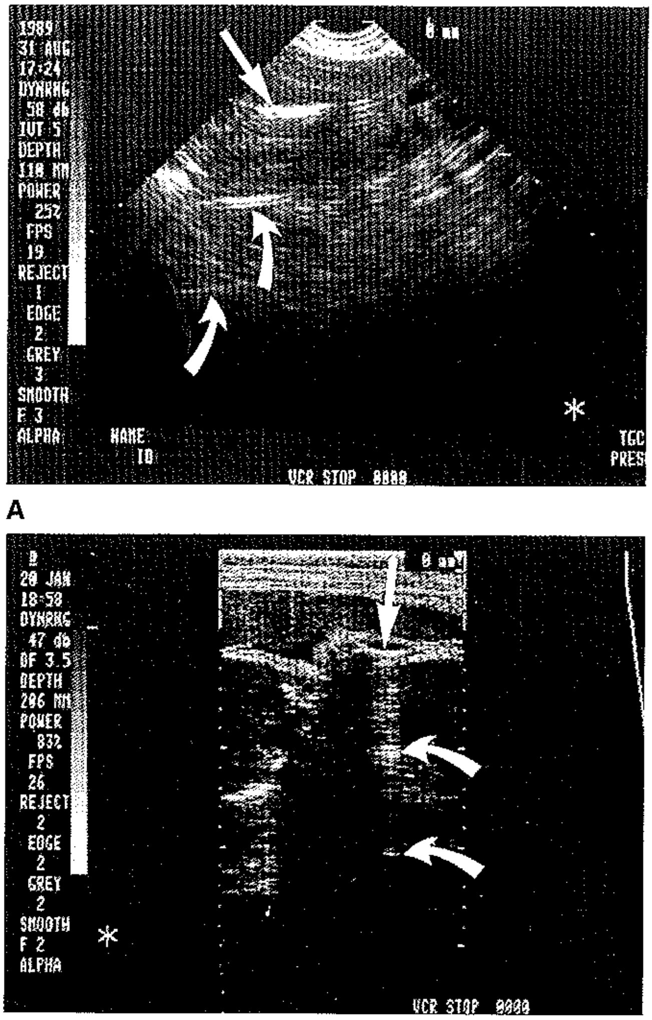


A



B

■ **FIGURE 8-3** **A,** Reverberation *(arrowheads)* resulting from multiple reflection through a water path between a linear array transducer *(straight arrow)* and the surface of an apple *(curved arrow)*. **B,** The behavior in **A** is explained as follows: A pulse *(T)* is transmitted from the transducer. A strong echo is generated at the real reflector and is received *(1)* at the transducer, allowing correct imaging of the reflector. However, the echo is reflected partially at the transducer so that a second echo *(2)* is received, as well as a third *(3)*. Because these echoes arrive later, they appear deeper on the display, where there are no reflectors. The lateral displacement of the reverberating sound path is for figure clarity. In fact, the sound travels down and back the same path repeatedly.



A
B

■ **FIGURE 8-4** **A,** A chorionic villi sampling catheter *(straight arrow)* and two reverberations *(curved arrows)*. **B,** A fetal scapula *(straight arrow)* and two reverberations *(curved arrows)*.

Figure 8-6 shows an artifact that appears similar but is fundamentally different. Discrete echoes cannot be identified here because continuous emission of sound from the origin appears to be occurring. This continuous effect, termed **ring-down artifact,** is caused by a **resonance** phenomenon associated with the presence of a collection of gas bubbles. Resonance is the condition in which a driven mechanical vibration is of a frequency similar to a natural vibration frequency of the structure. The bubbles are stimulated into vibration by the incident ultrasound pulse. They then pulsate (expand and contract) for several cycles, acting as a source of ultrasound, producing a continuous stream of ultrasound that progresses distal to the bubble collection as the echo stream returns.

Reverberations are multiple reflections between a structure and the transducer or within a structure.

Mirror Image

The mirror-image artifact, also a form of reverberation, shows structures that exist on one side of a strong reflector as being present on the other side as well. Figure 8-7 explains how this happens and shows examples. Mirror-image artifacts are common around the diaphragm and pleura because of the total reflection from air-filled lung. They occasionally occur in other locations. Sometimes the mirrored structure is not in the unmirrored scan plane (Figure 8-7, *C*).

Mirror-image artifact duplicates a structure on the other side of a strong reflector.

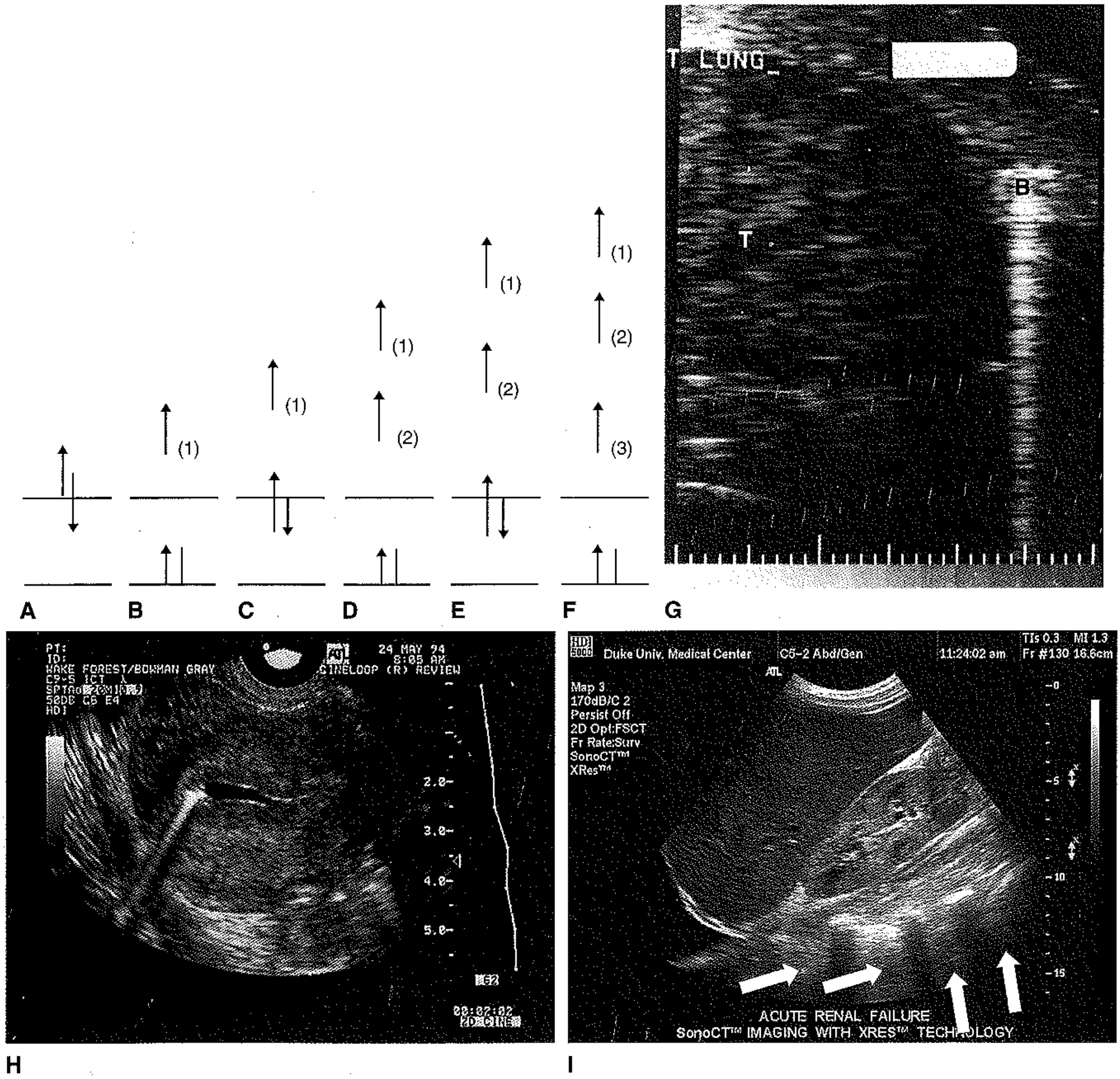
Refraction

Refraction of light enables lenses to focus and distorts the presentation of objects, as shown in Figure 8-8. Refraction can cause a reflector to be positioned improperly (laterally) on a sonographic display (Figure 8-9). This is likely to occur, for example, when the transducer is placed on the abdominal midline (Figures 8-9, *C*, and 8-10), producing doubling of single objects. Beneath are the rectus abdominis muscles, which are surrounded by fat. These tissues present refracting boundaries because of their different propagation speeds.

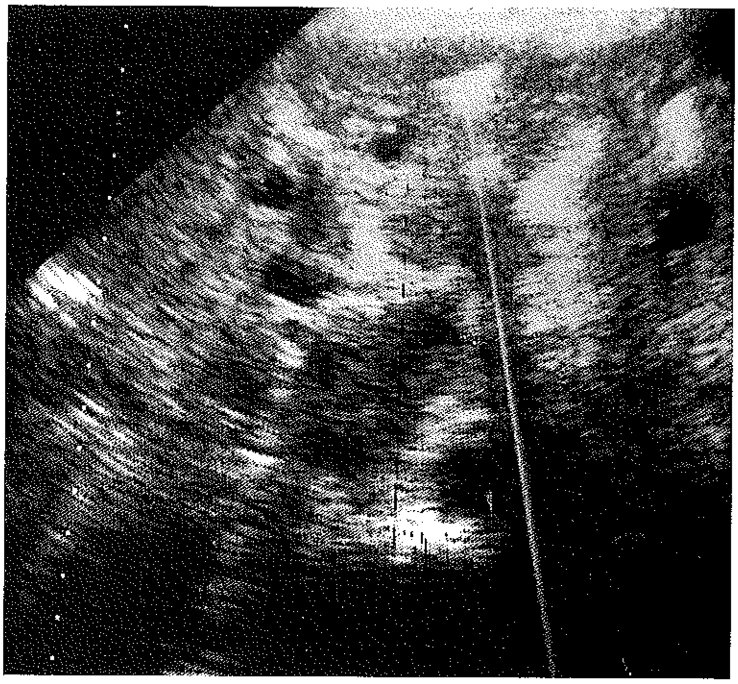
Refraction displaces structures laterally from their correct locations.

