BASIC CHARACTERISTICS OF THE ULTRASOUND EQUIPMENT

2

INTRODUCTION

Performing and successfully completing an ultrasound examination requires multitude of skills that include the medical knowledge, the technical dexterity, and the know-how to navigate the various knobs of the ultrasound equipment. Today's ultrasound machines are complex and quite advanced in electronics and in post-processing capabilities. Being able to optimize the ultrasound image is much dependent on the understanding of the basic functionality of the ultrasound equipment. This chapter will focus on the review of various components of the ultrasound equipment and the basic elements of image optimization. The following chapter (chapter 3) will introduce some helpful scanning techniques.

THE ULTRASOUND EQUIPMENT

Ultrasound technology has changed drastically over the past decade allowing for significant miniaturization in the design and manufacturing of ultrasound equipment. The spectrum of ultrasound equipment today includes machines that can fit in the palm of one's hand and high-end machines that can perform very sophisticated ultrasound studies. It is important to note that before you acquire ultrasound equipment, you should have an understanding of who will be using the equipment, for which medical purpose it is intended to be used, in which environment it will be used and how will it be serviced. The answer to these important questions will help in guiding you to the appropriate type of ultrasound equipment for the right setting. For instance, ultrasound equipment destined for low-resource (outreach) settings should have special characteristics such as portability, sturdiness and a back-up battery in order to adjust to fluctuation in electricity. Furthermore, ultrasound equipment designed for the low-resource (outreach) setting should be easily shipped for repairs and service.

Ultrasound Transducers

Ultrasound transducers are made of a transducer head, a connecting wire or cable and a connector, or a device that connects the transducer to the ultrasound machine. The transducer head has a footprint region (**Figure 2.1**) where the sound waves leave and return to the transducer. It is this footprint region of the transducer that needs to remain in contact with the body in order to transmit and receive ultrasound waves. A gel is applied to the skin/mucosa surface of the body to facilitate transmission of ultrasound waves given that sound waves do not transmit well in air. Each transducer also has a transducer (probe) marker located next to the head of the transducer in order to help identify its orientation (**Figure 2.2**). This probe marker can be a notch, a dot or a light on the probe's head. The use of this probe marker in handling the transducer and its orientation will be further discussed in the following chapter (Chapter 3).

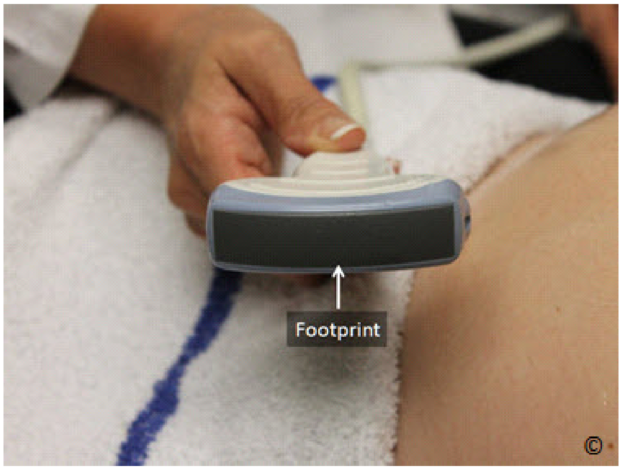

Figure 2.1: Footprint of a curvilinear abdominal transducer. The footprint region is where the sound waves leave and return to the transducer.

Figure 2.2: Probe marker of a curvilinear abdominal transducer. The probe marker is essential in the proper handling and orientation of the transducer (discussed in chapter 3).

Transducers are produced in an array of shapes, sizes and frequencies and are adapted for specific clinical applications. In general, transducers for cardiac applications have small footprints. Vascular transducers have high frequencies and are linear in shape and obstetric and abdominal transducers are curvilinear in footprint shape in order to conform to the shape of the abdomen (**Figure 2.3**).

Figure 2.3: Abdominal transducer used for obstetric applications. Note the curvilinear shape of the footprint, which helps to conform to the abdominal curvature.

