PRINCIPLES OF OB-GYN SONOGRAPHY

SONOGRAPHIC IMAGING

Sonography is a term combining the Latin for sound and Greek to write. Thus it is a term meaning writing with sound. In diagnostic medical sonography, short pulses of ultrasound are sent into the body by a device called a transducer (Fig 1).

Figure 1. Sonographic transducers.

Each pulse travels down a straight path, interacting with the biological structures and producing a stream of echoes that is received and displayed as a straight line of dots on the sonographic display. This line of dots is called a scan line. Approximately 100 to 250 scan lines combine to yield a gray-scale presentation of anatomy on the display of a sonographic instrument (Fig. 2).

Figure 2. Sonographic instruments: Cart

Figure 2. Sonographic instruments: Hand-held

Figure 2. Sonographic instruments: Pocket.

An image like that in Figure 3 can be generated in a fraction of a second. Thus, many images (called frames) can be generated per second yielding real-time sonography capable of following motion as it occurs. This motion can be the motion of the tissue (e.g. pulsating vessels walls) or the motion of the moving scan plane as the sonographer manually slides the transducer over the surface of the patient.

Figure 3. Two-dimensional, rectangular image of the fetal neck.

Echo arrival time is used to determine the proper location in depth of each echo on each scan line. Echo strength is indicated by its brightness (gray level).
Sonographic displays are of two types. The rectangular image in Fig. 3 is good for superficial imaging with its wide field of view up close. The pie-slice-shaped, sector image is good for deep imaging, providing a wide field of view deep while requiring a small contact area on the surface (Fig. 4). Several 2D images can be acquired and combined into a 3D volume (Fig. 5). This stored volume can then be presented in multiple ways. Figure 6 gives an example.

Figure 4. Two dimensional, sector-format image of the fetal head.

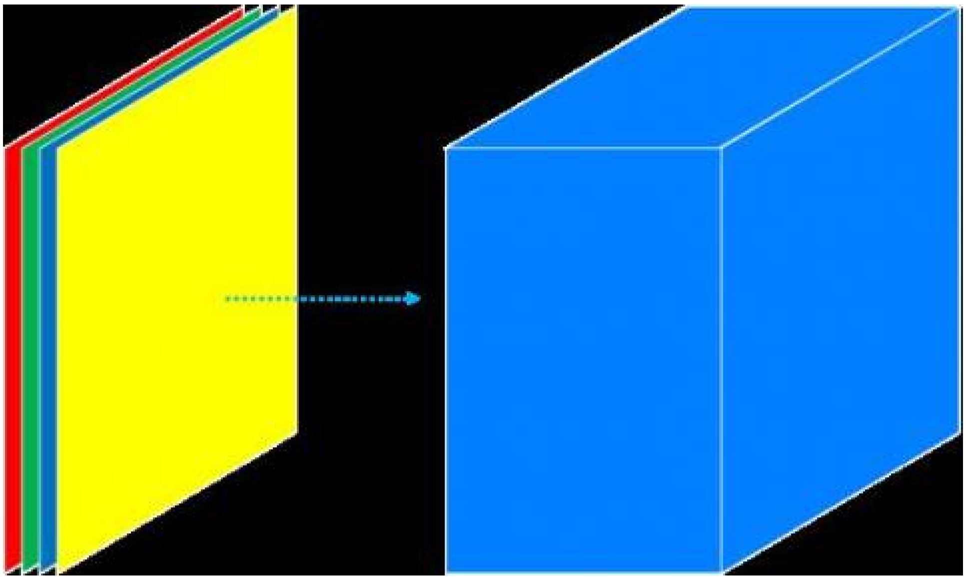
Figure 5. 2D images combining into a 3D volume image.

Figure 6. Fetal volume image.

ULTRASOUND

Sound is a traveling (propagating) pressure variation. The number of complete variations (cycles) per second is called frequency. Frequency determines the pitch of the sound that humans hear.

