

# An Introduction to Ultrasound Equipment and Knobology

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## KEYWORDS

- Ultrasound • Equipment • Knobology • Probes • Transducers • Doppler • B-mode • M-mode

## KEY POINTS

- The use of ultrasonography in medical practice has evolved dramatically over the last few decades and will continue to improve as technological advances are incorporated into daily medical practice.
- Although ultrasound machine size and equipment have evolved, the basic principles and fundamental functions have remained essentially the same.
- Becoming familiar with the machine and the controls used for image generation optimizes the scans being performed and enhances the use of ultrasound in patient care.

## INTRODUCTION

The use of ultrasonography in medical practice has evolved dramatically over the last few decades and will continue to improve as technological advances are incorporated into daily medical practice. Although ultrasound (US) machine size and equipment have changed over time, the basic principles and fundamental functions have remained essentially the same. This article reviews the general US apparatus design, the most common probe types available, and the system controls used to manipulate the images obtained. A detailed discussion of the physics involved in medical ultrasonography is presented elsewhere in this issue of *Critical Care Clinics*.

## US MACHINES

The fundamental principle of ultrasonography can be traced to approximately 200 years ago when Lazzaro Spallanzani, an Italian biologist, theorized that bats used echolocation to hunt in the dark.<sup>1</sup> During the late 1800s, the concept of sound

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was expressed mathematically by the English physicist Lord Raleigh.<sup>2</sup> In 1880, the piezoelectric effect of crystals was first described by Pierre and Jacques Curie.<sup>3</sup> These principles in physics were initially incorporated into industrial applications (eg, identifying structural metal flaws) and eventually were applied in medical practice.<sup>1</sup> The first known published medical US application was in 1942 by the Viennese brothers, Karl and Friederich Dussik.<sup>1</sup> It was not until 1963 that the first real-time commercial US machine became available by Vidison Siemens, Corp.

Almost 50 years after the first bulky US machine made its debut, compact and portable US machines started making their way into standard bedside use. Many of the popular US machines being used in patient care areas are no larger than small laptop computers. As technology continues to evolve at a dramatic pace, there are US machines being developed that are comparable with the size of an average cellular phone (Figs. 1 and 2).<sup>4-6</sup> Furthermore, there are applications for actual smart phones that connect to a scanning probe enabling the operator to perform ultrasonography without an actual US machine (Fig. 3).

The discussion here is limited to the compact, laptop size US machines used most frequently for point-of-care (POC) scans in the acute care setting. There are a variety of US machine brands (Figs. 4-6) available for POC US at the bedside. All of the machines include a user interface with a keyboard and, depending on the brand, a variety of knobs, buttons, track ball, or touch screen for manipulation and storage of the images. Deciding which US machine to purchase for POC scans depends not only on the price of the machine, but also its durability, the life span of the battery, need for AC energy, boot-up time, portability, and previous experience with a particular US machine brand.

Most of the US machines for POC use are attached to a cart that not only provides a base for the machine itself, but also facilitates portability to different areas of the department and hospital. These carts also have the space to store different probes, cables for AC connection, sterile probe covers, bottles of gel, and other supplies that can be used as needed during the scans (Fig. 7).

A secondary viewing screen can be attached to the cart, above the main US screen. This secondary screen can be used for patient viewing or for bedside teaching (Fig. 8).

## US PROBES

Although there are many US transducers designed for specific uses in medical practice, most of POC ultrasonography can be accomplished using one of four basic types of probes: (1) curvilinear, (2) linear, (3) sector/phased, and (4) intracavity (Figs. 9-12).



**Fig. 1.** Portable handheld ultrasound machine Acuson P-10. (Courtesy of Siemens Healthcare Copyright 2013; with permission.)