Linear transducers produce sound waves that are parallel to each others with a corresponding rectangular image on the screen. The width of the image and number of scan lines is uniform throughout all tissue levels (**Figure 2.4**). This has the advantage of good near field resolution. Linear transducers are not well suited for curved parts of the body as air gaps are created between the skin and transducer (**Figure 2.5**).

Figure 2.4: Transverse plane of the fetal chest in the second trimester of pregnancy using a linear transducer. Note the rectangular screen image and a good near-field resolution.

Figure 2.5: Linear transducer used for obstetric scanning in the late second trimester of pregnancy. Note the gap produced between the transducer footprint and the abdominal wall (white arrows). This can be eliminated by simply applying gentle pressure on the abdomen.

Sector transducers produce a fan like image that is narrow near the transducer and increase in width with deeper penetration. Sector transducers are useful when scanning in small anatomic sites, such as between the ribs as it fits in the intercostal space, or in the fontanel of the newborn (**Figure 2.6**). Disadvantages of the sector transducer include its poor near field resolution and somewhat difficult manipulation.

Figure 2.6: Sector transducer; note the small footprint, which allows for imaging in narrow anatomic locations such as the intercostal spaces or the neonatal fontanels.

Curvilinear transducers are perfectly adapted for the abdominal scanning due to the curvature of the abdominal wall (**Figure 2.3**). The frequency of the curvilinear transducers ranges between 2 and 7 MHz. The density of the scan lines decreases with increasing distance from the transducer and the image produced on the screen is a curvilinear image, which allows for a wide field of view (**Figure 2.7**).

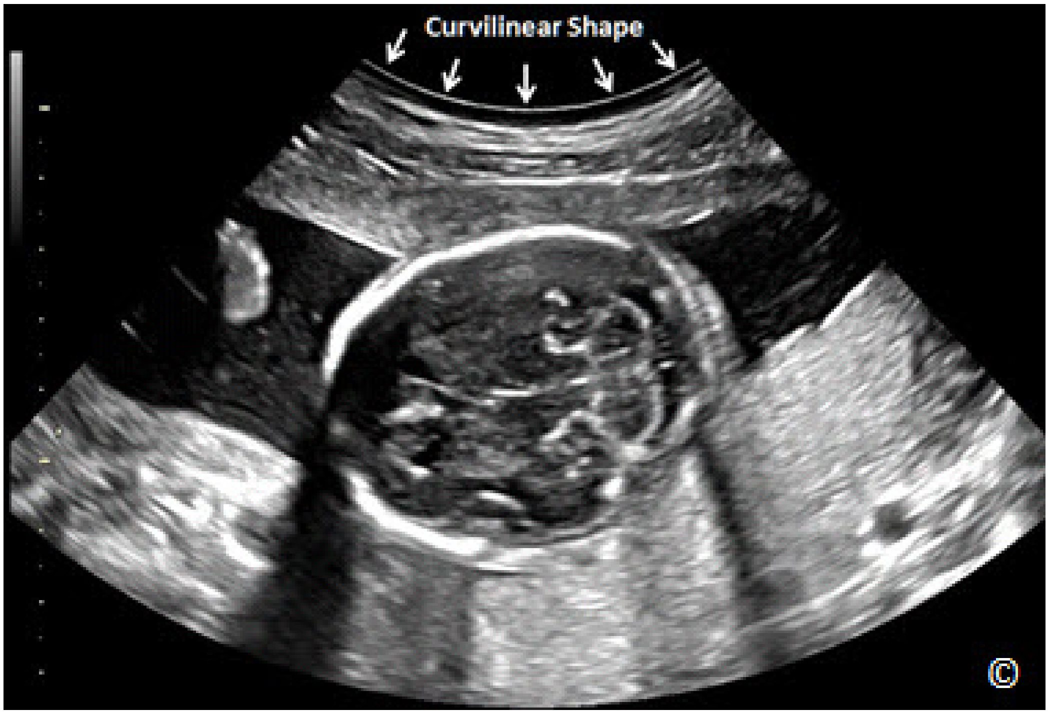

Figure 2.7: Ultrasound image of the fetal head using a curvilinear transducer. Note that the image is curvilinear in shape (arrows) and has a wide field of view.