Sound of frequency higher than detectable with human hearing is called ultrasound (the prefix ultra means “beyond”). The speed of sound travel is determined by the medium through which the sound is traveling, biological tissue in this case. The average speed in tissue is 1.54 mm. This speed yields the round-trip travel-time rule of 13 /cm. This means that if an echo arrives at the transducer 13 after the pulse is emitted, the echo came from an echo-generating object 1-cm in depth from the transducer. Arrival times of 39 ?s, 65 ?s and 130 correspond to depths of 3, 5 and 10 cm, respectively. For 10-cm depth imaging, an image containing 100 scan lines requires 130 × 100 = 13,000 or 13 ms to acquire. Therefore, for those conditions, 1 ÷ (13 × 10-3) = 77 images per second can be generated. This is called the frame rate. Frame rate determines the ability to follow the temporal detail of moving objects which is called

temporal resolution. Frame rate decreases with increasing imaging depth or increasing scan lines per frame and with multiple focuses.

The length and width of the ultrasound pulse determines the detail resolution of the image. Lateral resolution is in the direction perpendicular to the direction of sound travel and across scan lines. Focusing the pulse decreases the pulse width, improves lateral resolution (and detail resolution) and provides the best lateral resolution at the focus. Axial resolution is in the direction of sound travel and the scan lines. Increasing frequency shortens pulses and improves the axial resolution (and detail resolution), but decreases penetration. This is because attenuation (the weakening of sound as it travels) increases with frequency. Therefore, increasing frequency improves detail resolution but degrades penetration. This is an image quality/quantity tradeoff.

TRANSDUCER

The transducer is held on the patient,s skin surface by the hand of the sonographer. It is composed of three primary parts (Fig. 7), elements, matching layers and damping layer. The elements are small rectangular slices of thin ceramic material. They respond to electrical pulses by vibrating, producing the outgoing ultrasound pulses.

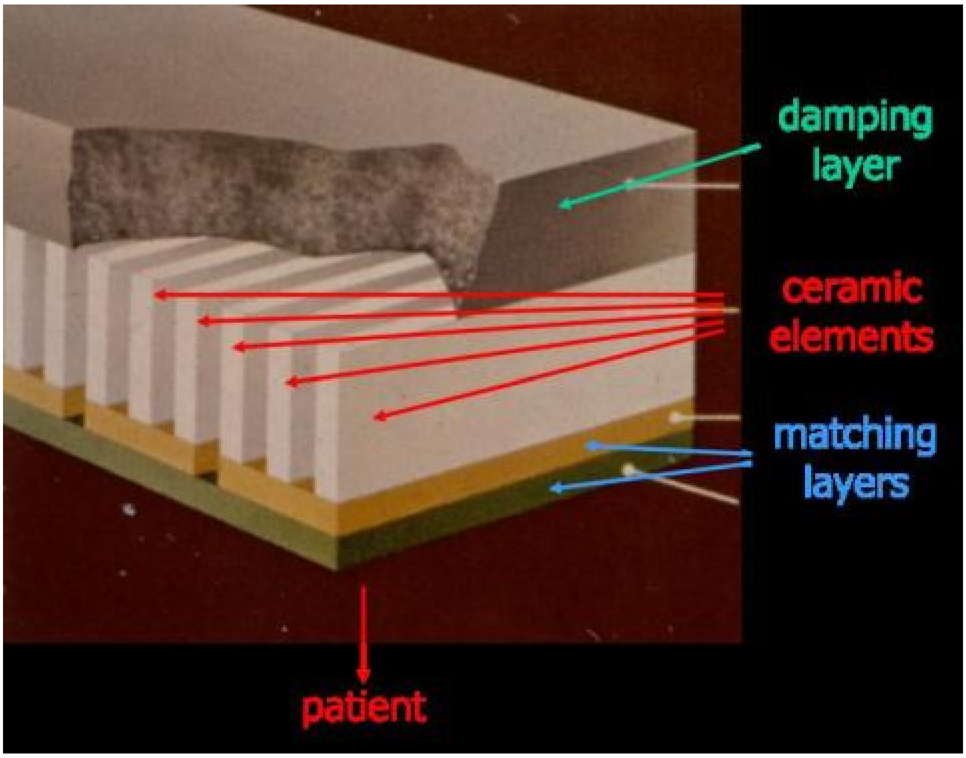

Figure 7. Internal parts of a transducer.