**Fig. 2.** Vscan handheld ultrasound. (Courtesy of General Electric Healthcare; with permission.)



**Fig. 3.** Ultrasound probe compatible with a smart phone. (Courtesy of Mobil US; with permission.)



**Fig. 4.** SonoSite bedside ultrasound machine. (Courtesy of FUJIFILM Sonosite Inc; with permission.)



**Fig. 5.** General Electric bedside ultrasound machine.



**Fig. 6.** Zonare bedside ultrasound machine. (Courtesy of Zonare Medical Systems Inc; with permission.)



**Fig. 7.** Universal stand for portable ultrasound machines. (Courtesy of FUJIFILM Sonosite Inc; with permission.)



**Fig. 8.** Ultrasound machine with teaching or secondary viewing screen mounted on the portable stand.

The basic US transducer is composed of the head, the wire, and the connector. In most machines, the transducer is interchangeable by detaching it completely from the US machine base. Many POC US machines can be fitted with a transducer connector that allows practitioners to select the appropriate probe for a study by simply pressing



**Fig. 9.** Low-frequency curvilinear transducer.



**Fig. 10.** High-frequency linear array transducer.

a button or touching the probe icon on a screen. These transducer connectors enable rapid interchangeability between probes without having to detach them individually from the US machine (**Fig. 13**).

Technology is advancing rapidly and, by the end of 2012, Siemens Corporation unveiled the first wireless US probe. Having a cordless US probe is beneficial in preventing cord entanglement and potentially allowing for more mobility and range of movement during a bedside scan. The disadvantages include risk of misplacing or losing the cordless probe, and interface malfunctions between the signal from the probe and the US machine.



**Fig. 11.** Low-frequency phased array transducer.



**Fig. 12.** Higher-frequency intracavitary transducer.

When discussing the general US equipment that is used for POC scans, it is important to know the standard names given to the various parts of the machine and probes.<sup>7,8</sup> The tip of the probe head is referred to as the footprint. The footprint is the part of the probe that is in direct contact with the patient through an acoustic



**Fig. 13.** Triple transducer connector (TTC) on a SonoSite bedside ultrasound machine. (Courtesy of FUJIFILM Sonosite Inc; with permission.)

window (eg, US gel). Larger footprints provide a more expansive scanning area. Smaller footprints are preferred for examinations that require maneuvering of the probe in smaller anatomic regions (eg, intercostal spaces in pediatric patients, fontanelles, cardiac examinations, and so forth). The type of scan being performed and individual patient characteristics determine which footprint is best suited for image acquisition.

Piezoelectric crystals are located at the footprint of the probe and, except for the sector probe, they are arranged according to the shape of the probe tip. The footprint is a transmitter and receiver of the US beam during scanning. Most modern probes use synthetic plumbium zirconium titanate, compared with quartz crystals that were used in earlier units. These plumbium zirconium titanate crystals are integral in the image quality obtained during the scan, and can be damaged or misaligned when probes are dropped, crushed, or thrown against other objects.

Every US probe should have a probe marker along one side of the head of the probe. This marker can be a colored light, dot, or a linear ridge that can be easily palpated while handling the probe (**Fig. 14**). This marker becomes important for orientation of the patient's anatomy in relationship to the marker displayed on the US machine screen (**Fig. 15**). In standard practice, this orientation marker should be pointed toward either the patient's right side or the patient's head during the scan. The exceptions to this rule occur during scans of a patient's internal jugular vein during a central venous access cannulation, and during some of the cardiac views (discussed elsewhere in this issue).

The fundamental principle of tissue penetration of the ultrasonic beam, expressed in megahertz, determines the type of transducer that should be used. Higher-frequency probes provide less penetration of the US waves through the tissue planes, but generate higher-resolution images. High-frequency probes should be used to visualize superficial structures, such as tendons, muscle, pulmonary pleura, vasculature, and so forth. Conversely, probes with a lower spectrum of frequency should be used to visualize deeper structures. The ability to visualize deeper structures comes at the expense of resolution. Lower-frequency probes are useful in evaluating the abdominal aorta, the gallbladder, the inferior vena cava (IVC), pelvic organs, and so forth.



**Fig. 14.** Indicator marker on the side of the ultrasound probe.

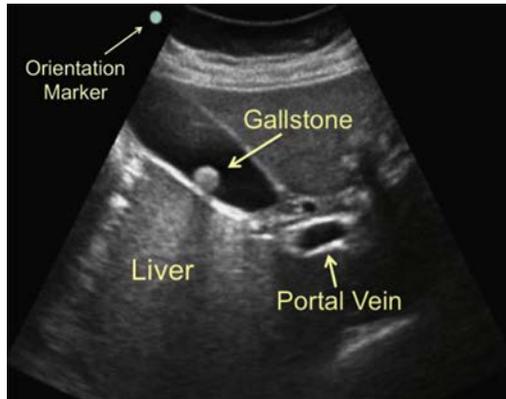


Fig. 15. Orientation marker on the left side of the ultrasound image.