Grating Lobes

Side lobes are beams that propagate from a single element in directions different from the primary beam. Grating lobes are additional beams emitted from an array transducer that are stronger than the side lobes of individual elements (Figure 8-11). Side and grating lobes are weaker than the primary beam and normally do not produce echoes that are imaged, particularly if they fall on a normally echogenic region of the scan. However, if grating lobes encounter a strong reflector



■ **FIGURE 8-5** Generation of comet-tail artifact (closely spaced reverberations). Action progresses in time from left to right. **A,** An ultrasound pulse encounters the first reflector and is reflected partially and is transmitted partially. **B,** Reflection and transmission at the first reflector are complete. Reflection at the second reflector is occurring. **C,** Reflection at the second reflector is complete. Partial transmission and partial reflection are again occurring at the first reflector as the second echo passes through. **D,** The echoes from the first *(1)* and second *(2)* reflectors are traveling toward the transducer. A second reflection (repeat of **B**) is occurring at the second reflector. **E,** Partial transmission and reflection are again occurring at the first reflector. **F,** Three echoes are now returning—the echo from the first reflector *(1)*, the echo from the second reflector *(2)*, and the echo from the second reflector *(3)*—that originated from the back side of the first reflector **(C)** and reflected again from the second reflector **(D).** A fourth echo is being generated at the second reflector **(F). G,** Comet-tail artifact from an air rifle BB shot pellet *(B)* adjacent to the testicle *(T)*. The front and rear surface of the BB shot are the two reflecting surfaces involved in this example. **H,** Comet-tail artifact from bubbles in an intrauterine saline injection. **I,** Comet tail *(arrows)* from diaphragm. (**G** from Kremkau FW, Taylor KJW: *J Ultrasound Med* 5:227, 1986.)



■ **FIGURE 8-6** Ring-down artifact from air in the bile duct. (From Kremkau FW, Taylor KJW: *J Ultrasound Med* 5:227, 1986.)

(e.g., bone or gas), their echoes may well be imaged, particularly if they fall within an **anechoic** region. If so, they appear in incorrect locations (Figure 8-12).

Grating lobes duplicate structures laterally to the legitimate ones.

Speed Error

Propagation **speed error** occurs when the assumed value for propagation speed (1.54 mm/μs, leading to the 13 μs/cm rule) is incorrect. If the propagation speed that exists over a path traveled is greater than 1.54 mm/μs, the calculated distance to the reflector is too small, and the display will place the reflector too close to the transducer (Figure 8-13). This occurs because the increased speed causes the echoes to arrive sooner. If the actual speed is less than 1.54 mm/μs, the reflector will be displayed too far from the transducer (Figure 8-14) because the echoes arrive later. Refraction and propagation speed error also can cause a structure to be displayed with incorrect shape.

Propagation speed error displaces structures axially.

Range Ambiguity

In sonographic imaging, it is assumed that for each pulse all echoes are received before the next pulse is emitted. If this were not the case, error could result (Figures 8-15 and 8-16). The maximum depth imaged correctly by an instrument is determined by its pulse repetition frequency (PRF). To avoid range ambiguity, PRF automatically is reduced in deeper imaging situations. This also causes a reduction in frame rate.

The range-ambiguity artifact places structures much closer to the surface than they should be.

Sometimes two artifacts combine to present even more challenging cases. An example involving range ambiguity is shown in Figure 8-17.

ATTENUATION

Shadowing

Shadowing is the reduction in echo amplitude from reflectors that lie behind a strongly reflecting or attenuating structure. A strongly attenuating or reflecting structure weakens the sound distal to it, causing echoes from

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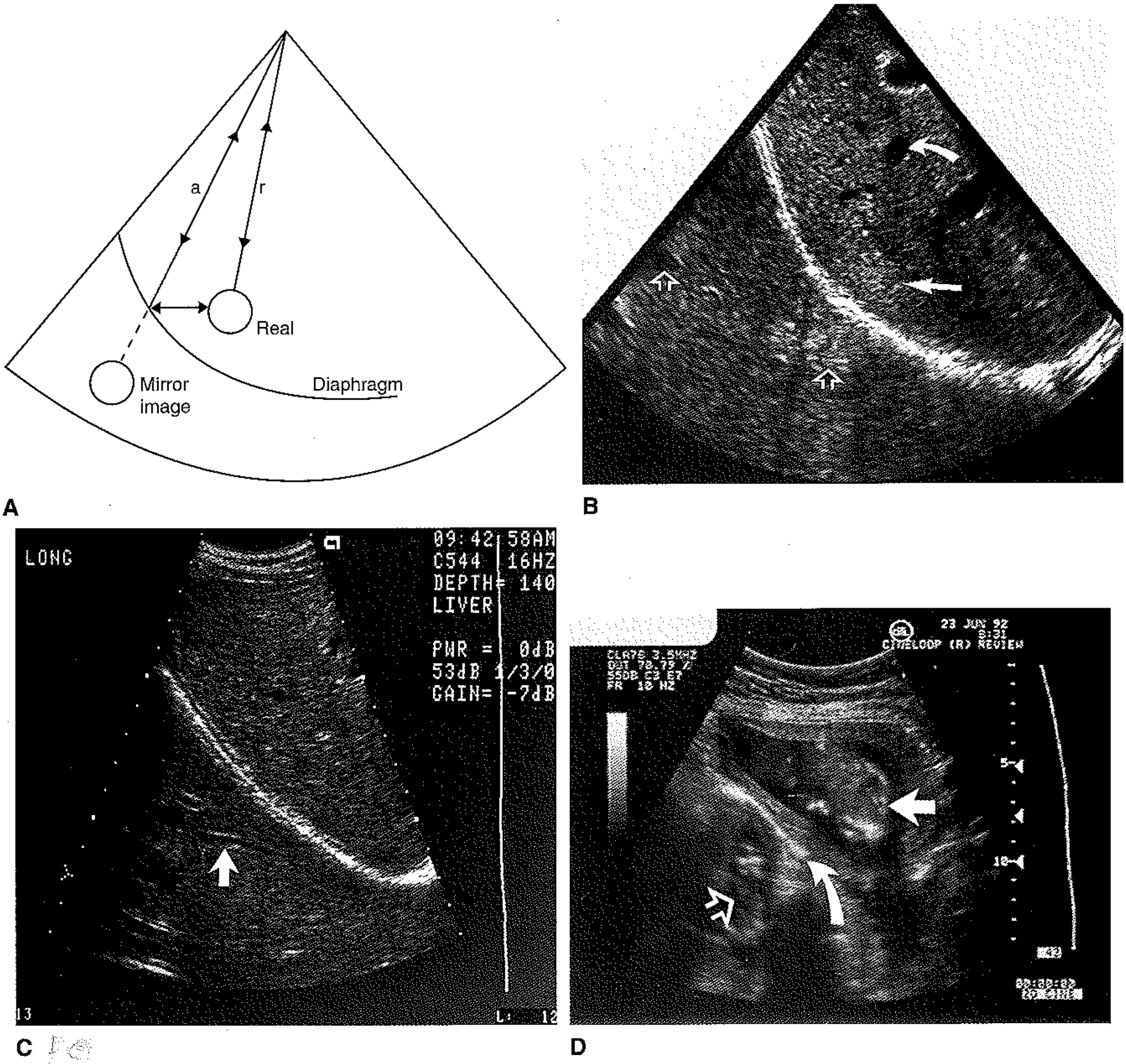
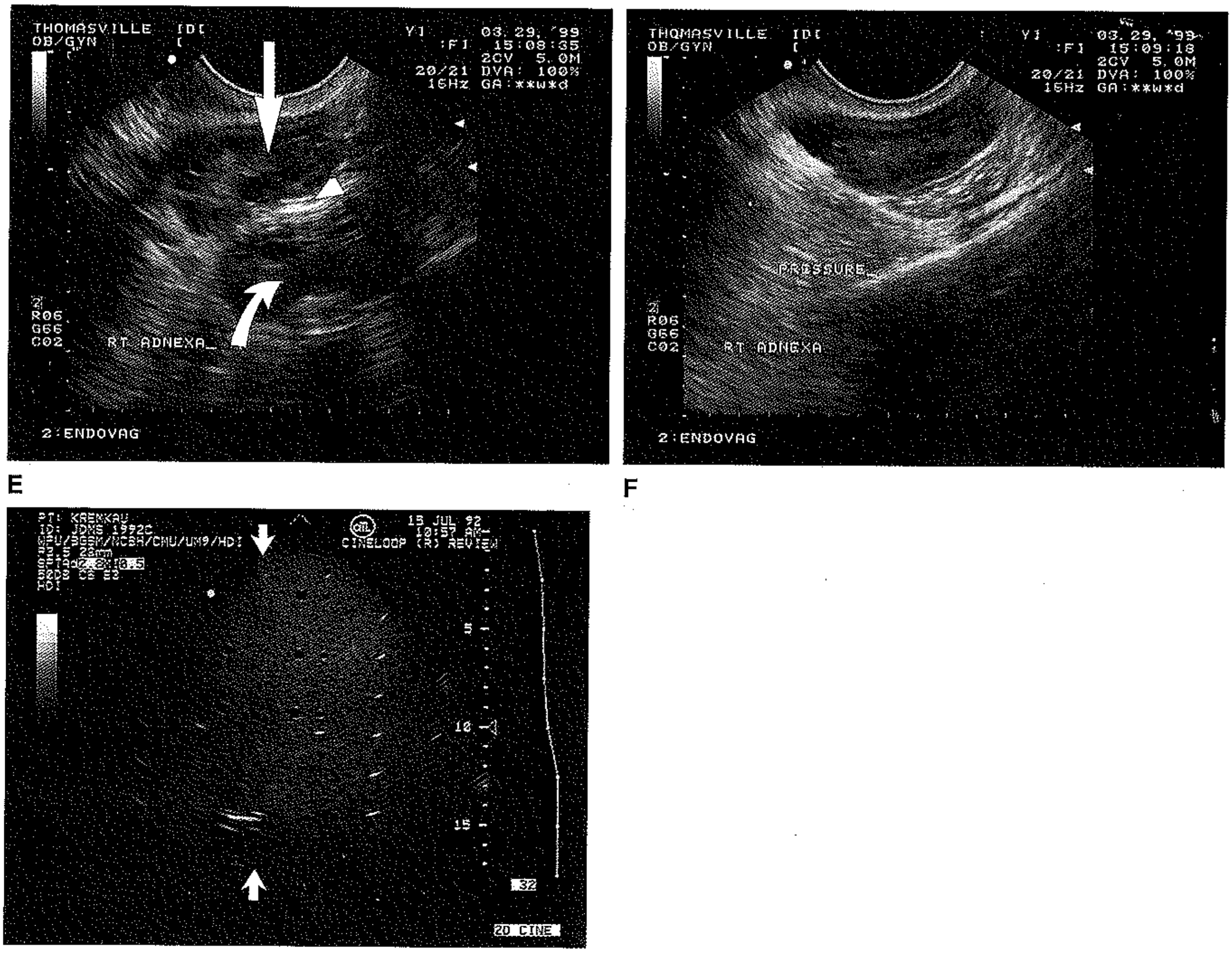


■ **FIGURE 8-7** **A,** When pulses encounter a real hepatic structure directly *(scan line r),* the structure is imaged correctly. If the pulse first reflects off the diaphragm *(scan line a)* and returns along the same path, the structure is displayed on the other side of the diaphragm. **B,** A hemangioma *(straight arrow)* and vessel *(curved arrow)* with their mirror images *(open arrows).* **C,** A vessel is mirror-imaged *(arrow)* superior to the diaphragm but does not appear inferior because it is outside the unmirrored scan plane. **D,** A fetus *(straight arrow)* also appears as a mirror image *(open arrow).* The mirror *(curved arrow)* is probably echogenic muscle.