A coupling gel is used to provide good acoustical contact of the transducer with the skin surface. The matching layers, in front of the elements, along with the coupling gel, facilitate the passage of the ultrasound pulses from the elements in the body and the passage of the returning echoes back into the elements. The coupling gel is inserted between the transducer and the patient,s skin. It removes air that would strongly reflect the ultrasound, inhibiting transmission into and out of the body. The returning echoes are converted into electric voltages that represent them in the instrument.

INSTRUMENT

The sonographic instrument is organized into four primary parts (Fig. 8).

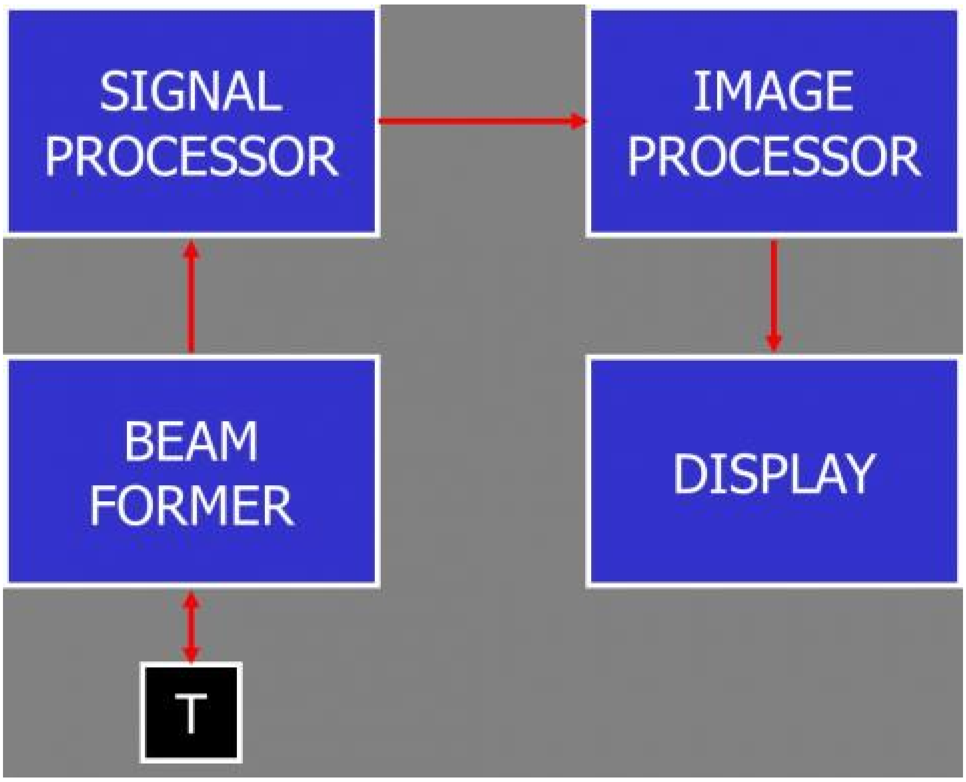

Figure 8. Organization of a sonographic instrument.

The transducer (T) is connected to the beam former. The beam former generates the electric voltage pulses that drive the transducer. The returning echo voltages from the transducer enter the beam former, are amplified and converted to digital form for processing in the signal processor. The signal processor converts the echo voltages to a simpler form and sends them on to the image processor where the scan lines form the image in image memory. Then the image is sent from memory to the flat-panel display for viewing.

DOPPLER ULTRASOUND

In addition to anatomic imaging, ultrasound can provide blood flow information using the Doppler Effect. The Doppler Effect is a change in frequency caused by motion. The motion can be that of a sound source (e.g., a horn or siren on a vehicle sounding higher in pitch as it approaches and shifting to a lower pitch as passes), that of a listener/receiver or that of a reflector (which is a combination of receiver and source). Most applications of the Doppler Effect take advantage of the latter. In the case of diagnostic Doppler ultrasound, pulses of ultrasound that encounter flowing blood produce echoes of a differing frequency from what was transmitted. Returning echoes have a higher or lower frequency depending on whether the blood flow is approaching or receding from the transducer, respectively. The greater the flow speed, the greater the change in frequency. The *difference* between the transmitted and returning frequencies is called the *Doppler shift*.