Transvaginal transducers, like other endocavitary transducers, have a small footprint and their frequencies are typically in the range of 5-12 MHz (**Figure 2.8**). They are designed to fit in small endocavitary spaces with the footprint at the top of the transducer (transvaginal) or at the dorsal aspect of the transducer (rectal). When performing a transvaginal ultrasound examination, a clean condom, or the digit of a surgical rubber glove, should cover the transvaginal transducer. Ultrasound gel should be placed inside and outside the protective cover in order to facilitate the transmission of sound.

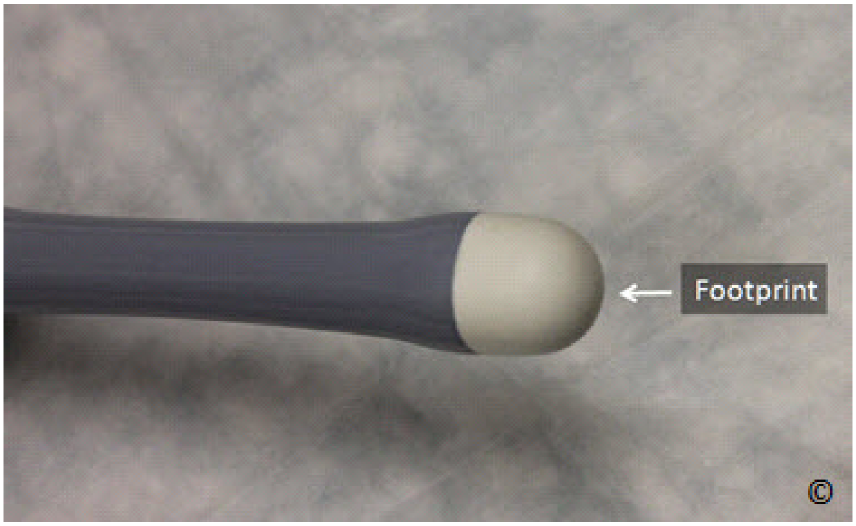

Figure 2.8: The head of a transvaginal transducer; note the small footprint (labeled) at the top of the transducer.

Protocols for ultrasound transducer cleaning should be adhered to in order to reduce the spread of infectious agents. Both the transabdominal and the transvaginal transducers should be wiped between ultrasound examinations and disinfection of the transvaginal transducer should be performed according to national or manufacturer guidelines (1).

Controls of the Ultrasound Equipment

Ultrasound equipment has a wide array of options and features. These features are typically operated from either the console of the ultrasound equipment, a touch screen monitor or a combination of both (**Figure 2.9**). The basic controls that you need to familiarize yourself in the early stages of ultrasound scanning are the following:

Figure 2.9: Ultrasound equipment showing a wide array of knobs for control of various features. Most ultrasound equipment have a keyboard and a trackball on their consoles.

Power or Output Control: This controls the strength of the electrical voltage applied to the transducer crystal at pulse emission. Increasing the power output increases the intensity of the ultrasound beam emitting and returning to the transducer, thus resulting in increase in signal to noise ratio. Increasing the power results in an increase in ultrasound energy delivered to the patient. It is therefore best practice to operate on the minimum power possible for the type of study needed. Resorting to lower frequency transducers can help achieve more depth while minimizing power output.

Depth: The depth knob allows you to increase or decrease the depth of the field of view on the monitor. It is important to always maximize the area of interest on your monitor and decrease the depth of your field of view, which enlarges the target anatomic organs under view. **Figures 2.10 A and B** show the importance of depth control in obstetrical scanning.

Gain: The gain knob adjusts the overall brightness of the image by amplifying the strength of the returning ultrasound echo. The overall brightness of the image can be increased or decreased by turning the gain knob clockwise or counterclockwise respectively. **Figures 2.11 A and B** show the same ultrasound image under low and high gain settings.