The curvilinear or convex array probe (Fig. 16) has a frequency range of 2 to 5 MHz. It provides a wide, fan-shaped scanning area on the US screen. This type of transducer is mostly used for evaluating deep structures in the abdomen and pelvis. Common clinical scenarios for this type of probe are patients with abdominal pain to evaluate for abdominal aortic aneurysm or gallbladder pathology, abdominal pain in pregnancy,<sup>9</sup> or the focused assessment with sonography in trauma (FAST examination).<sup>10</sup>

The intracavitary probe also has a curvilinear crystal array with a wide view. However, the frequency is much higher (8–13 MHz) than other curved probes. Because of the higher frequency, the resolution of the images is better. Examples of applications with this probe are oral pathology (eg, peritonsillar abscess)<sup>11</sup> and transvaginal pelvic evaluations (eg, ovarian torsion, pregnancy, and so forth) (Fig. 17).

The linear transducer has a rectangular footprint shape with a frequency range of 6 to 15 MHz (Fig. 18). This probe provides detailed anatomic resolution and is ideal for evaluating superficial structures. A wide variety of pathology can be seen at the bedside with this type of probe, such as deep venous thrombosis,<sup>12</sup> musculoskeletal trauma,<sup>13</sup> subcutaneous foreign bodies and abscesses,<sup>14</sup> testicular torsion,<sup>15</sup> pneumothorax,<sup>16</sup> and ocular pathology.<sup>17,18</sup> The linear array probe can also be used to guide such procedures as venous access (central and peripheral);<sup>19</sup> arthrocentesis; needle aspirations; and lumbar punctures.<sup>20</sup>

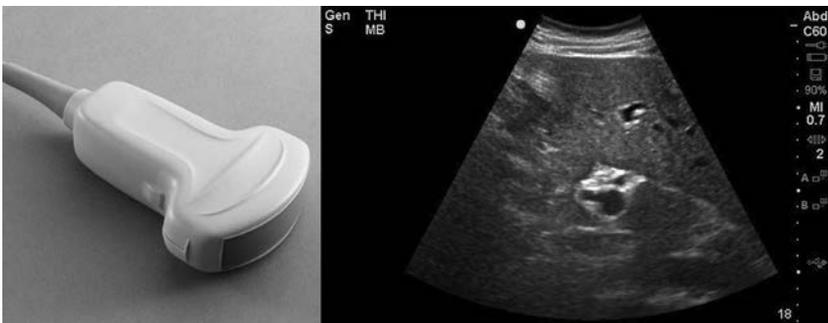


Fig. 16. Curvilinear probe and corresponding ultrasound image.



Fig. 17. Intracavitary probe and corresponding ultrasound image.

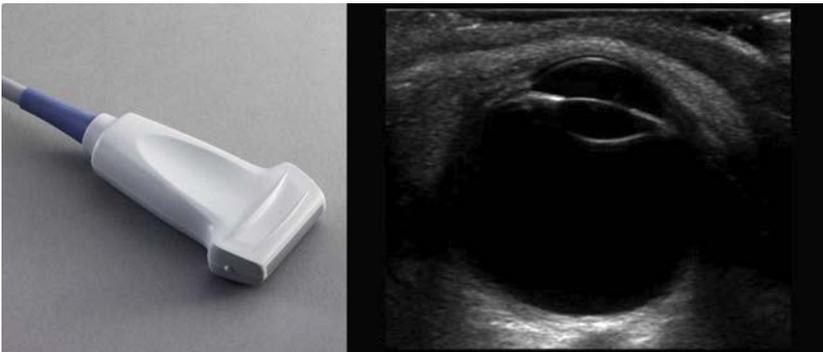


Fig. 18. Linear array transducer and corresponding ultrasound image.