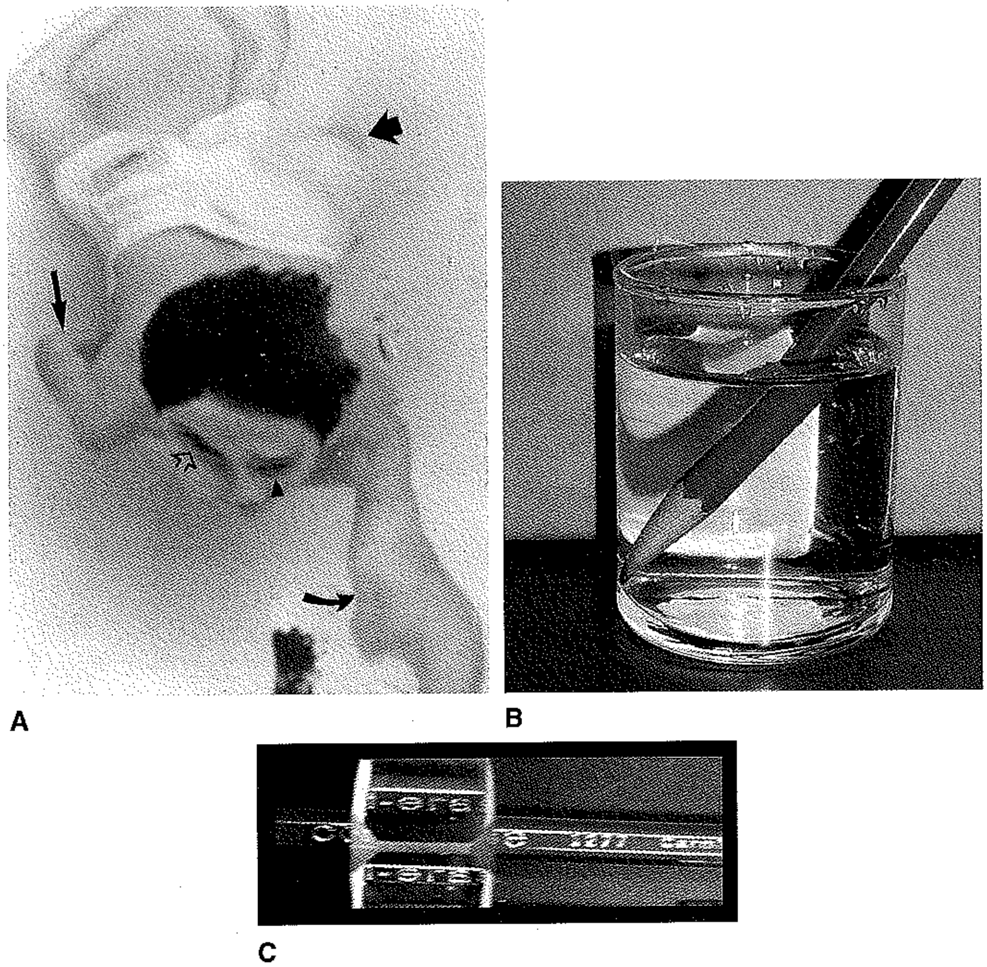


E

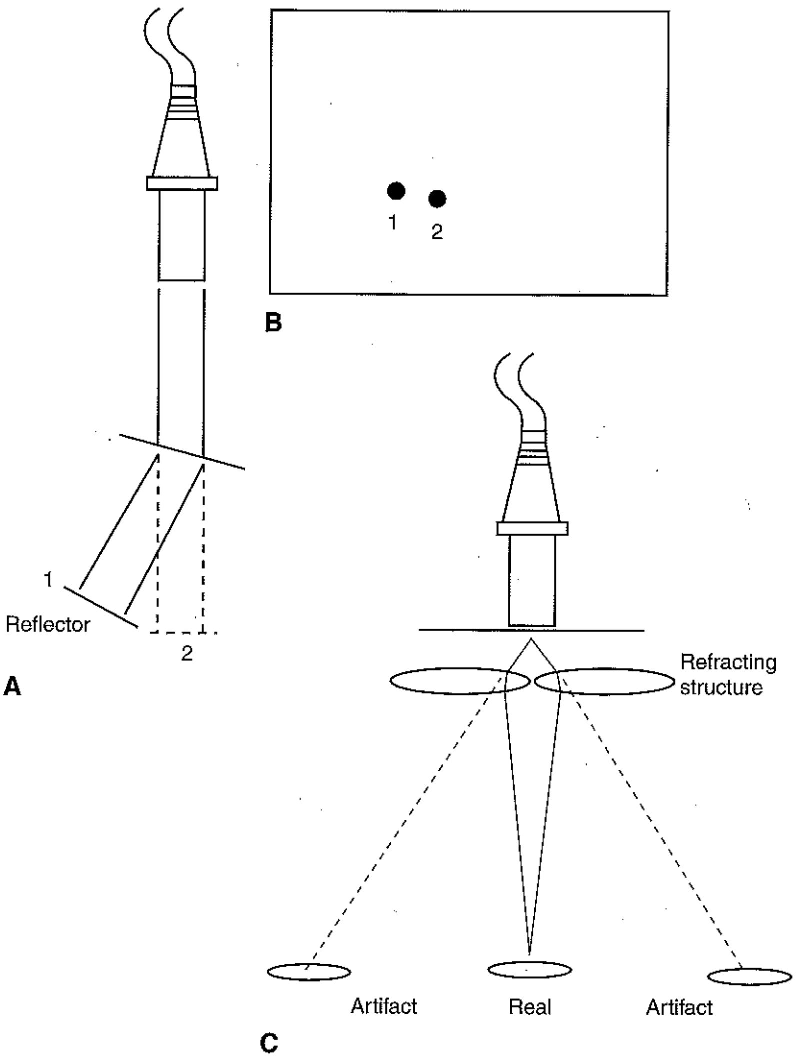
F

G

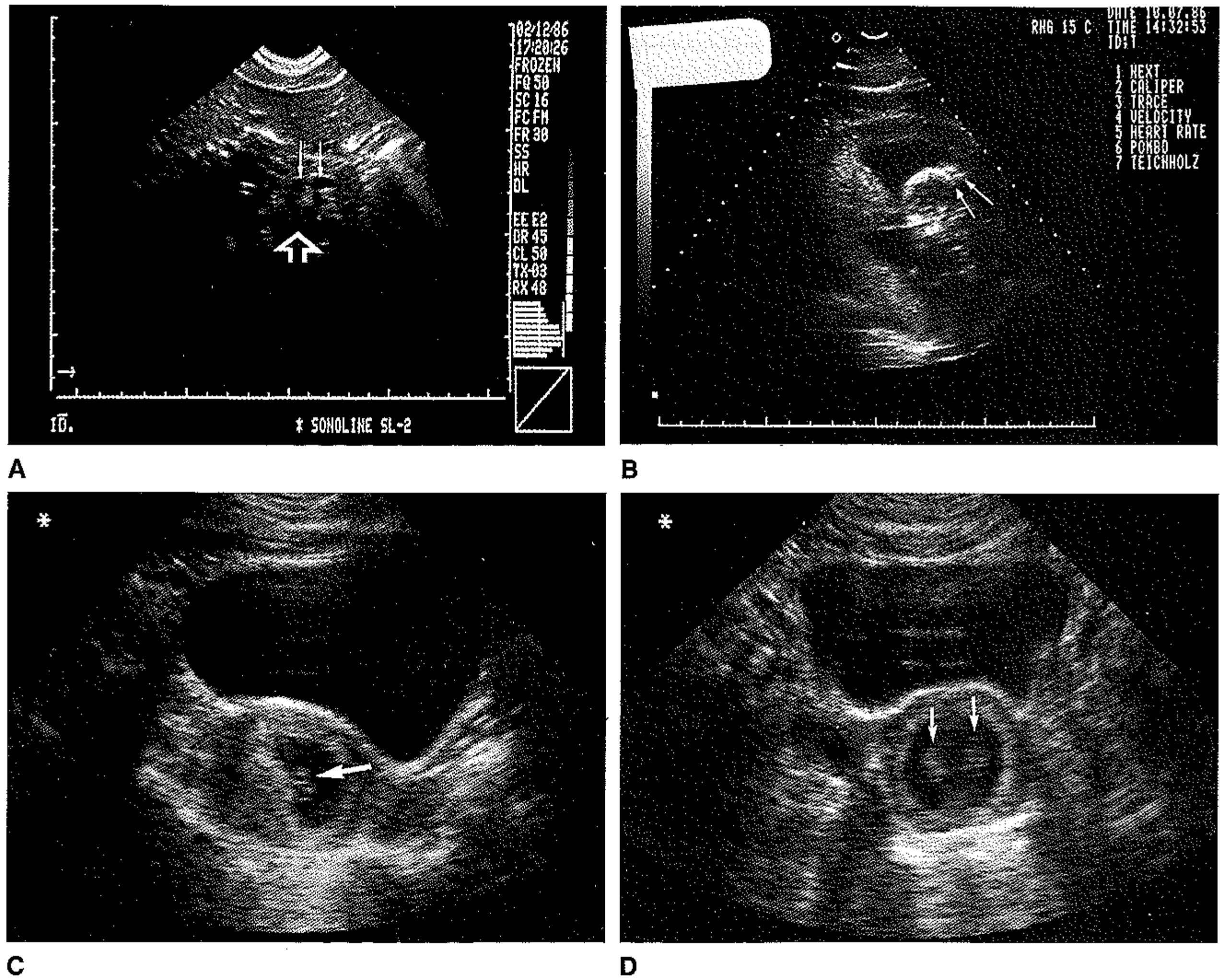
■ **FIGURE 8-7, cont'd** **E,** Ovary *(arrow)* with mirror image *(curved arrow)* that could be mistaken for an adnexal mass or ectopic pregnancy. Bowel gas *(arrowhead)* is apparently the mirror in this case. **F,** Applying external abdominal pressure displaces the gas, eliminating the mirror image. **G,** Mirror image of cystic regions in a tissue-equivalent phantom. The edge of the phantom is indicated by the arrows. The image to the right of the arrows is a correct presentation. Everything to the left is mirror-image artifact.