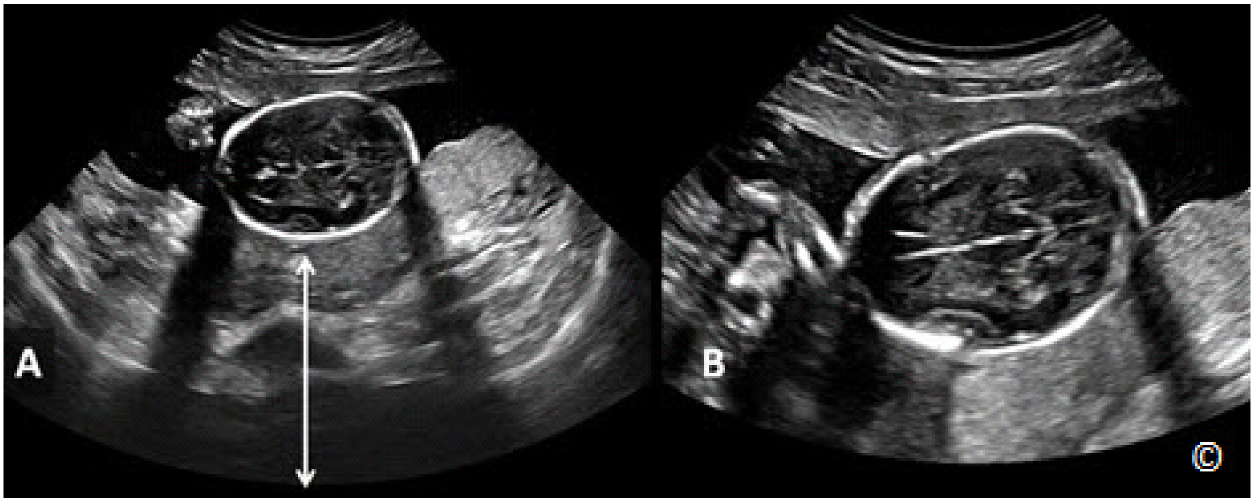

Figure 2.10 A and B: Figures A and B represent transverse view of the same fetal head at the level of the biparietal diameter. In A, the depth (white double arrow) is increased, resulting in a small head, whose anatomic details are consequently difficult to see. In B, the depth is reduced, which allows for a larger head thus improving visualization.

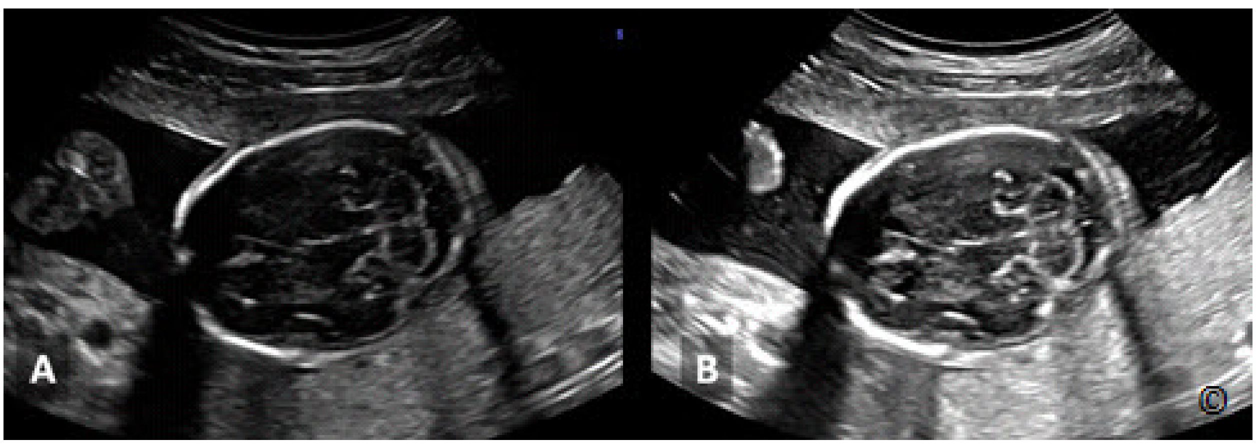

Figure 2.11 A and B: Figures A and B represent transverse view of the same fetal head at the level of the cerebellum. In A, the gain is too low and in B, the gain is adequate. Note better visualization of intracranial anatomy with a higher gain (B). Adjusting the gain to the correct level comes with experience.