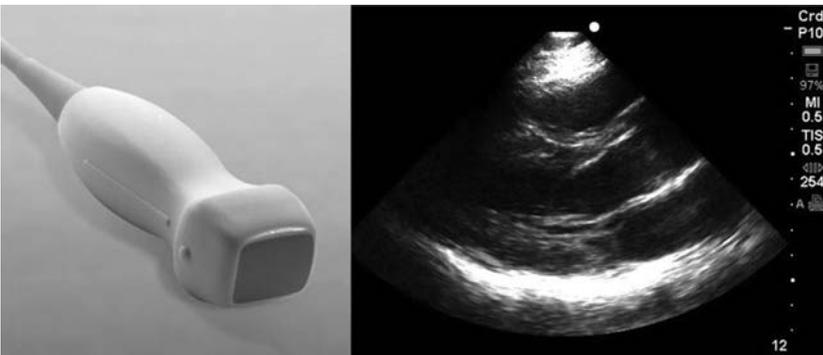


Fig. 19. Phased array transducer and corresponding ultrasound image.

<b>Probe Type</b>	<b>Frequency (MHz)</b>	<b>Applications</b>
Curvilinear	2–5	FAST, renal, aorta, IVC, pelvic, bladder, bowel, appendicitis
Linear	6–15	Ocular, trachea, thyroid, thoracic, vascular access, DVT, MSK, soft tissue, appendicitis
Intracavitary	8–13	Peritonsillar abscess, pelvic
Phased array/sector	1–5	Cardiac, abdominal, renal, pediatric abdomen, bladder, bowel, IVC

*Abbreviations:* DVT, deep venous thrombosis; FAST, focused assessment with sonography in trauma; IVC, inferior vena cava; MSK, musculoskeletal.

The phased or sector array transducer has a frequency range of 1 to 5 MHz. The crystal arrangement in the footprint is bundled in the center and fans out creating a pie-like image on the US machine screen (Fig. 19). Because of the smaller footprint, this probe is commonly used for echocardiography and is particularly useful in the evaluation of pediatric patients.<sup>21,22</sup> The phased array probe can also be used for the FAST examination in patients with tight intercostal spaces. The most commonly used US probes and beside US applications are summarized in Table 1.

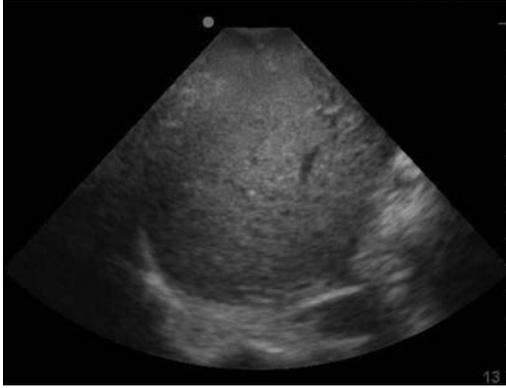
Some US machines allow the user to change the broadband frequency used during the scan. For example, when using a multifrequency transducer, it is useful to be able to scan at the lower or higher ends of the probe frequency. On the US machine, there may be image optimization controls that allow the user to increase penetration (scan at a lower frequency); increase resolution (scan at a higher frequency); or scan in general settings (between the highest and lowest frequency available).

## IMAGE PRODUCTION AND SYSTEM CONTROLS

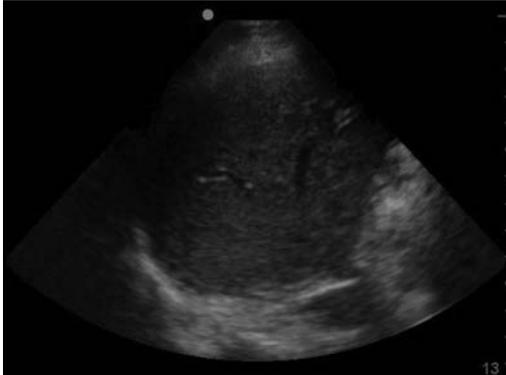
To produce US images for evaluation, the machine and probes work in concert to transmit, receive, and depict sound waves. The US machine receives the beam signal as amplitude, frequency, and the changes of the frequency over time. The two-dimensional gray scale of the image is generated from the amplitude of the echoes. The change of the frequency and wavelength of the US echoes from a target in motion is known as the Doppler effect. Further information about the physics of bedside US can be found in elsewhere in this issue.

Before beginning a scan, it is important to set up the US machine for the type of scan being performed. Most modern-day US machines have standard presets for common applications (eg, abdomen, obstetrics, vascular, musculoskeletal). These presets can be selected by a menu available on the US machine, and are often programmable based on the user's preferences.