It is positive for approaching flow and negative for receding flow. For a given flow, the maximum Doppler shift occurs if the sound direction and flow are parallel. The angle between these two directions is called the *Doppler angle* (Fig. 9).

The greater the Doppler angle, the smaller the Doppler shift. Because of this dependence, Doppler angle must be incorporated into Doppler ultrasound. The sonographer estimates the Doppler angle by placing a marker parallel to the assumed flow direction (usually parallel to the vessel walls). The instrument then calculates the flow speed from the Doppler shift and angle.

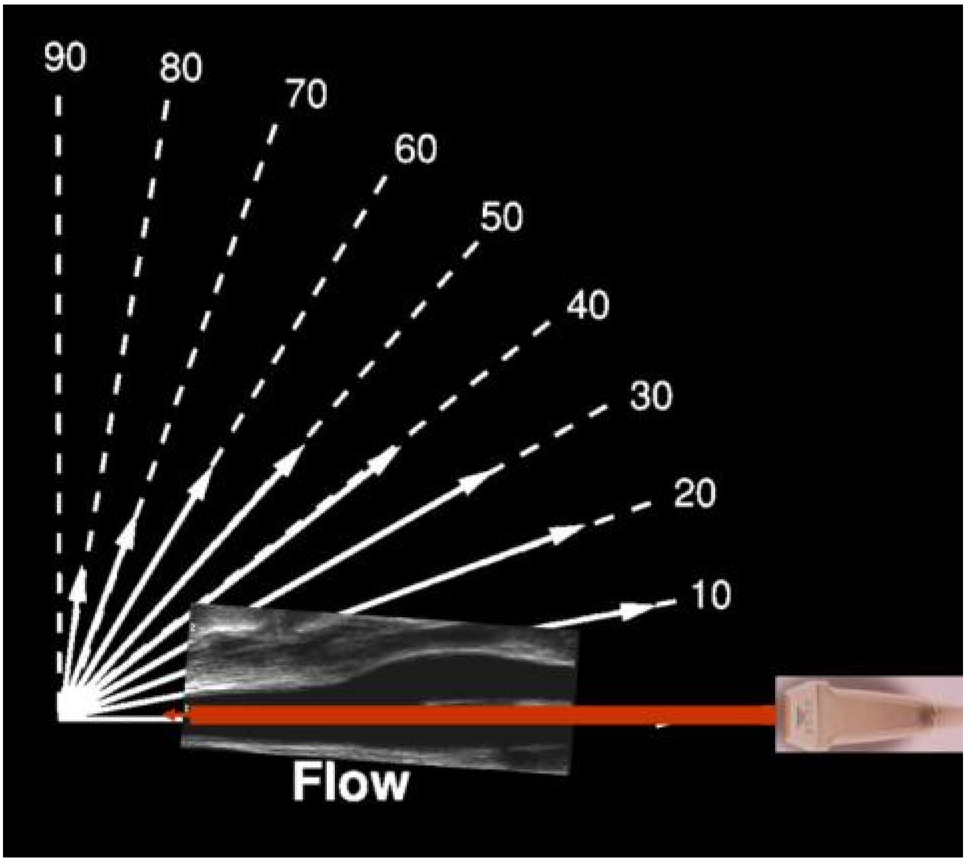

Figure 9. The Doppler angle is the angle between the ultrasound beam (shown in red) and the flow. The beam and flow are parallel here (zero Doppler angle), yielding the maximum Doppler shift. The graph shows that, as Doppler angle increases, Doppler shift decreases, as indicated by the shorter arrows. For example, at 60 degrees, the Doppler shift is half what it is at zero degrees.