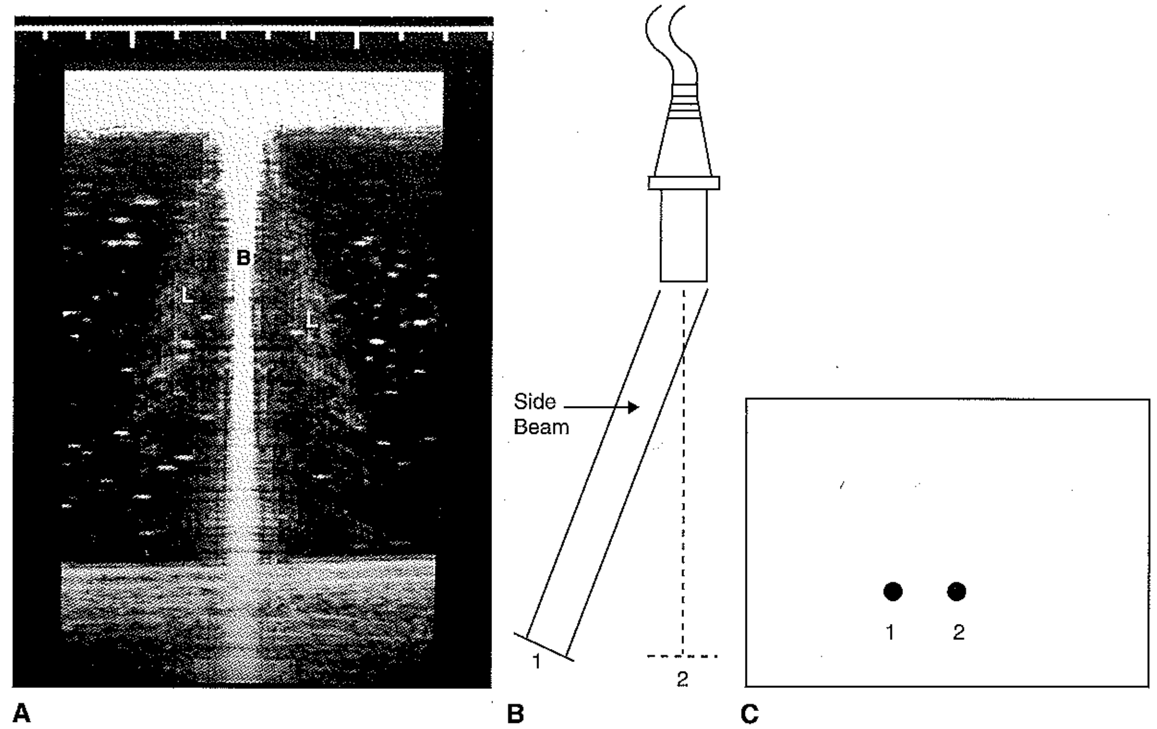
■ **FIGURE 8-8** **A,** Refracted light from a child in a swimming pool distorts his appearance. We see a thin arm *(straight arrow)* and a thick one *(curved arrow)*, a large eye *(open arrow)* and a small one *(arrowhead)*, and even a third lower limb emerging *(thick arrow)*. **B,** A pencil in water appears to be broken. **C,** A pencil beneath a prism appears to be split in two.



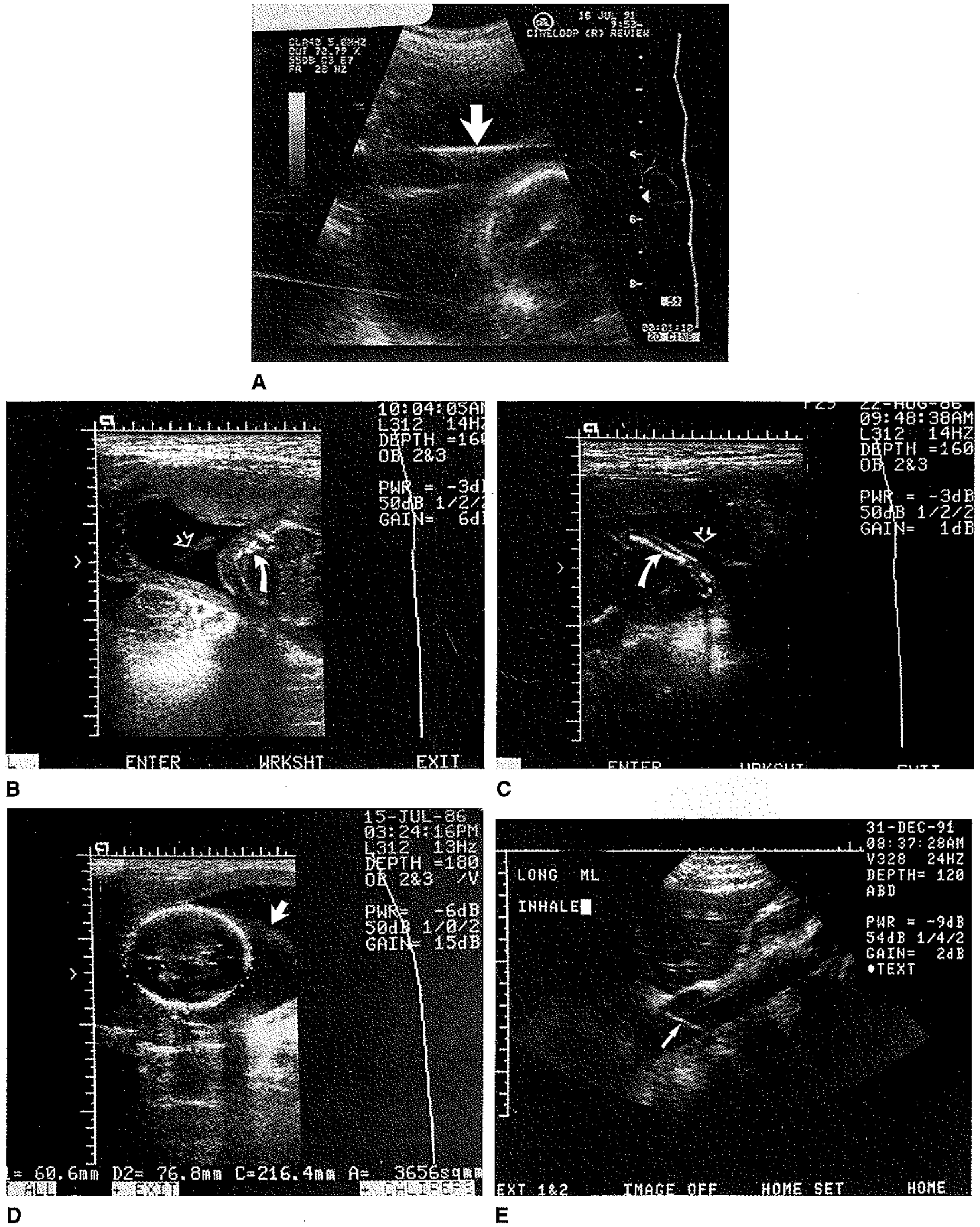
■ **FIGURE 8-9** Refraction **(A)** results in improper positioning of a reflector on the display **(B)**. The system places the reflector at position 2 (because that is the direction from which the echo was received) when in fact the reflector is actually at position 1. **C,** One real structure is imaged as two artifactual objects because of the refracting structure close to the transducer. If unrefracted pulses can propagate to the real structure, a triple presentation (one correct, two artifactual) will result.



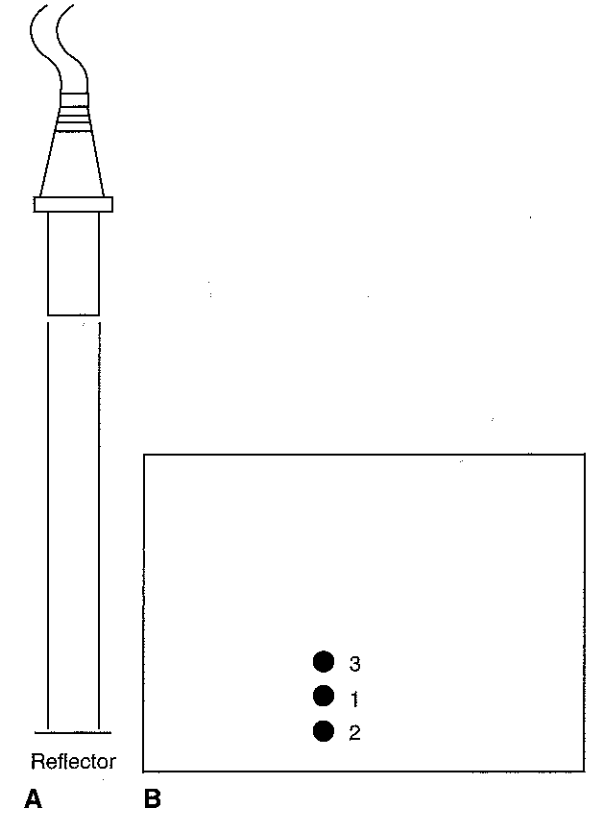
■ **FIGURE 8-10** **A,** Refraction (probably through the rectus abdominis muscle) has widened the aorta *(open arrow)* and produced a double image of the celiac trunk *(arrows)*. **B,** Refraction has produced a double image of a fetal skull *(arrows)*. Refraction also may cause a single gestation **(C)** to appear as a double gestation **(D)**.



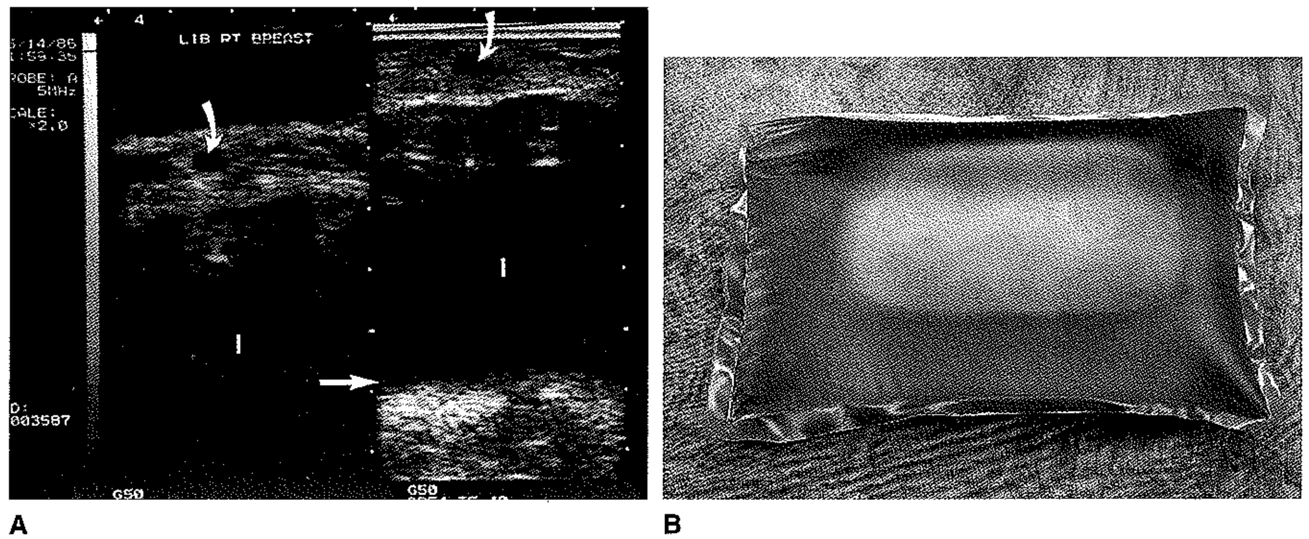
■ **FIGURE 8-11** **A,** The primary beam *(B)* and grating lobes *(L)* from a linear array transducer. **B,** A side lobe or grating lobe can produce and receive a reflection from a "side view." **C,** This will be placed on the display at the proper distance from the transducer but in the wrong location (direction) because the instrument assumes that echoes originate from points along the main beam axis. The instrument shows the reflector at position 2 because that is the direction in which the main beam travels. The reflector is actually in position 1.



