Introduction to Ultrasonography

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Background:

Proficiency in ultrasound can be an advantage to a surgeon practicing in a resource-limited setting. Ultrasound performed by the surgeon can give tremendous insight into the patient's disease, especially if more advanced imaging such as CT or MRI aren't immediately available. In this Chapter we explain the principles of Ultrasonography as they relate to you, and we give some basic guidelines for performing ultrasound and interpreting the images. In other chapters, we will discuss Focused Abdominal Sonography for Trauma (FAST) and Ultrasound-Guided Interventions.

Physics:

The Piezoelectric Effect:

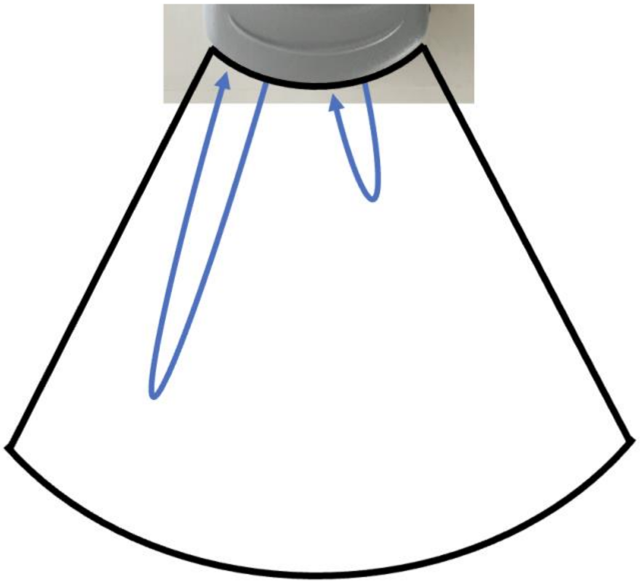
Quartz is a solid made of Silicone and Oxygen molecules in a highly ordered structure. Ultrasound transducers contain a quartz crystal. According to the Piezoelectric effect, when electricity passes through a crystal it causes the crystal to vibrate. And conversely, if a crystal is made to vibrate, it emits electricity. The properties of the crystal determine the frequency of the vibration.

A piece of Quartz crystal. Source: JJ Harrison (https://www.jjharrison.com.au/) - Own work, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=6023737

Inside the transducer, both forms of the Piezoelectric effect occur. First, the ultrasound waves are generated: electrical energy is applied to the crystal and converted to high frequency soundwaves, which enter enter the tissue below the transducer. These soundwaves interact with the tissue, and then are reflected back towards the transducer at different frequencies, based on the characteristics of the tissue. When these sound waves return, they interact with the same crystal. Here again, mechanical energy is converted to electrical energy, this time containing information about the tissue it has been reflected from. This energy is then converted to an image.

The sound waves emitted by the crystal are in the range of 2-10 Megahertz (mHz, millions of cycles per second.) By comparison, human hearing occurs at 20Hz to 20kHz.

The tissue below the probe reflects the sound waves differently based on its characteristics. The more dense a tissue is, the more "bright" it appears on the screen. Therefore, the image on the screen is a reflection of the amount of time a sound wave takes to return to the transducer (depth of the structure) and the strength of the sound wave (brightness of the image.)



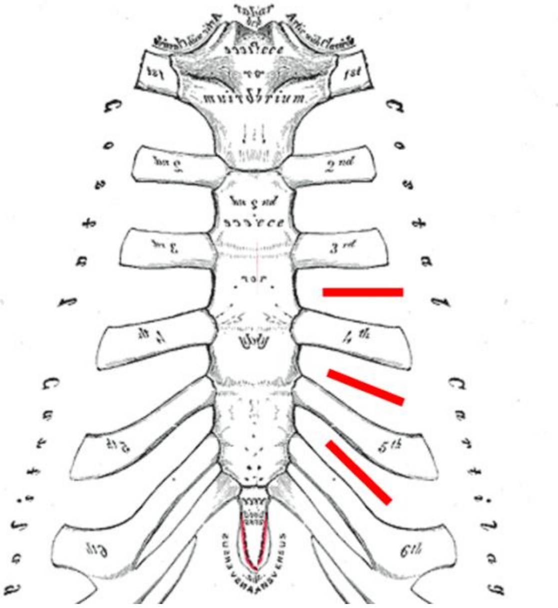
The distance the wave travels, and its strength on return, cause the crystal to vibrate differently than when the signal was generated. The vibrations are transformed into electrical signals, which are reconstructed to make a two dimensional (depth and width) image.