Doppler shifts are presented on sonographic instruments three ways:

1. Doppler shifts for physiologic flows are largely audible frequencies, thus are sent to loudspeakers to be observed audibly
2. Anatomic images including Doppler shifts in a global-qualitative form called *color-Doppler or color-flow* (Fig. 10).
3. A *localized-quantitative* form called *spectral-Doppler* presents Doppler shift on the vertical axis (normally converted to calculated flow speed, incorporating Doppler angle) and time on the horizontal axis (Fig. 11). The zero-Doppler shift, horizontal baseline separates positive and negative Doppler shifts on the vertical axis. Positive shift can be place above or below the baseline as an operator choice, with negative appearing on the opposite side.

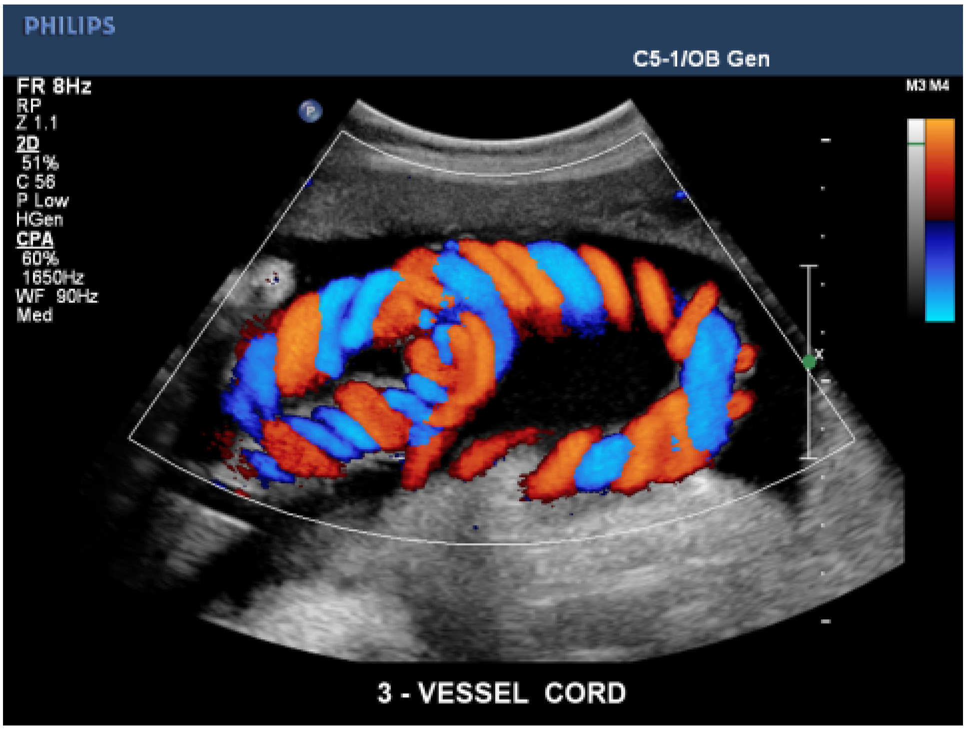

Figure 10. Color Doppler of three-vessel cord.