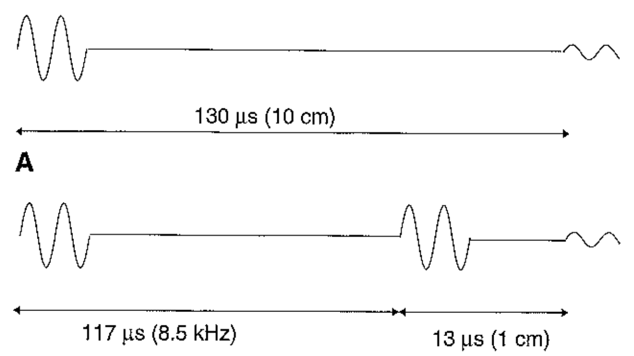
■ **FIGURE 8-12** Grating lobes in obstetric scans can produce the appearance of amniotic sheets or bands. **A,** A real amniotic sheet *(arrow)*. **B** and **C,** Grating lobe duplication *(open arrows)* of fetal bones *(curved arrows)* resembles amniotic bands or sheets. **D,** Grating lobe duplication *(arrow)* of a fetal skull. **E,** Artifactual grating lobe echoes *(arrow)* cross the aorta. In these examples, we observe that the grating lobe artifact is always weaker than the correct presentation of the structure.



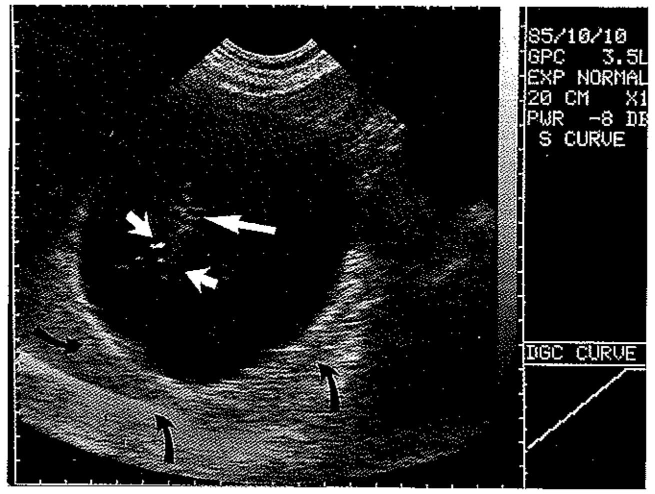
■ **FIGURE 8-13** The propagation speed over the traveled path **(A)** determines the reflector position on the display **(B).** The reflector is actually in position 1. If the actual propagation speed is less than that assumed, the reflector will appear in position 2. If the actual speed is more than that assumed, the reflector will appear in position 3.



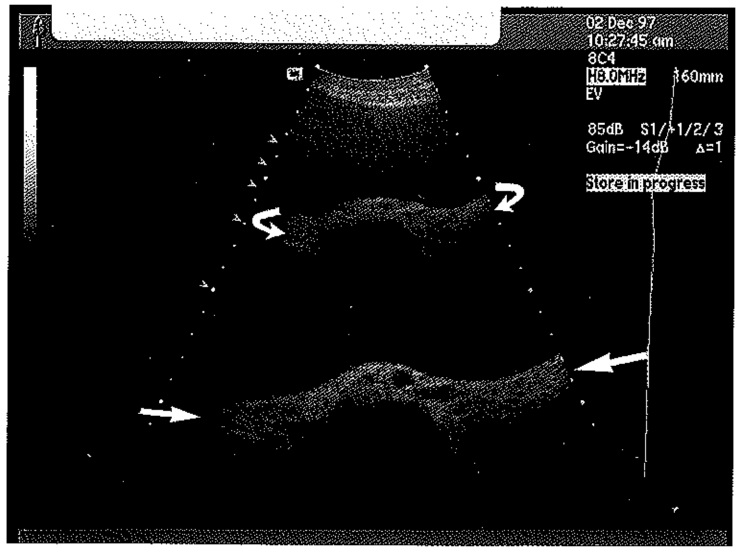
■ **FIGURE 8-14** The low propagation speed in a silicone breast implant *(I)* causes the chest wall *(straight arrow)* to appear deeper than it should **(A).** Note that a cyst *(curved arrow)* is shown more clearly on the left image than on the right because a gel standoff pad **(B)** has been placed between the transducer and the breast, moving the beam focus closer to the cyst.



■ **FIGURE 8-15** **A,** An echo (from a 10-cm depth) arrives 130 μs after pulse emission. **B,** If the pulse repetition period were 117 μs (corresponding to a pulse repetition frequency of 8.5 kHz), the echo in **A** would arrive 13 μs after the next pulse was emitted. The instrument would place this echo at a 1-cm depth rather than the correct value. This range location error is known as the range-ambiguity artifact.



■ **FIGURE 8-16** A large renal cyst (diameter about 10 cm) has artifactual range-ambiguity echoes within it *(white arrows)*. They are generated from structure(s) below the display. These deep echoes arrive after the next pulse is emitted. Because the time from the emission of the last pulse to echo arrival is short, the echoes are placed closer to the transducer than they should be. Echoes arrive from much deeper (later) than usual in this case because the sound passes through the long, low-attenuation paths in the cyst. These echoes may have come from bone or far body wall. Low attenuation in the cyst is indicated by the strong echoes (enhancement) below it *(curved black arrows)*.



■ **FIGURE 8-17** A large pelvic cyst produces a large echo-free region in this scan. A structure is located at a depth of about 13 cm *(straight arrows)*. Located in the anechoic region at a depth of about 6 cm is a structure *(curved arrows)* shaped like that at 13 cm. How could this artifact appear closer than the actual structure, implying that these echoes arrived earlier than those from the correct location? It turns out that the artifact is actually a combination of two phenomena: reverberation and range ambiguity. The artifact seen is a reverberation from the deep structure and the transducer. But a reverberation should appear at twice the depth of the actual structure, that is, at about 26 cm. However, the arrival of the reverberation echoes occurs about 78 μs after the next pulse is emitted so that they are placed at a 6-cm depth. Single artifacts are difficult enough. Fortunately, combinations like this occur infrequently.

the distal region to be weak and thus to appear darker, like a shadow. Of course, the returning echoes also must pass through the attenuating structure, adding to the shadowing effect. Examples of shadowing structures include calcified plaque (Figure 8-18, *A*), bone (Figure 8-18, *B*), and stone (Figure 8-19, *A*). Shadowing also can occur behind the edges of objects that are not necessarily strong attenuators (Figure 8-20). In this case the cause may be the defocusing action of a refracting curved surface. Alternatively, it may be attributable to destructive interference caused by portions of an ultrasound pulse passing through tissues with different propagation speeds and subsequently getting out of phase. In either case the intensity of the beam decreases beyond the edge of the structure, causing echoes to be weakened.

Shadowing is the weakening of echoes distal to a strongly attenuating or reflecting structure or from the edges of a refracting structure.

Enhancement

Enhancement is the strengthening of echoes from reflectors that lie behind a weakly attenuating structure (Figures 8-16; 8-18, *B*; and 8-19). Shadowing and enhancement result in reflectors being placed on the image with amplitudes that are too low and too high, respectively. Brightening of echoes also can be caused by the increased intensity in the focal region of a beam because the beam is narrow there. This is called focal enhancement or focal banding (Figure 8-21). Shadowing and enhancement artifacts are often useful for determining the nature of masses and structures. Shadowing and enhancement are reduced with spatial compounding because several approaches to each anatomic site are used, allowing the beam to "get under" the attenuating or enhancing structure. This is useful with shadowing because it can uncover structures (especially pathologic ones) that were not imaged because they were located in the shadow.

Enhancement is the strengthening of echoes distal to a weakly attenuating structure.

External influences also can produce artifacts. As an example, interference from electronic equipment adds unwanted noise to the image (Figure 8-22).