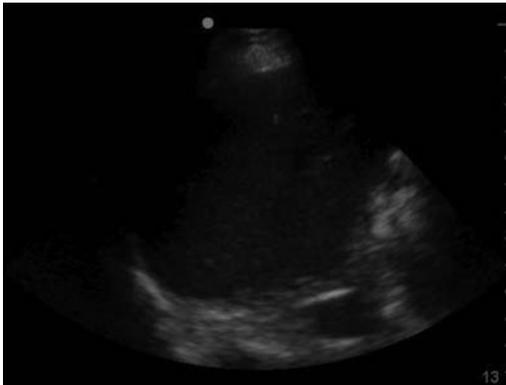
During the scan, real-time images of the tissue anatomy and motion can be obtained in B-mode scanning, M-mode scanning, and with Doppler. B-mode, otherwise known as “brightness” mode, displays a two-dimensional, gray scale image on the screen. The gray scale of the image can be manipulated by adjusting the gain (Figs. 20–22). By increasing the gain, the US machine allows processing of more incoming echoes, thereby creating a brighter image. A darker image is obtained when the gain is decreased (see Fig. 22). Gain can be adjusted in the nearfield, farfield, or overall field of the screen display. Increasing the gain leads to a brighter image on the screen, but it also increases image noise and artifact, with loss of contrast and finer details.



**Fig. 20.** Evaluation of the liver with increased gain.



**Fig. 21.** Evaluation of the liver with normal gain.



**Fig. 22.** Evaluation of the liver with decreased gain.

As the US beam travels deeper into a medium, the returning echoes are attenuated, resulting in less resolution. A feature known as time gain compensation allows the sonographer to adjust the image brightness at specific depths. The top row of buttons controls nearfield gain, whereas the bottom row of buttons controls farfield gain (Fig. 23). Advanced US machines may also have an “auto gain” button, which resets the machine back to standard gain presets for the type of scan being performed.

Most US machines allow the user to freeze and save still images and to capture video clips (Fig. 24). Having the ability to freeze an image on the US screen becomes important when measurements are being obtained, or fine details of a scan are being examined. These still images can be saved or printed for further review and archiving.

The ability to obtain video clips is another useful function of modern day US machines. Video clips are most often used in documenting cardiac wall motion; in monitoring needle trajectory during US-guided procedures; and evaluating dynamic movement of organs during scans, such as the E-FAST examination. The length of the video clips can be manually adjusted using standard control buttons and options on the machine. The format of the video clips differs depending on the manufacturer presets (eg, .mov, .mp4).

The still images or video clips can be stored on the US machine hard drive or transferred to a remote hard drive or system using various transfer methods. Most machines allow for the transfer of data by USB ports, FireWire, expansion cards, Ethernet ports, or wireless portals. Newer US machines are equipped to transmit images for review and storage on systems with digital imaging and communication in medicine (DICOM) capabilities.

In addition to B-mode capabilities, most machines also allow scanning in M-mode (“motion” mode). M-mode obtains an image in the B-mode and displays it graphically as changes over a period of time. Useful applications for this modality include assessment of the IVC for intravascular volume, estimating wall movement and cardiac contractility, and the evaluation of a pneumothorax (Fig. 25).

The use of the Doppler principle in POC ultrasonography includes color Doppler, pulse wave Doppler, and color power Doppler. Color Doppler detects the overall blood



Fig. 23. Time gain compensation (TGC) control.