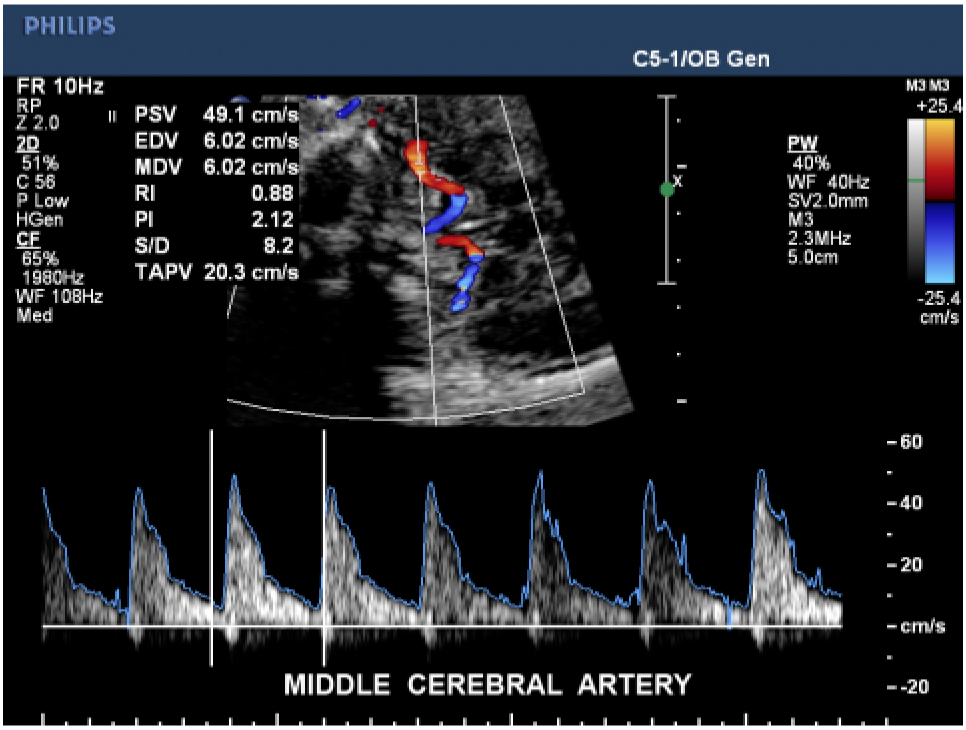

Figure 11. Spectral display of fetal flow in the MCA.

The color-Doppler presentation provides a global view of flow. The spectral display is used to quantitatively evaluate the flow locally. In addition to evaluating flow conditions at the site of measurement, the spectral display can indicate downstream and upstream conditions.

ARTIFACTS

Occasionally one of the assumptions in pulse-echo sonography is violated and the image fails to faithfully represent the anatomy. There are about two dozen ways in which this can occur, yielding what are called artifacts. Only two of the more common examples are treated here.

Figure 12 shows reverberation artifact (curved arrow) with a chorionic villi sampling catheter (straight arrow). The distal reverberation artifacts result from multiple reflections between the transducer and the catheter. Each subsequent round-trip produces an additional presentation of the catheter. The separations between the multiple presentations are equal to the correct distance between the transducer and the catheter.

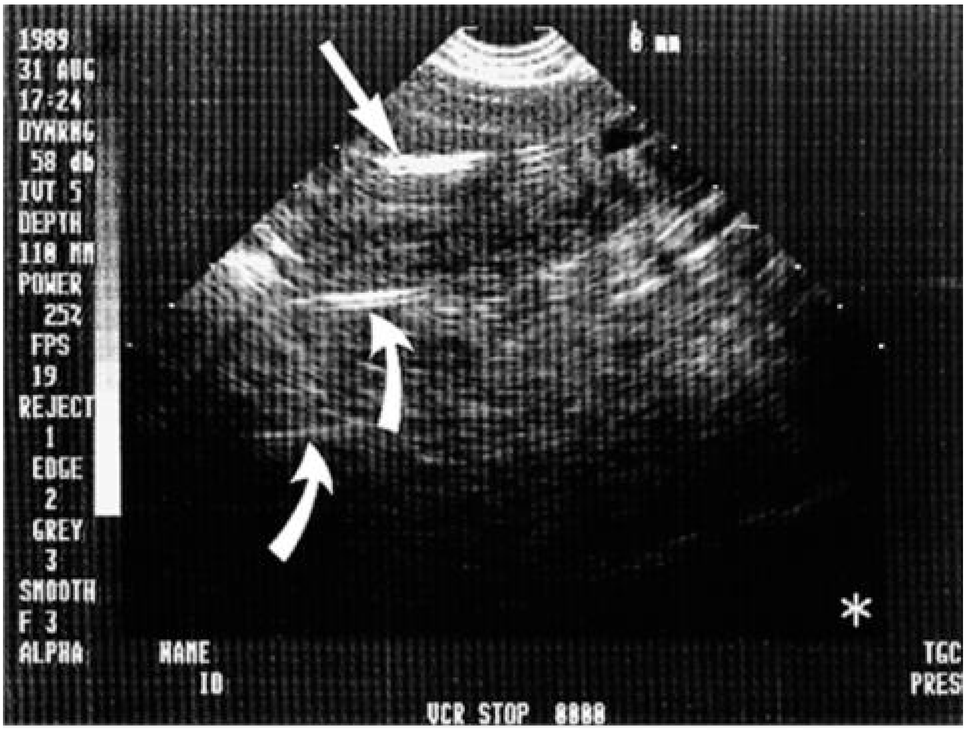

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Figure 12. Reverberation artifact.