Anatomy:

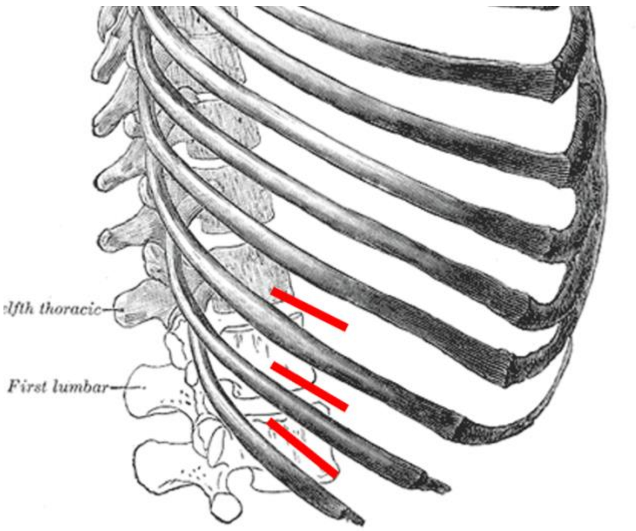
Acoustic Shadowing:

Some tissue does not allow sound to pass through it at all. This causes an "acoustic shadow" deep to the tissue, as no sound waves return from below that area. The simplest example of this is when the gel between the probe and the skin is inadequate, literally all of the image will be an acoustic shadow.

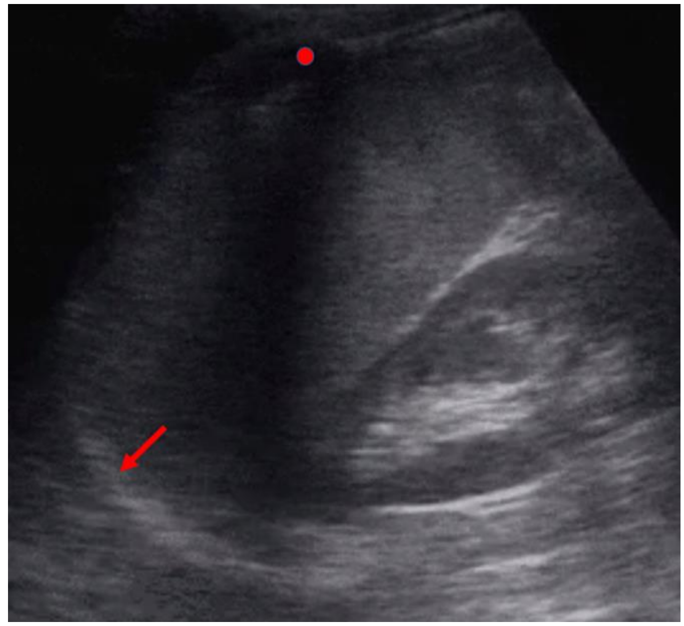
When attempting to scan the chest cavity, the ribs cause acoustic shadows. The best way to overcome this effect is to rotate the transducer so that it lies entirely within the space between the ribs. The operator must therefore keep in mind the orientation of the ribs wherever the transducer is being used.



Location and orientation of the ultrasound transducer for echocardiography, over the anterior intercostal spaces.

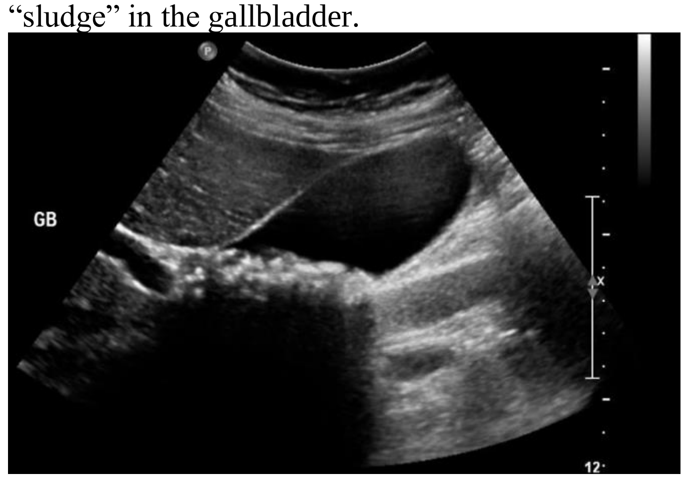


Location and orientation for liver ultrasound, including assessment of the hepatorenal space for FAST scan to detect intra-abdominal fluid. By sliding the transducer posteriorly along the intercostal space, the diaphragm and any fluid in the thoracic cavity can be seen.