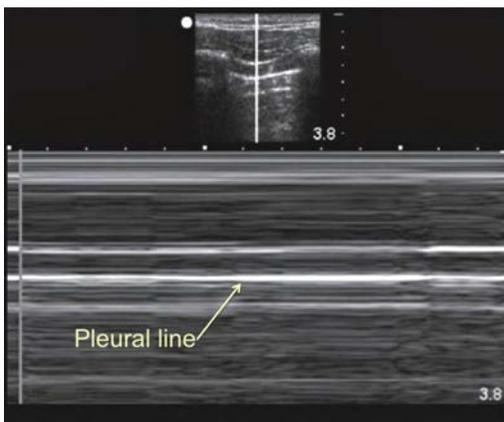


**Fig. 24.** Freeze, save, and video clip buttons on an ultrasound machine.

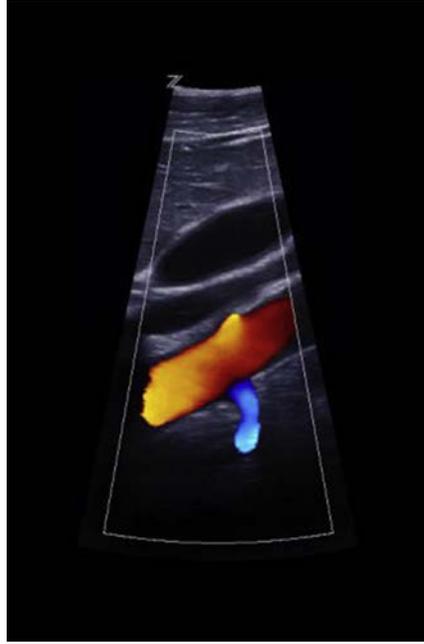
flow and its direction of flow under a region of interrogation (eg, identification of vessels close to an abscess before incision, or turbulent flow in an abdominal aortic aneurysm) (Fig. 26). The energy of the returning echoes is displayed as an assigned color on the US screen. By convention, echoes demonstrating flow toward the transducer are seen in shades of red. Those representing flow away from the transducer are seen as shades of blue. The color display is usually superimposed on the B-mode image, thus allowing simultaneous visualization of anatomy and flow dynamics.

In pulse wave Doppler, the direction and velocity of the blood flow can be displayed graphically and audibly (Fig. 27). If blood is moving away from the transducer, a lower frequency (negative shift) is detected. If blood is moving toward the transducer, a higher frequency (positive shift) is detected. This Doppler modality also provides information about laminar versus turbulent flow (eg, flow within an abdominal aortic aneurysm).

Color power Doppler identifies the amplitude or power of the Doppler signals rather than the frequency shifts. It is more sensitive than pulse wave Doppler to detect blood flow in organs with typically low-flow states, such as the ovaries or testicles. Color power Doppler is particularly useful in the evaluation of ovarian or testicular torsion (Fig. 28).



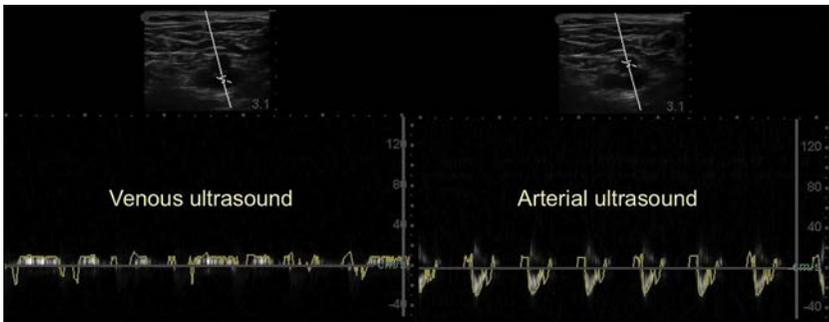
**Fig. 25.** M-mode evaluation of a pneumothorax. (Courtesy of Teresa Wu, MD, Associate Professor, Emergency Medicine, University of Arizona, College of Medicine-Phoenix, Phoenix, AZ.)



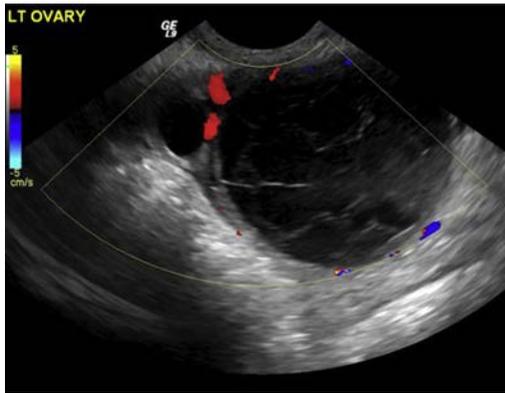
**Fig. 26.** Color Doppler flow through the aorta farfield to the IVC and gallbladder. (Courtesy of Zonare Medical Systems Inc; with permission.)