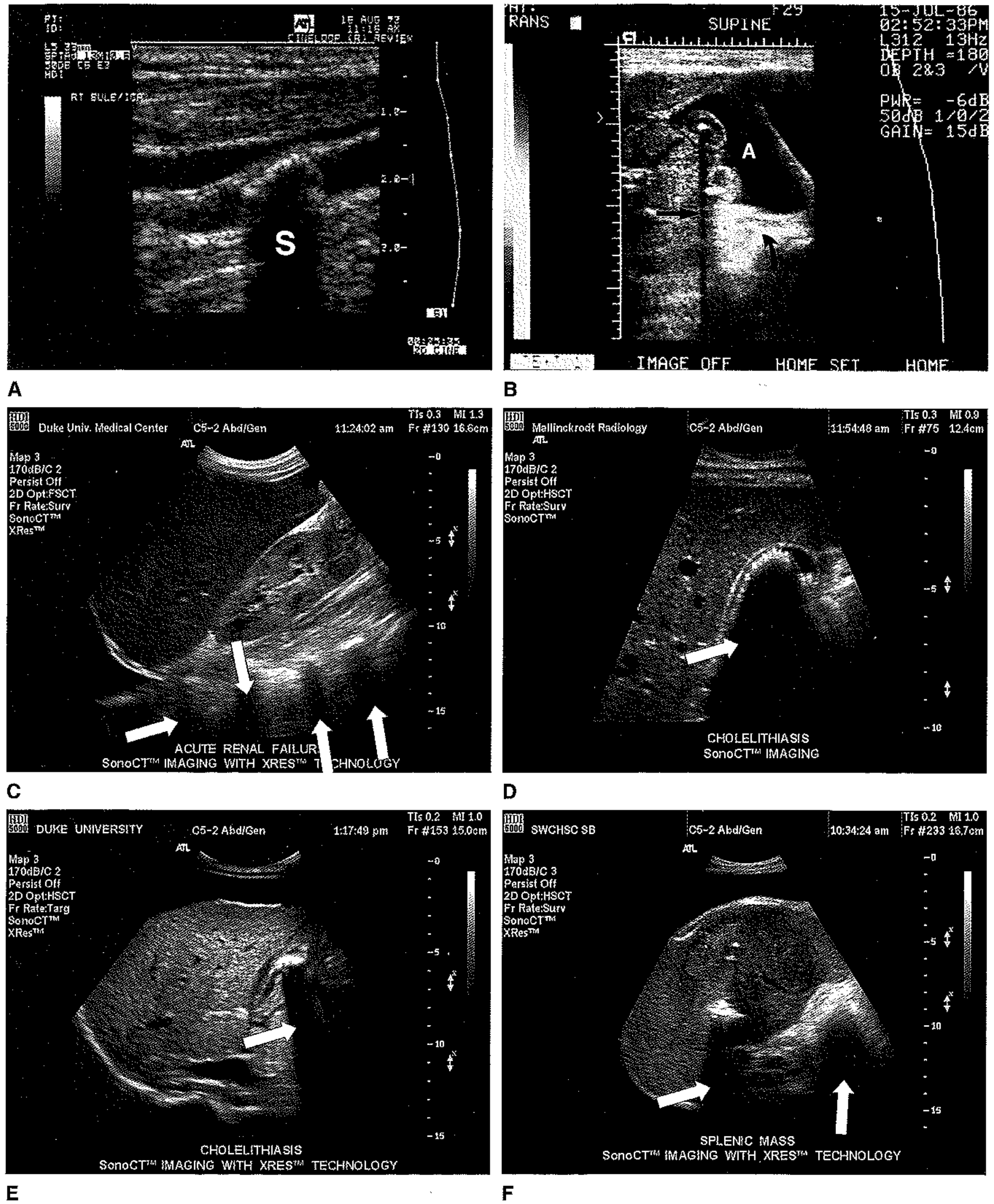
SPECTRAL DOPPLER

Aliasing

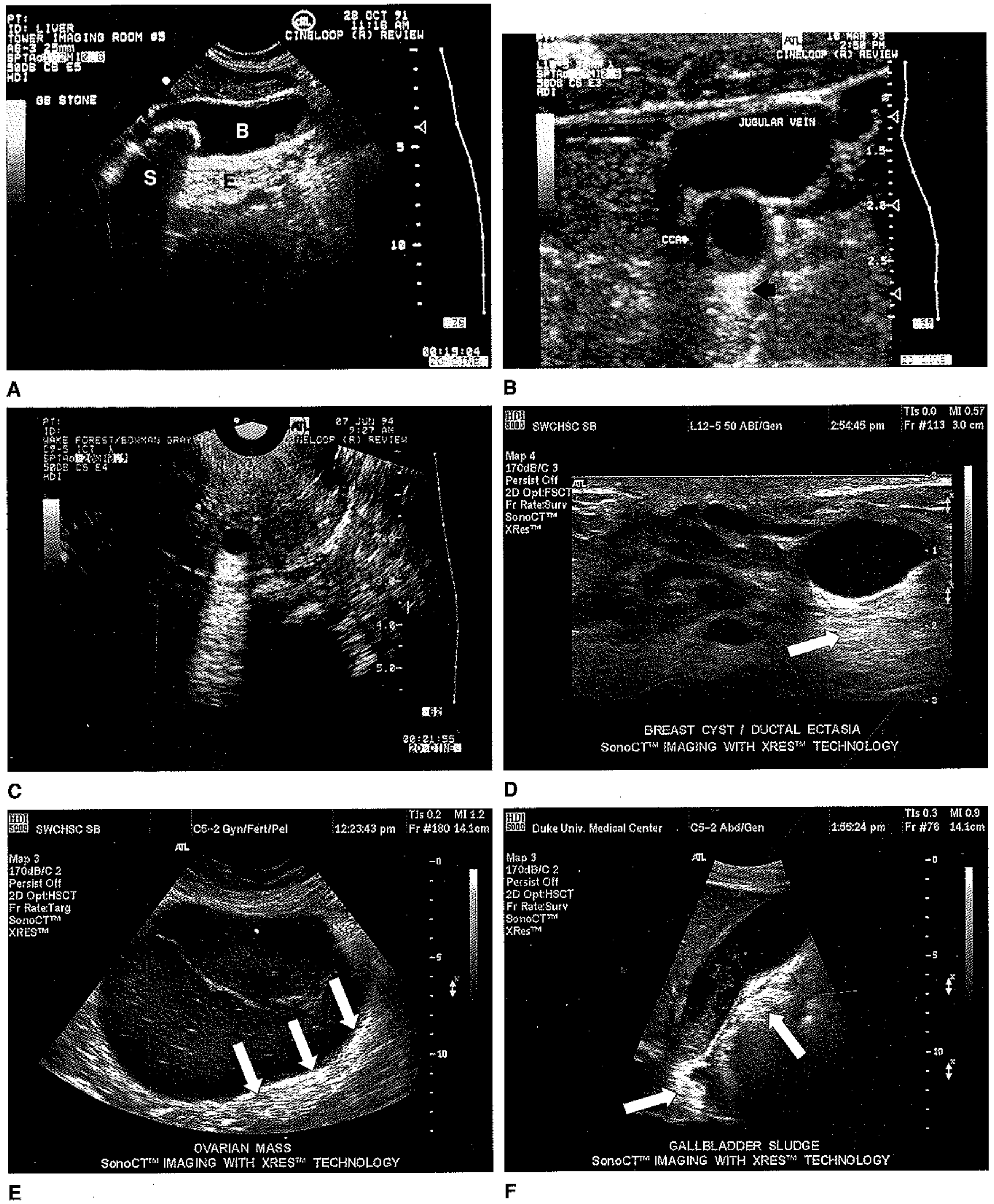
Aliasing is the most common artifact encountered in Doppler ultrasound. The word *alias* comes from Middle English *elles,* Latin *alius,* and Greek *allos,* which mean "other" or "otherwise." Contemporary meanings for the word include (as an adverb) "otherwise called" or "otherwise known as" and (as a noun) "an assumed or additional name." Aliasing in its technical use indicates improper representation of information that has been sampled insufficiently. The sampling can be spatial or temporal. Inadequate spatial sampling can result in improper conclusions about the object or population sampled. For example, we could assemble 10 families, each consisting of a father, a mother, and a child, and line them up in that order—father, mother, child, father, mother, child—for all the families. If we wanted to sample the contents of these families by taking 10 photographs, we could choose to photograph one out of every three persons (e.g., the first, fourth, and seventh persons in the line). However, if we did this, we would conclude that all families are made up of three adult males, no women, and no children. In this example, spatial undersampling of one third of the population would result in an incorrect conclusion regarding the total population.

Another example of inadequate spatial sampling is shown in Figure 8-23. In *A* we see what we might call a "Doppler flower," containing 12 double-pointed petals. Each petal is made up of four lines. If we sample at the intersections of these lines, we get a 48-point dot-to-dot child's puzzle, as shown in *B.* Connecting the dots properly will yield the flower shown in *A.* In *C,* the even-numbered dots from *B* have been eliminated so that there are now 24 dots (samples). When these dots are connected, a reasonable representation of the original flower results, but it is not as good as the representation in *B.* The higher-frequency information delineating the double pointing of the petals has been lost. In *D* the even-numbered dots from *C* have been eliminated. This representation of the flower, containing 12 samples, yields a 12-sided polygon that approximates a circle and is a poor representation of the original flower. The lower-frequency information about the 12 petals has been lost. Parts *E* and *F* each eliminate half of the previous samples, yielding a hexagon and a triangle, respectively. Part *F* yields virtually no information regarding the round, double-pointed, 12-petaled flower.

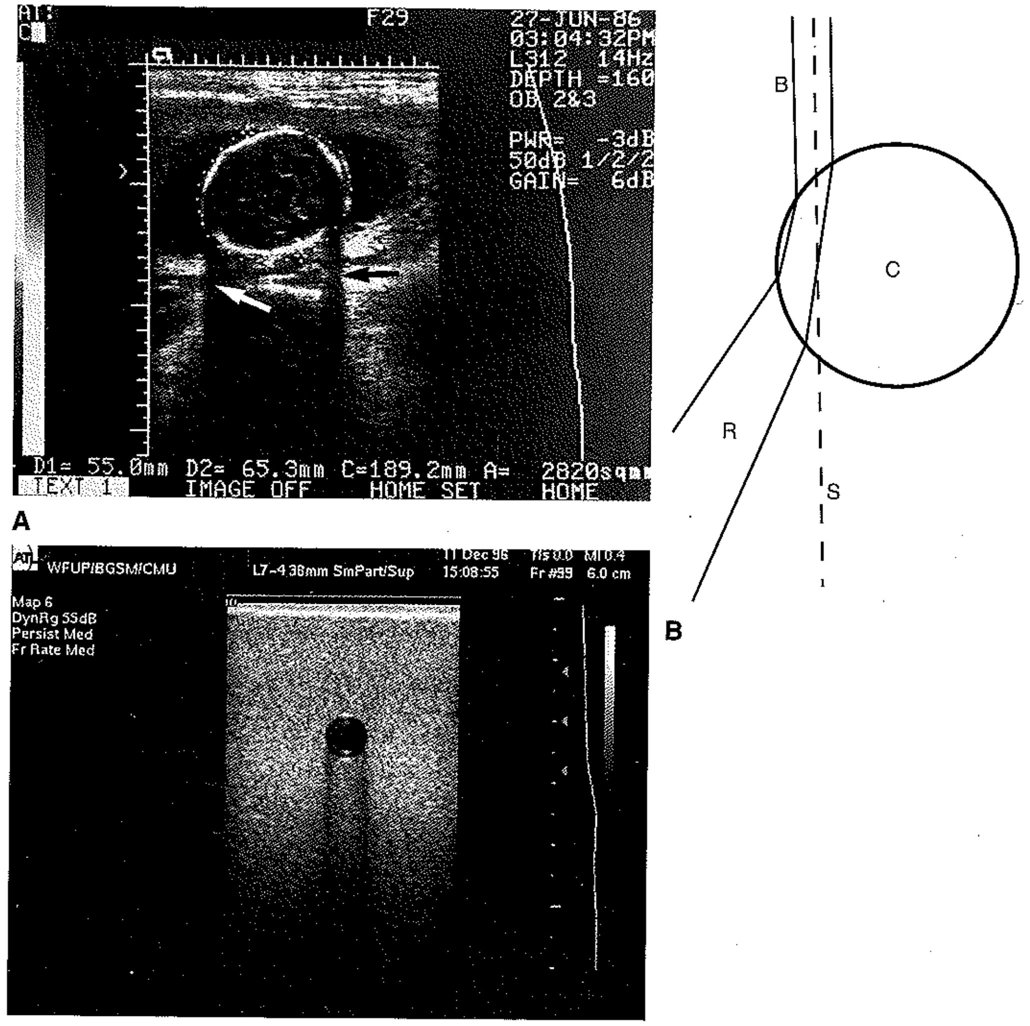
In these examples, we see that inadequate spatial sampling yields an incorrect representation of the object sampled. This is similar to a disguise (false appearance or assumed identity) or alias. As the sampling was reduced, we first lost the double-pointed character of each petal, then the presence of the 12 petals, and finally