Time Gain Compensation (TGC): The Time Gain Compensation (TGC) allows adjustment of brightness at a specific depth of the image. The upper knobs increase or decrease brightness closer to the transducer footprint and the lower knobs increase or decrease brightness farthest from the transducer footprint. **Figure 2.12** shows the TGC location on one of the ultrasound machine console. As a general rule, in transabdominal ultrasound, the upper field gain knobs should be kept slightly to the left than lower field ones (in this way the eye of the operator can focus on the deeper part of the screen where the fetus is). The reverse is true with transvaginal ultrasound, where the region of interest is often in the near field.

Figure 2.12: Time Gain Compensation (TGC) on an ultrasound consol. The upper and lower knobs adjust brightness in the upper and lower fields respectively (labeled). The overall knob (labeled) adjusts brightness in the whole image.

Focal Zones: The focal zones should always be placed at the depth of interest on the ultrasound image in order to ensure the best possible lateral resolution. Multiple focal zones can be used to maximize lateral resolution over depth; however this will result in a slower frame rate and is thus less desirable when scanning moving structures such as in obstetrics or the fetal heart specifically.

Freeze: The freeze knob allows the image to be held (frozen) on the screen. While the image is frozen measurements can then be taken and organ annotations can be applied to the image before saving it. Furthermore, the option to "cineloop" (scroll) back to previous time frames is an option that is available on most ultrasound equipment. This is a very important function in obstetric ultrasound imaging, as it assists in capturing frames during fetal movements, such as measurement of long bones.

Trackball: The Trackball or Mouse pad is used for moving objects on the monitor and for scrolling back in freeze mode. It has a multi-function and can be used in conjunction with caliper placement, screen annotation, or moving the zoom or Doppler boxes to the desired location.

Res or Zoom: Some ultrasound equipment has this function, which allows magnification of areas of the ultrasound image displayed on the monitor in real time. The trackball is used in conjunction with the Res/Zoom knob to choose the area for magnification.

2-D: The 2-D knob stands for the 2-D mode of scanning or the traditional B-mode imaging. B stands for brightness (mode). In this mode, the image is displayed in grey scale and is comprised of pixels arranged in a sector or linear fashion with various shades of grey thus representing the intensity of the returning signal (**Figure 2.13**). When the operator presses this knob, the traditional 2-D image is activated. This knob is also used to get back to grey scale imaging from color Doppler and/or Pulsed Wave Doppler.

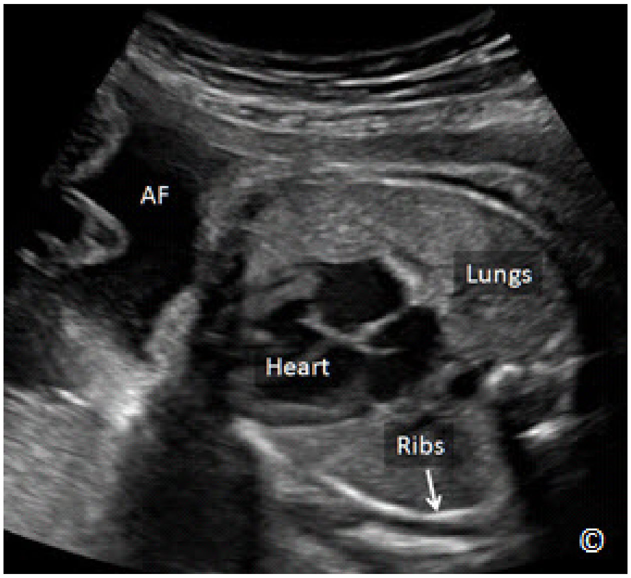

Figure 2.13: Two-dimensional ultrasound image of the fetal chest at the level of the four-chamber view. Note the various gradation of grey with the ribs being the brightest (echogenic) followed by the lungs and heart (labeled). The amniotic fluid (AF) is black in color (anechoic) reflecting a weak intensity of the returning echo.

M-Mode: The M-Mode knob activates the M-Mode function of the ultrasound machine. M-Mode stands for Motion mode and in this function an M-Mode cursor line appears on the upper section of the image with an M-Mode display on the lower part of the image **(Figure 2.14)**. The M-Mode display corresponds to the anatomic components that the M-Mode cursor intersects. The M-Mode is used primarily to document motion, such as cardiac activity of the fetus in early gestation (**Figure 2.15**).