The liver, right kidney and hepatorenal recess are seen in this ultrasound view taken with the transducer in between the ribs on the right. The diaphragm is also seen (Red arrow.) By sliding the transducer posteriorly within the intercostal space, more of the diaphragm and lower right hemithorax could be seen. A rib shadow (Red dot and below) obscures the view of the liver; this view could be improved if the transducer was rotated a bit, so that it aligned better with the intercostal space. Case courtesy of Dr David Carroll, from the case https://radiopaedia.org/cases/64279?lang=us

Another effect of acoustic shadowing is the detection of gallstones and other calculi. Although calculi of the kidney, bladder or gallbladder can often not be directly seen by ultrasound, their acoustic shadows can be seen. An exception is any stone that is not sufficiently calcified; these will reflect some sound waves and may be seen as "masses" or "sludge" in the gallbladder.



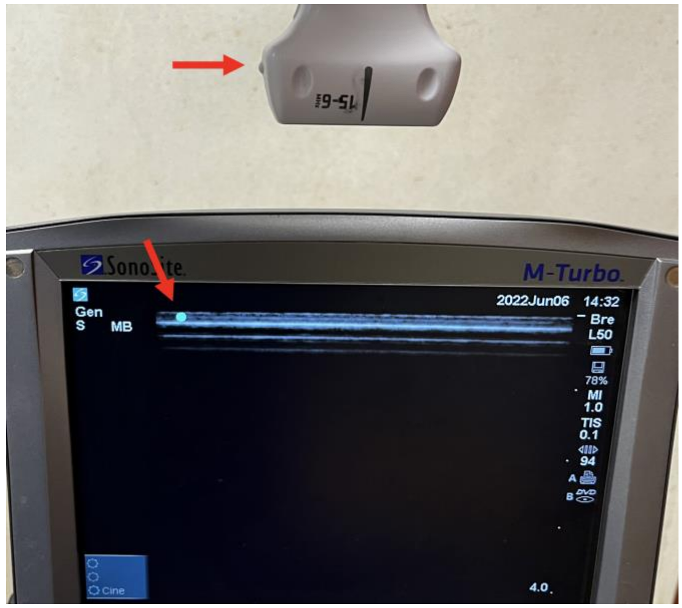
Ultrasound image of the gallbladder with stones and acoustic shadowing. There is no data available from below the stones, as no ultrasound waves are reflected back towards the *transducer. Case courtesy of Dr Hani Makky Al Salam, From the case https://radiopaedia.org/cases/14461?lang=us*

Setup and Orientation

If you have a portable machine, try to place it opposite the patient from you. Then, as you are performing the study or doing any interventions, the images are right in front of you. Having the machine on the same side as you forces you to turn your neck or torso in an awkward manner to see the images as you obtain them.

If possible, position yourself on the other side of the patient from the monitor, so that you can see it without turning to one side.

Every transducer has external markings that can be seen (or felt, when it is inside a sterile probe cover.) These allow you to align the transducer with the image on the screen, which also has a marker. The screen marker is usually a blue dot. When the transducer's marker and screen's marker are aligned, the image on the screen correlates with the anatomy being examined, and the images move in the same direction as you move the transducer.



The transducer is held so that its marker aligns with the one on the screen (Red arrows.) If you do not do this, the image you see on the screen may be a "mirror image" of what you would expect, and it will not correspond with your movements if you attempt to maneuver the probe.

Transducers and Settings

Assuming you have a choice of transducers at all, it is helpful to understand the different types and their intended use.

The shape and frequency of the transducer will determine its best use. The two shapes of transducers are linear and curved.

Linear array transducers will be better for shallow work such as breast assessment and biopsy, vascular studies and vascular access. These will have a higher frequency of 5-7.5mHz which can show greater detail but will not penetrate tissue as deeply.

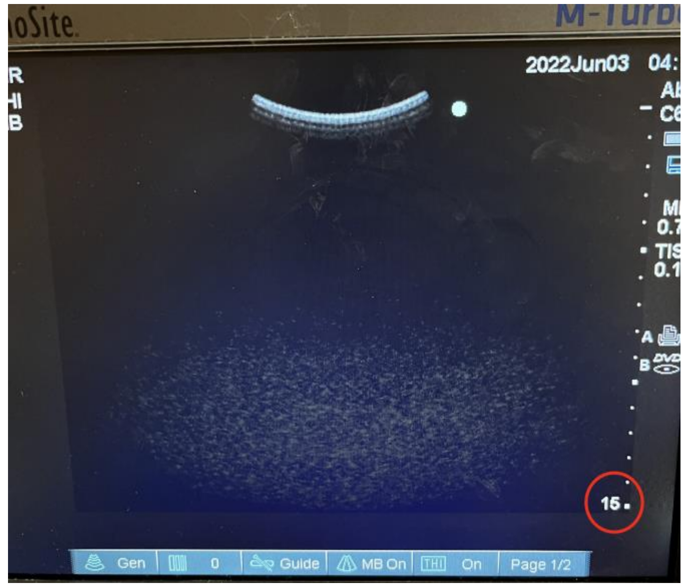
A linear array transducer. Note the arrow in the center of the head improves accuracy during venous cannulation.