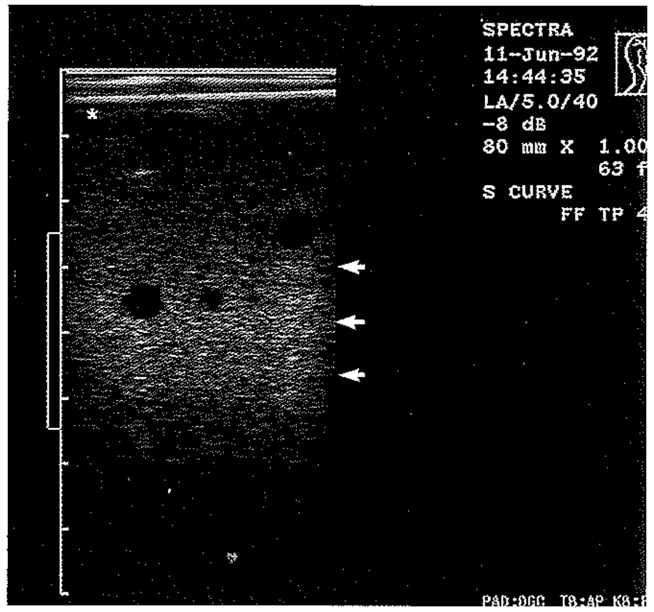
■ **FIGURE 8-18** **A,** Shadowing *(S)* from a high-attenuation calcified plaque in the common carotid artery. **B,** Shadowing *(straight arrow)* from a fetal limb bone and enhancement *(curved arrow)* caused by the low attenuation of amniotic fluid *(A)* through which the ultrasound travels. **C** to **F,** Examples of shadowing *(arrows).*



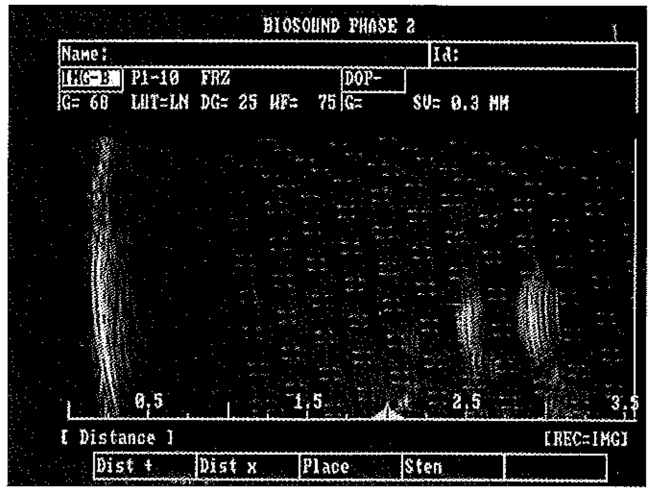
■ **FIGURE 8-19** **A,** Shadowing *(S)* from a gallstone and enhancement *(E)* caused by the low attenuation of bile *(B).* **B,** Enhancement *(arrow)* from the low attenuation of blood in the common carotid artery *(CCA)* and jugular vein in transverse view. **C,** Enhancement beyond a cervical cyst. **D** to **F,** Examples of enhancement *(arrows).*



■ **FIGURE 8-20** **A,** Edge shadows *(arrows)* from a fetal skull. **B,** As a sound beam *(B)* enters a circular region *(C)* of higher propagation speed, it is refracted, and refraction occurs again as it leaves. This causes spreading of the beam with decreased intensity. The echoes from region *R* are presented deep to the circular region in the neighborhood of the dashed line. Because of beam spreading, these echoes are weak and thus cast a shadow *(S)*. **C,** Edge shadows from a tube (shown in transverse view) are embedded in tissue-equivalent material in a flow phantom.



■ **FIGURE 8-21** Focal banding *(arrows)* is the brightening of echoes around the focus, where intensity is increased by the narrowing of the beam.



■ **FIGURE 8-22** Interference *(repeating white specks)* from nearby electronic equipment.

Aliasing is the appearance of Doppler spectral information on the wrong side of the baseline.

the circular nature of the flower. In each case, we were experiencing spatial aliasing. Another example of spatial aliasing is given in Figure 8-24.

An optical form of temporal aliasing occurs in motion pictures when wagon wheels appear to rotate at various speeds and in reverse direction. Similar behavior is observed when a fan is lighted with a strobe light. Depending on the flashing rate of the strobe light, the fan may appear stationary or rotating clockwise or counterclockwise at various speeds.

Nyquist Limit

Pulsed wave Doppler instruments are sampling instruments. Each emitted pulse yields a sample of the desired Doppler shift. The upper limit to Doppler shift that can be detected properly by pulsed instruments is called the **Nyquist limit** (NL). If the Doppler-shift frequency exceeds one half the PRF (which, for Doppler functions, is normally in the 5- to 30-kHz range), temporal aliasing occurs.

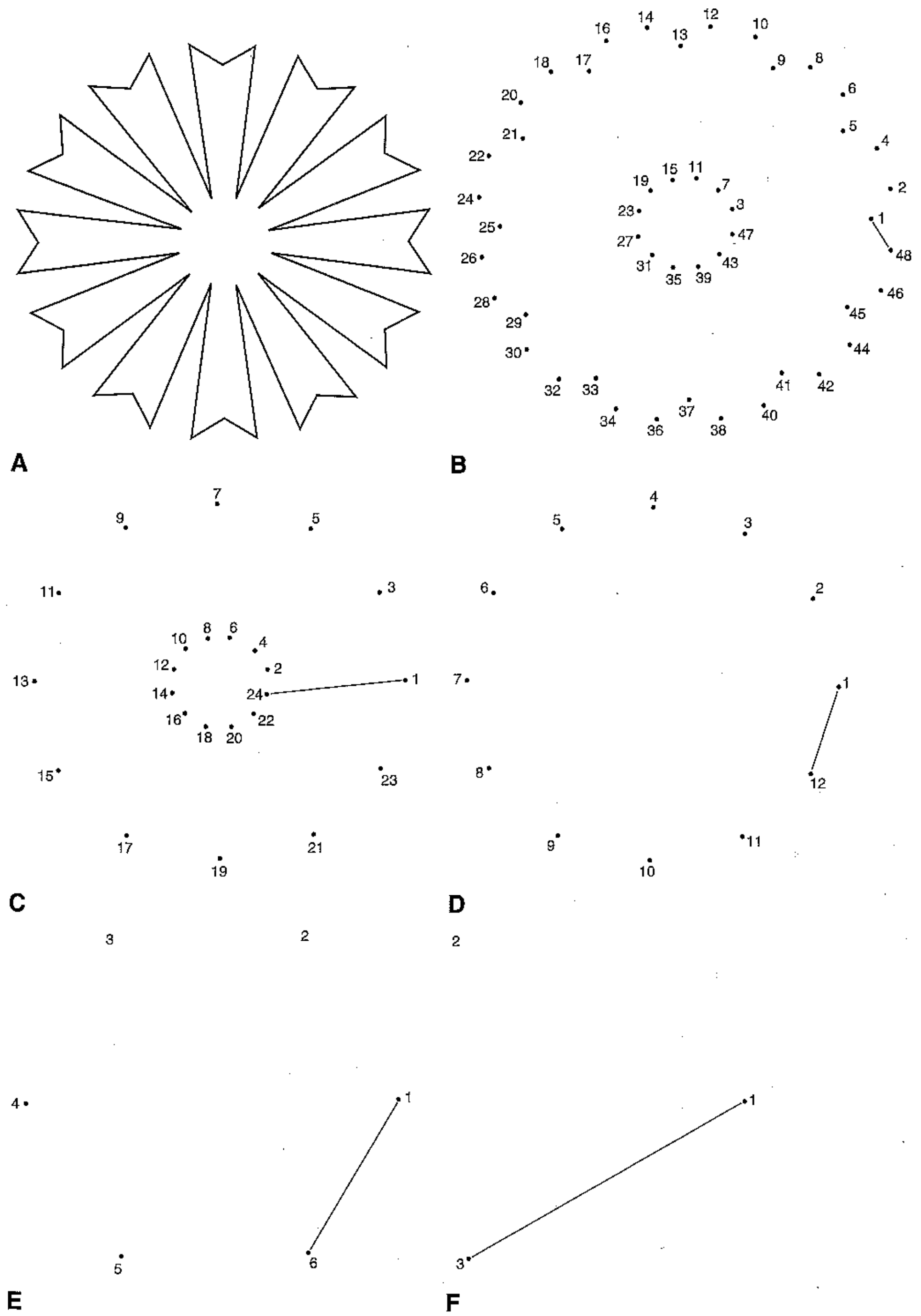
$$\text{NL (kHz)} = \tfrac{1}{2} \times \text{PRF (kHz)}$$

Improper Doppler shift information (improper direction and improper value) results. Higher PRFs (Table 8-1) permit higher Doppler shifts to be detected but also increase the chance of the range-ambiguity artifact occurring. Continuous wave Doppler instruments do not experience aliasing. However, recall that neither do they provide depth localization.

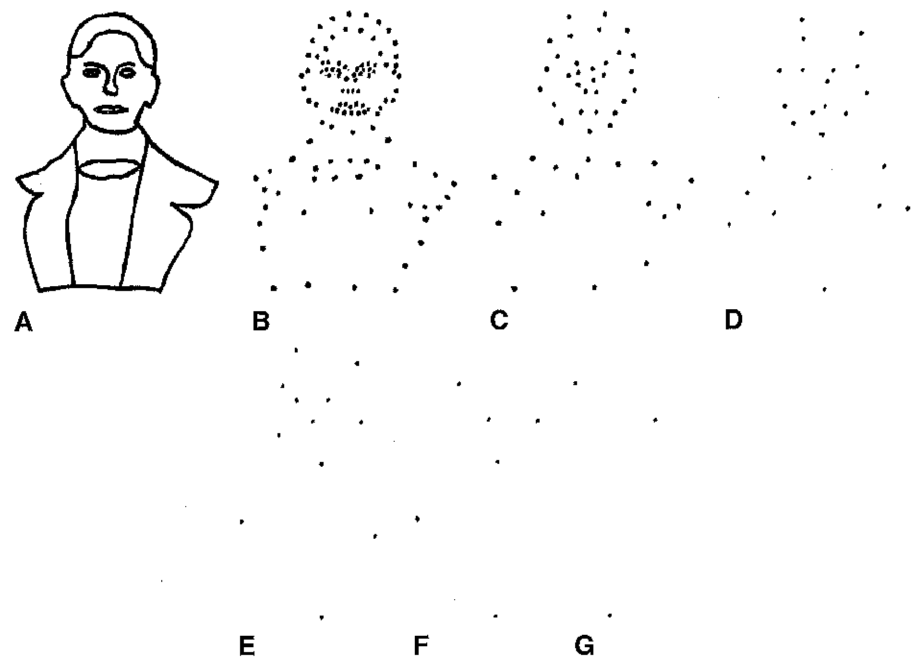
Figure 8-25 illustrates aliasing in the popliteal artery and in the heart of a normal subject. This figure also illustrates how aliasing can be reduced or eliminated (Box 8-2) by increasing PRF, increasing Doppler angle (which decreases the Doppler shift for a given flow), or by **baseline shift.** The latter is an electronic cut-and-paste technique that moves the misplaced aliasing peaks over to their proper location. The technique is successful as long as there are no legitimate Doppler shifts in the region of the aliasing. If there are legitimate Doppler shifts, they will get moved over to an inappropriate location along with the aliasing peaks. (This would happen if the baseline were shifted farther down in Figure 8-25, *E.*) Baseline shifting is not helpful if the desired information (e.g., peak systolic Doppler shift) is buried in another portion of the spectral display, as in Figure 8-25, *F.* Other approaches to eliminating aliasing include changing to a lower-frequency Doppler transducer (Figure 8-25, *G* and *H*) or switching to continuous wave operation. The common and convenient solutions to aliasing are shifting the baseline, increasing PRF, or doing both in extreme cases.