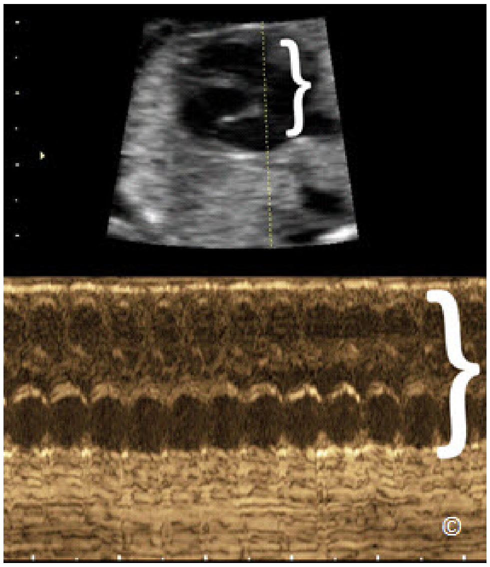

Figure 2.14: M-Mode cursor line (dashed line) is shown through the fetal heart (small bracket) in the upper image. Note the corresponding M-Mode display (large bracket) in the lower image showing cardiac motion.

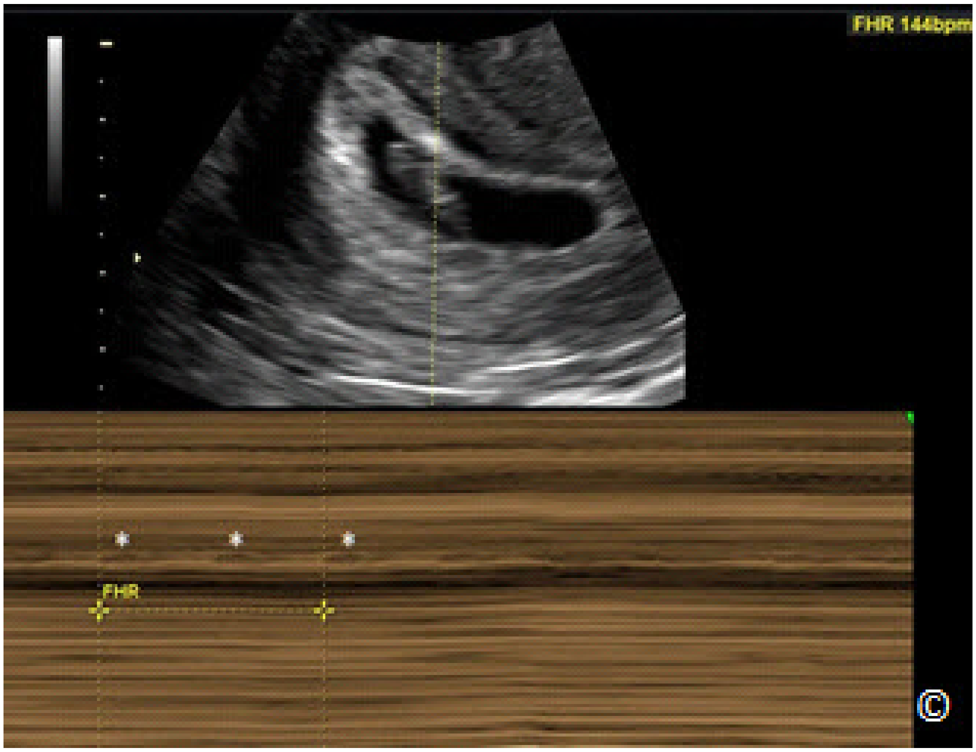

Figure 2.15: M-Mode applied in the first trimester for documentation of fetal heart activity. Reflections in the M-Mode tracing (asterisks) represent cardiac motion. Calipers are measuring fetal heart rate (FHR) at 144 beats per minute (bpm).