Figure 13 illustrates the mirror-image artifact. Here, a fetus is correctly presented in the uterus (red arrows), but an artifactual presentation is shown also (green arrows). This second presentation is caused by the strongly reflecting structure (the mirror – white arrows) between the two presentations. Multiple reflections between the actual fetus and the mirror produce the artifact.

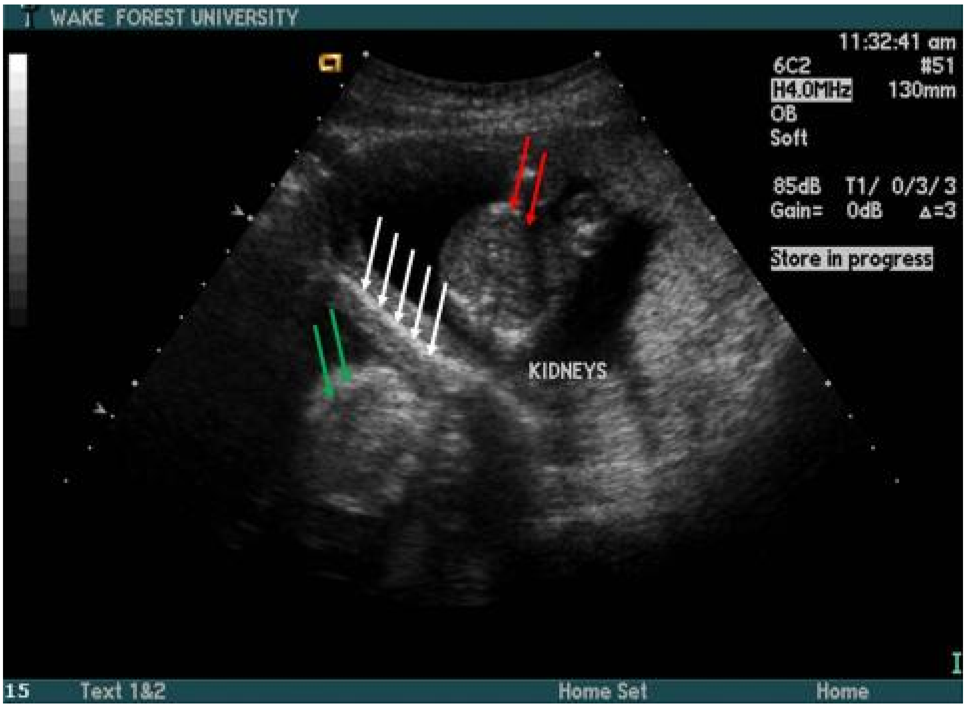

Figure 13. Mirror-image artifact.

Figure 14 shows the shadow artifact. The facial bones strongly attenuate the ultrasound causing the echoes beyond them to be weakened, producing the black area beneath the face.