### OBTAINING CALCULATIONS ON BEDSIDE US

During bedside scans, it is often useful to obtain specific measurements of the structure being evaluated. For example, measurements of the IVC diameter are being used to guide resuscitation attempts (Fig. 29). Most machines have a caliper button that allows the user to measure the absolute distance between two points. The select key is typically used to toggle between the two calipers. Once both calipers have been aligned along the border of the object being measured, the distance between the calipers is displayed on the US screen (Fig. 30).



**Fig. 27.** Pulse wave Doppler flow through a vessel. (Courtesy of Teresa Wu, MD, Maricopa Medical Center, University of Arizona, College of Medicine-Phoenix, Phoenix, AZ.)



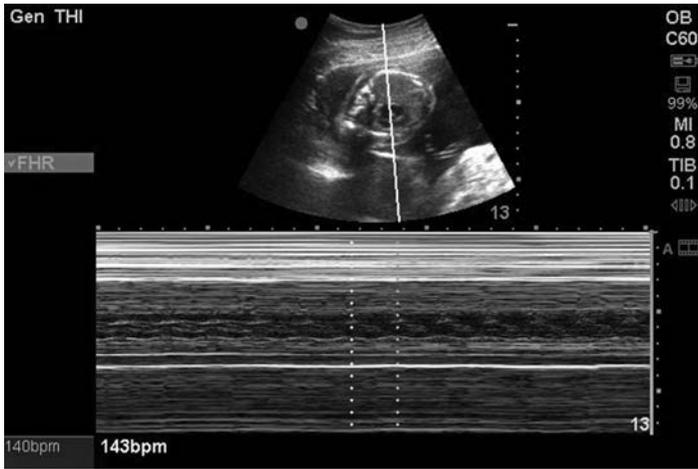
**Fig. 28.** Evaluation of ovarian torsion using color Doppler. (Courtesy of Mary Connell, MD, Department of Radiology, Maricopa Medical Center, Phoenix, AZ.)



**Fig. 29.** Measuring IVC diameter using bedside ultrasound. (Courtesy of Teresa Wu, MD, Maricopa Medical Center, University of Arizona, College of Medicine-Phoenix, Phoenix, AZ.)



**Fig. 30.** Using the calipers to calculate the diameter of an enlarged common bile duct. Note that the dimensions of the common bile duct are shown in the bottom left side of the image ( $0.92 \times 1.29$  cm). (Courtesy of Teresa Wu, MD, Maricopa Medical Center, University of Arizona, College of Medicine-Phoenix, Phoenix, AZ.)

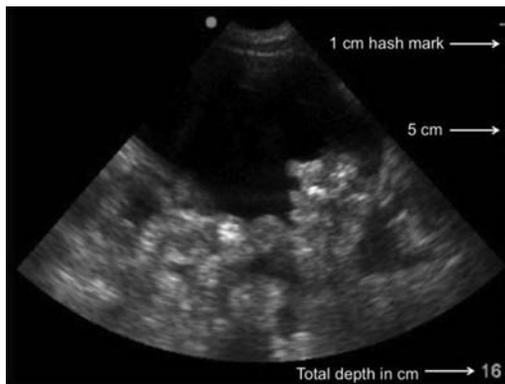


**Fig. 31.** Obtaining fetal heart rate using the calculations option during a bedside obstetric ultrasound. (Courtesy of Teresa Wu, MD, Maricopa Medical Center, University of Arizona, College of Medicine-Phoenix, Phoenix, AZ.)

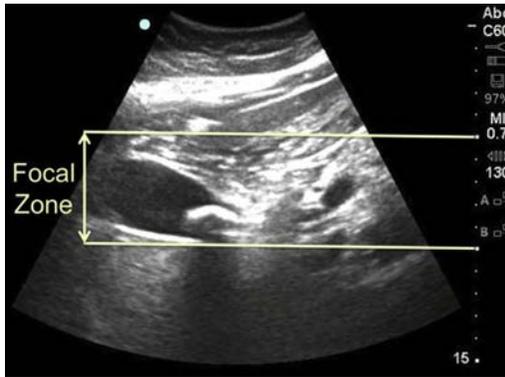
Many US machines have preset calculations available for the particular imaging mode or examination type being used. For example, if an obstetric US is being performed, common preset calculations include fetal heart rate, crown rump length, biparietal diameter, and head circumference. Selecting the desired calculation from the available menu provides automatic calculations of the region being measured (**Fig. 31**).