Aliasing is caused by undersampling of the Doppler shifts.

In Figure 8-25, *A,* we can see that aliasing occurs at Doppler shifts greater than 1.75 kHz. The aliased peaks



■ **FIGURE 8-23** **A,** A "Doppler flower." **B,** Forty-eight samples. **C,** Twenty-four samples. **D,** Twelve samples. **E,** Six samples. **F** Three samples. (From Kremkau FW: *J Vasc Technol* 14:41-42, 1990.)



■ **FIGURE 8-24** **A,** A freehand drawing of Christian Doppler. As sampling progressively decreases from 96 samples **(B)** to 48 samples **(C),** 24 samples **(D),** 12 samples **(E),** 6 samples **(F),** and 3 samples **(G),** connecting the dots, especially in the latter three cases, yields an image that bears no resemblance to **A.** Indeed, in **G** a triangle would result. These cases are undersampled, resulting in an "aliased" image.

TABLE 8-1 Aliasing and Range-Ambiguity Artifact Values

Pulse Repetition Frequency (kHz)	Doppler Shift Above Which Aliasing Occurs (kHz)	Range Beyond Which Ambiguity Occurs (cm)
5.0	2.5	15
7.5	3.7	10
10.0	5.0	7
12.5	6.2	6
15.0	7.5	5
17.5	8.7	4
20.0	10.0	3
25.0	12.5	3
30.0	15.0	2

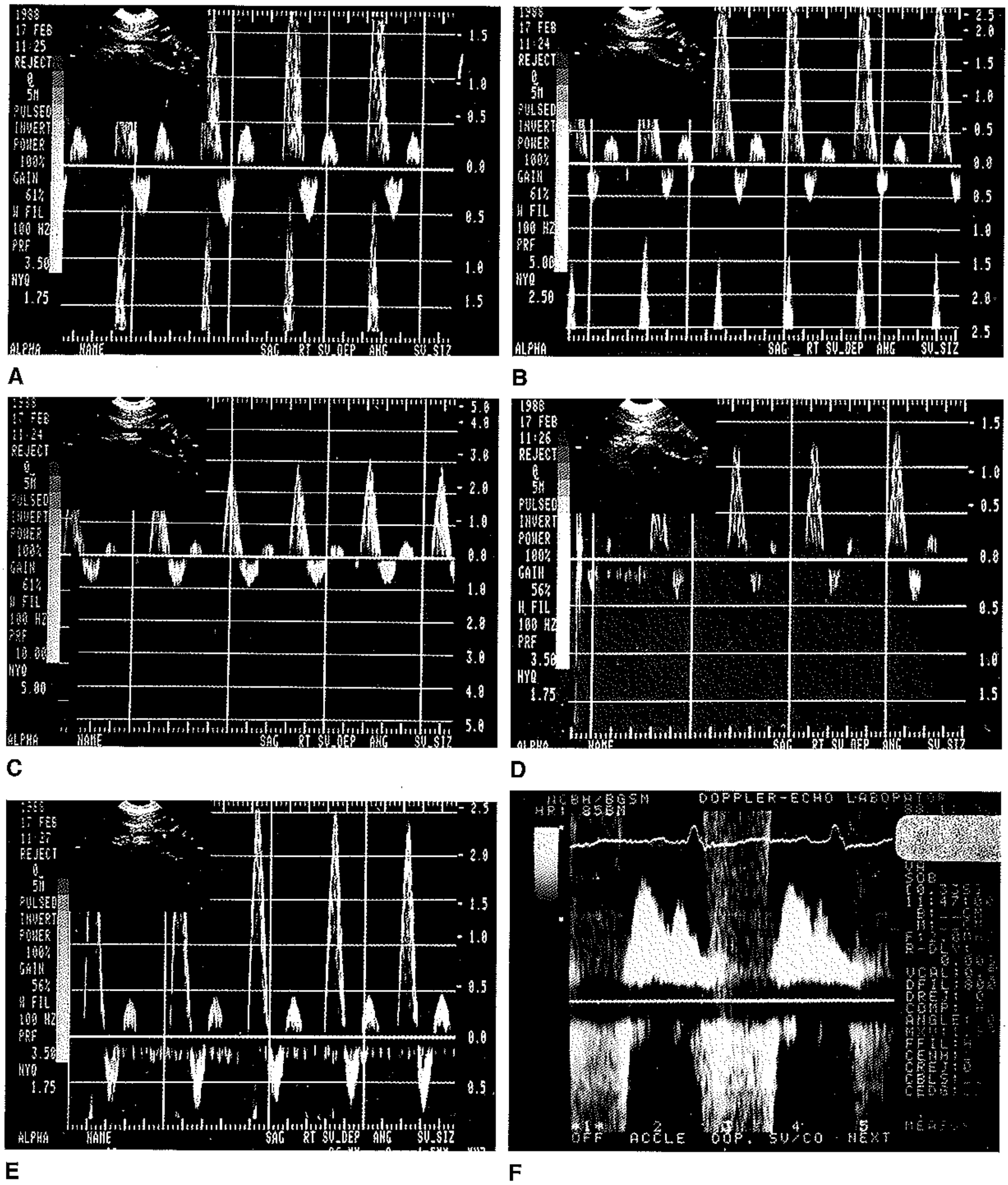
add another 1.25 kHz of Doppler shift, so the correct peak shift is 3.0 kHz. With the higher PRF in Figure 8-25, *C,* this result is confirmed. Thus at the lower PRF, the peak shift can be determined and baseline shifting is not necessary (but is convenient). However, if the peaks were buried in other portions of the Doppler signal (as in Figure 8-25, *F*), baseline shifting would not help, but a higher PRF, a larger Doppler angle, or a lower operating frequency would help.

Aliasing occurs with the pulsed system because it is a sampling system; that is, a pulsed system acquires samples of the desired Doppler shift frequency from which it must be synthesized (see Figure 7-11). If samples are taken often enough, the correct result is achieved. Figure 8-26 shows temporal sampling of a signal. Sufficient sampling yields the correct result. Insufficient sampling yields an incorrect result.

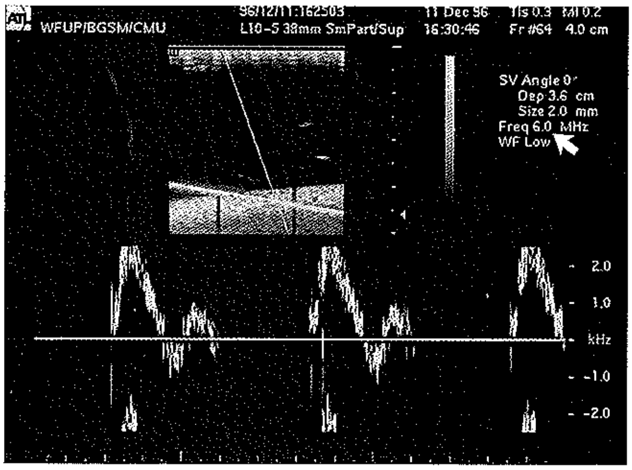
The Nyquist limit, or Nyquist frequency, describes the minimum number of samples required to avoid aliasing. At least two samples per cycle of the desired Doppler shift must be made for the image to be obtained correctly. For a complicated signal, such as a Doppler signal containing many frequencies, the sampling rate must be such that at least two samples occur for each cycle of the highest frequency present. To restate this rule, if the highest Doppler-shift frequency present in a signal exceeds one half the PRF, aliasing will occur (Figure 8-27).

Aliasing is corrected by shifting the baseline, increasing the pulse repetition frequency, or both.

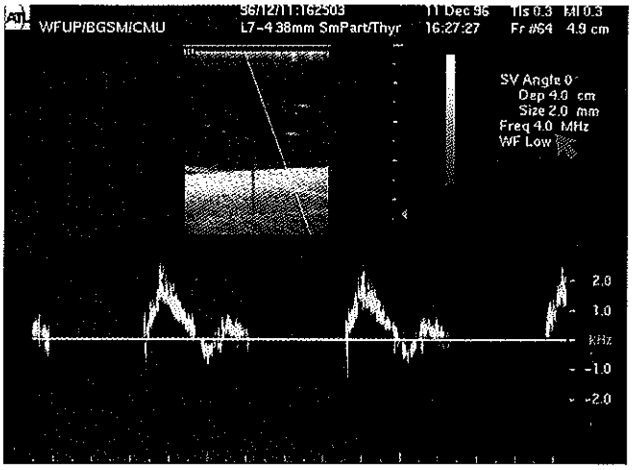
Text continued on p. 288.



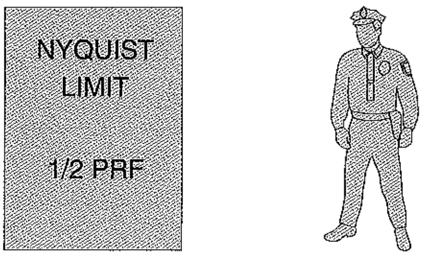
■ **FIGURE 8-25** **A,** Aliasing in the popliteal artery. **B,** Pulse repetition frequency (PRF) is increased. **C,** The PRF is increased further. **D,** Doppler angle is increased with original PRF. **E,** Baseline is shifted down with original PRF. **F,** An example of aliasing in Doppler echocardiography.



G



H



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■ **FIGURE 8-25, cont'd** **G,** Aliasing is occurring with an operating frequency of 6 MHz *(arrow)*. **H,** When operating frequency is reduced to 4 MHz, the Doppler shifts are reduced to less than the Nyquist limit, thereby eliminating the aliasing seen in **G. I,** The Nyquist limit is equal to one half the pulse repetition frequency. (**A** to **E** from Taylor KJW, Holland S: *Radiology* 174:297-307, 1990.)

BOX 8-2 Methods of Reducing or Eliminating Aliasing

1. Increase the pulse repetition frequency.
2. Increase the Doppler angle.
3. Shift the baseline.
4. Use a lower operating frequency.
5. Use a continuous wave device.