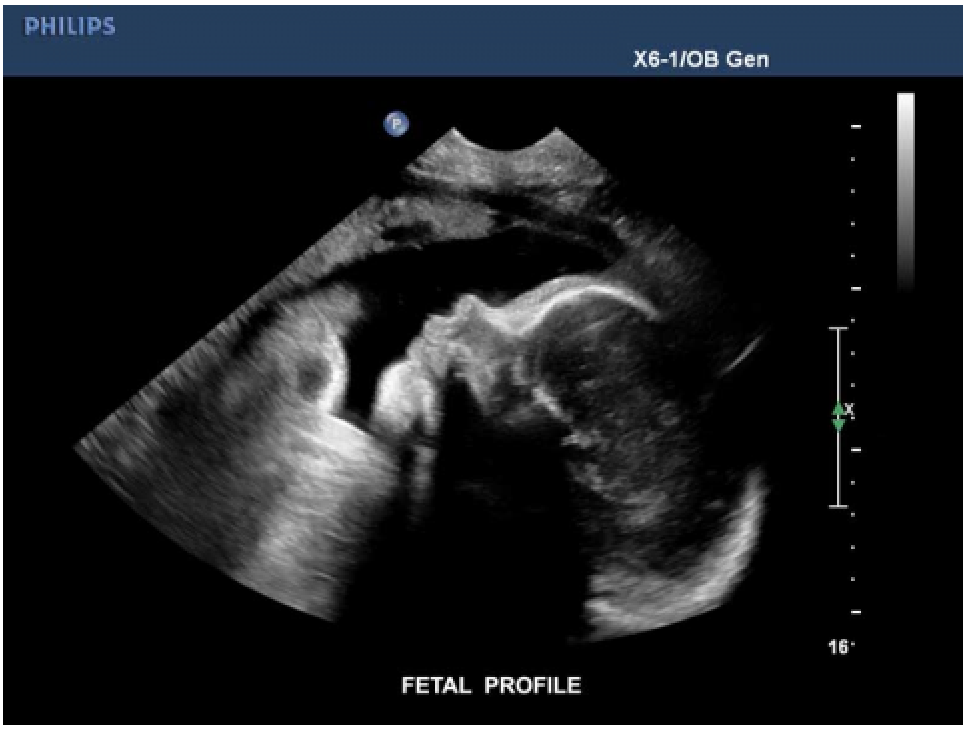

Figure 14. Shadow artifact.

Figure 15 illustrates the opposite of shadowing, namely enhancement. This occurs when the ultrasound passes through a low-attenuation region, producing stronger echoes beyond it. Thus, the brightened region distal to the pelvic cyst which contains low-attenuation fluid.

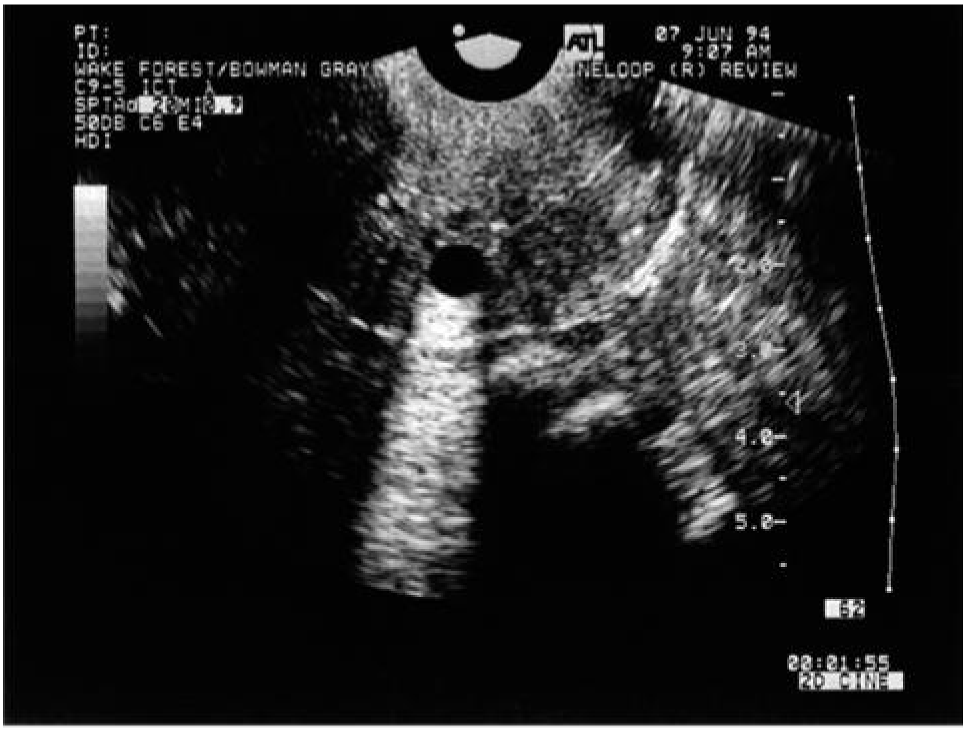

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Figure 15. Enhancement artifact.

Figures are from Reference 1 by permission.

Reference 1. Kremkau, FW: Sonography Principles and Instruments, 8th Edition, Elsevier/Saunders, 2011.