### ADJUSTING THE DEPTH OF THE SCAN

The penetration of the US beam on a particular transducer can be altered by manipulating the frequency of the probe and adjusting the depth or penetration button/knob on the US machine. The depth and penetration achieved during the scan are displayed



**Fig. 32.** Depth hash marks on the side of an ultrasound machine. (Courtesy of Teresa Wu, MD, Maricopa Medical Center, University of Arizona, College of Medicine-Phoenix, Phoenix, AZ.)

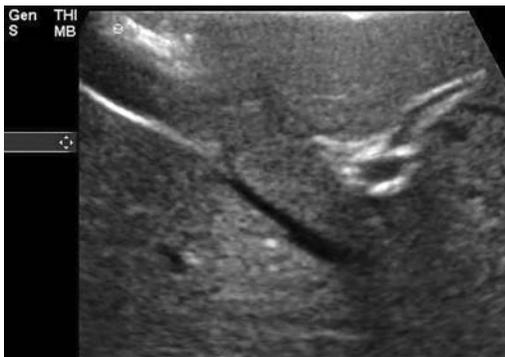


**Fig. 33.** Adjust the depth of the scan so that the target structure is visualized within the “focal zone” (middle and narrowest portion of the ultrasound beam). (Courtesy of Teresa Wu, MD, Maricopa Medical Center, University of Arizona, College of Medicine-Phoenix, Phoenix, AZ.)

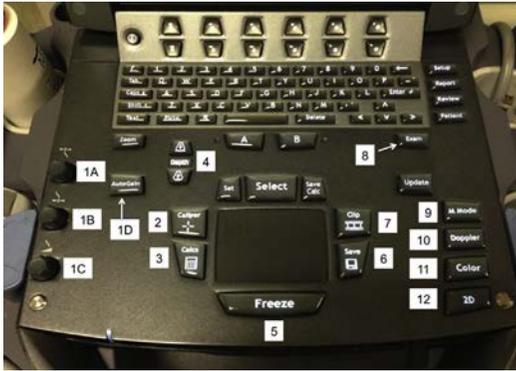
as a scale on the left or right side of the US screen. By convention, these hash marks are designated at 0.1-, 0.5-, and 1-cm increments (Fig. 32). During the initial part of a scan, it is often useful to start with an increased depth for orientation purposes and to evaluate surrounding structures. Once the target structure has been localized, scanning depth should be decreased to minimize the display of irrelevant deeper structures. Scanning at increased depths reduces the frame rate and compromises image quality.

In between the nearfield and farfield of the US beam is what is known as the “focal zone.” This is the narrowest part of the beam and provides the greatest lateral resolution during the scan. It is important to manually adjust the depth of the scan so that the target structure is visualized within the focal zone of the US beam (Fig. 33).

Many advanced US systems also provide the option to zoom in on or magnify an area of particular interest. By zooming in on an object, the US field and processing is restricted to that particular target area and assigned to the image matrix. Pressing the zoom button on the US machine brings up a box on the screen. Using the track



**Fig. 34.** Using the zoom function to magnify the common bile duct and portal vein for analysis. (Courtesy of Teresa Wu, MD, Maricopa Medical Center, University of Arizona, College of Medicine-Phoenix, Phoenix, AZ.)



- 1A: Nearfield gain
- 1B: Farfield gain
- 1C: Overall gain
- 1D: Auto gain
- 2: Calipers
- 3: Calculations
- 4: Depth
- 5: Freeze
- 6: Save (for still images)
- 7: Clip (to save video clips)
- 8: Exam (to select exam types)
- 9: M Mode
- 10: Pulse Wave Doppler
- 11: Color Doppler
- 12: 2D (B Mode)

Fig. 35. Standard ultrasound controls, buttons, and knobs.

pad, this magnification box can be maneuvered over the area of interest. Pressing the zoom button again enlarges the area that has been selected (Fig. 34).

## SUMMARY

Understanding basic US instrumentation and knobology is an important step in learning how to perform bedside US examinations. Although US machines may differ in some of their capabilities, the standard instrumentation and functionality remain essentially the same (Fig. 35). Becoming familiar with the machine and the controls used for image generation optimizes the scans being performed and enhances the use of US in patient care.

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