Color Flow: The color flow knob activates color flow or color Doppler, which adds a box superimposed on the 2-D real-time image on the screen. The operator can control the size and location of the color box on the 2-D image. Color flow or color Doppler detects blood flow in the insonated tissue and assigns color to the blood flow based upon the direction of blood flow. By convention, red is assigned for blood flow moving in the direction of the transducer (up) and blue is assigned for blood moving in the direction away from the transducer (down). The operator can also control the velocity scale of blood flow (pulse repetition frequency) and the filter or threshold of flow. These parameters are important in assessing various vascular beds. Note that the display of color flow follows the physical principles of Doppler flow and thus if the ultrasound beam is perpendicular to the direction of flow, color Doppler information will not be displayed on the monitor (see chapter 1 for details). Newer ultrasound equipment tries to overcome this limitation by providing other means for display of blood flow such as **Power Doppler** which primarily relies on wave amplitude and **B-flow** (not to be confused with B-Mode) both of which are relatively angle independent.

Pulsed Wave Doppler: The pulse wave Doppler (Pulsed Doppler) or **Spectral Doppler** knob activates the pulse Doppler display. In this display a cursor line with a gate appears in the upper half of the screen and a pulse or spectral Doppler display appears in the lower half of the screen **(Figure 2.16)**. The pulsed wave Doppler gate can be moved by the operator and placed within a vessel as imaged by color Doppler. Typically, this mode is activated when a vessel is first identified or suspected and after color flow Doppler is activated. Pulsed Doppler allows obtaining specific quantitative information about a vessel such as S/D ratio of the umbilical artery (**Figure 2.17**). Flow towards the transducer is displayed above the baseline and flow away from the transducer is displayed below the baseline. The operator has the option to invert the display of the Doppler spectrum in order to display the waveforms above the line **(Figure 2.16)**. See chapter 1 for more details.

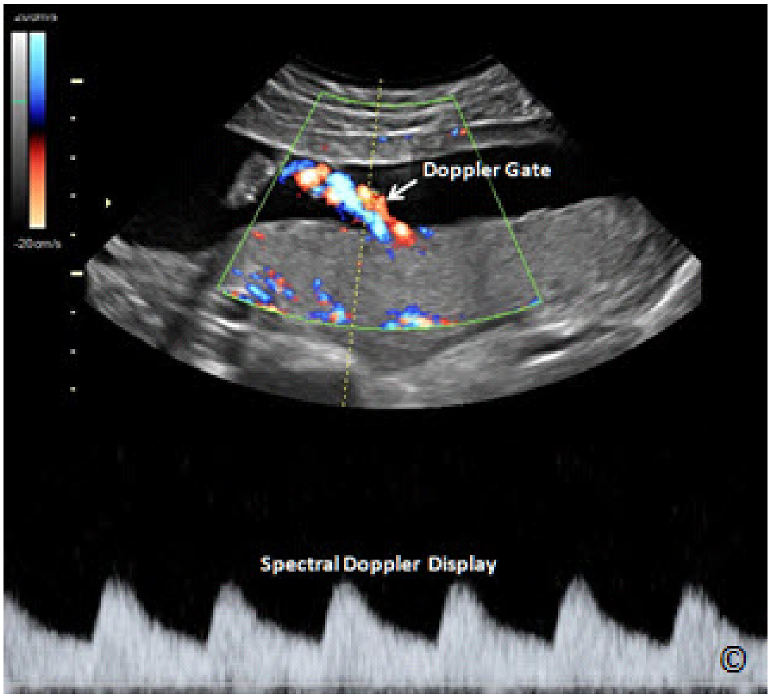

Figure 2.16: Pulsed wave Doppler of the umbilical artery. Note that the Doppler gate is placed within the umbilical artery as seen in the upper part of the image and the spectral Doppler waveform is displayed in the lower part of the image. The spectral Doppler is inverted to display the waveforms above the line.

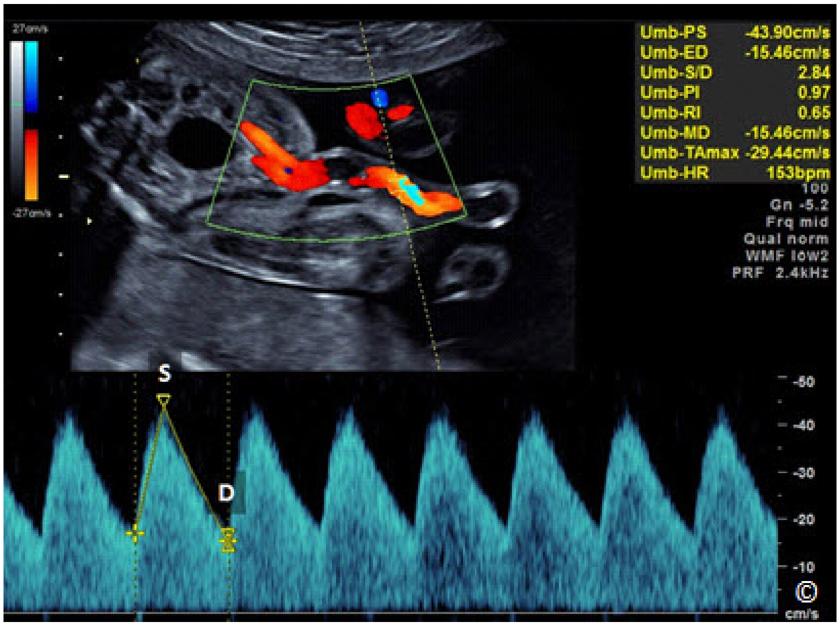

Figure 2.17: Pulsed wave Doppler of the umbilical artery at the abdominal insertion. Doppler waveforms are shown in blue color. S stands for flow at peak systole and D stands for flow at end diastole. Note the Doppler indices in the right upper corner of the image (yellow). For more details, refer to Chapter 1.

Measurement: The measurement function or knob can also be displayed as Measure or Cal (Calculation) on the ultrasound console. This function allows the operator to measure, in different formats, various objects on the screen. When the measure button is pressed, a caliper appears on the screen. Use the trackball to move the caliper to the desired location and set it. Once set, a second caliper appears, which can be set in similar fashion. Stored normograms within the ultrasound equipment allow for determination of gestational age and estimation of fetal weight when various fetal biometric parameters are measured.

STARTING AN EXAMINATION

Before starting an ultrasound examination, it is important to ensure that essential information about the patient is entered into the ultrasound equipment in order to be able to save ultrasound images on the hard drive of the ultrasound machine, accurately calculate gestational age in pregnancy and print ultrasound images for documentation purposes. Minimal relevant information that is required to be entered includes the patient's name, date of birth and first day of the last menstrual period. On many ultrasound equipment, a knob identified as "Patient or Start" leads you to this screen where this information can be entered (**Figure 2.18**). If you do not enter this information or any other patient identifier at the initiation of your examination (patient name); most ultrasound systems will not allow you to print or save an image from your examination.

Figure 2.18: Consol of an Ultrasound equipment showing the knob identified as "Patient" (white circle), which leads you to a screen on the monitor (not shown) where patient identifiers are entered before initiating the ultrasound examination.

When a patient returns for a follow-up examination, modern ultrasound equipment allows you to retrieve the patient information automatically without a need to reenter the data.

DOCUMENTING AN EXAMINATION

An ultrasound report is required at the conclusion of the ultrasound examination. Chapter 15 details the parameters of an ultrasound report in obstetrics and gynecology. It is important to know that image documentation is an essential component of the ultrasound examination and report. Images can be produced in paper format or stored digitally on the ultrasound equipment. Several ultrasound systems have knobs for images, which can be formatted to allow for printing on a thermal printer and for saving a digital copy in a DICOM format on the equipment hard drive. The operator also has the option of downloading and saving a study on an external hard drive or a USB jump drive. This is an important function in the low-resource setting as it allows for exchange of cases for educational and consultative function. Typically these knobs can be formatted for these functions, such as for thermal paper printer, for saving on the hard drive and for downloading to the USB outlet. A permanent copy of the ultrasound report, including ultrasound images, should be kept and stored in accordance with national regulations.

References:

1) American Institute of Ultrasound in Medicine (AIUM) Guidelines for Cleaning and Preparing Endocavitary Ultrasound Transducers Between Patients (Approved 6/4/2003) – http://www.aium.org/officialStatements/27