Curved array transducers are better suited for abdominal or pelvic work. These have a lower frequency, in the range of 2-3mHz, so they penetrate tissue more deeply.

A curved array transducer.

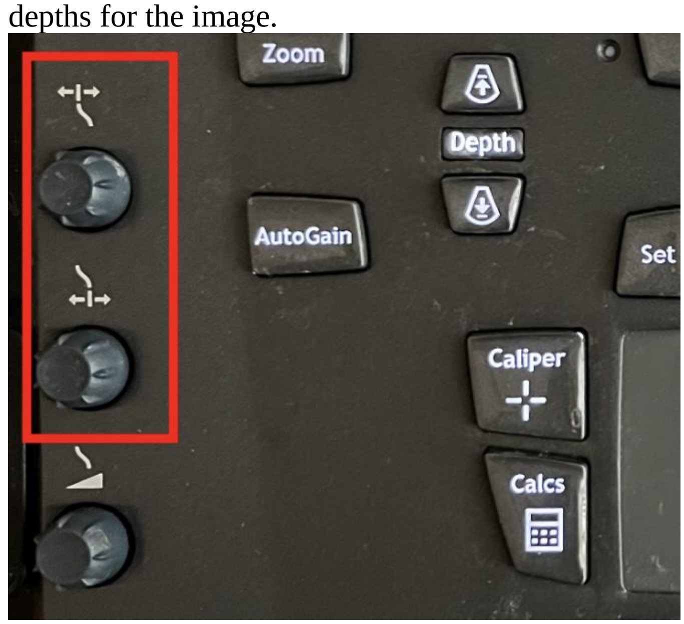
The depth at which each transducer sees can be set by the user. This will be visible as a column of numbers on the right side of the screen. Each transducer has a preset depth beyond which it will not go, depending on its intended function. A vascular transducer (linear array) can usually see up to about 6cm. If you are trying to examine a vessel that is 2cm deep, set the depth to 3cm to see maximum detail. Similarly, when using a curved transducer to examine all of the liver, set the depth around 13cm. Once you have settled on a tumor that is 6cm deep and decide to biopsy it, change the depth on the probe to around 8cm. This allows you to see the tumor in greater detail.

The depth setting on the ultrasound console.

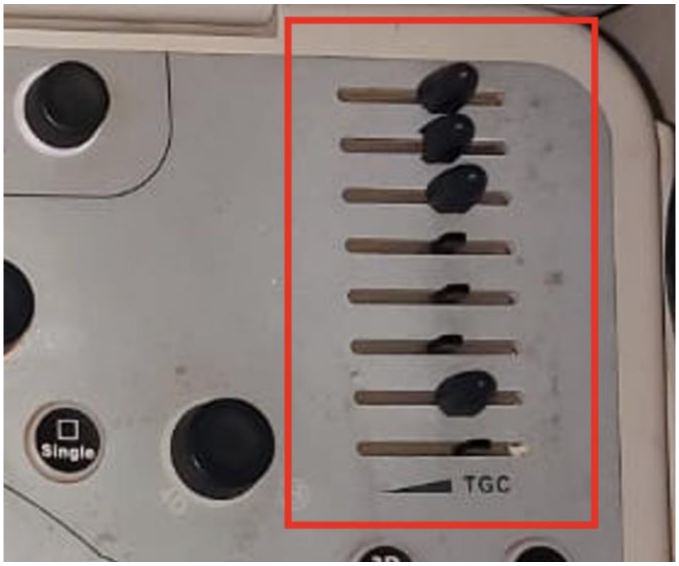


The vertical column on the right of the screen shows the depth setting. This can be adjusted to allow you to see the area of interest in greater detail. Once you know their scale, the dots also allow you to estimate the size of a structure on the screen. In this case, the depth is set to 16cm (Red circle.)

The gain allows the surgeon to manipulate the image by amplifying it. If the image is not amplified enough, it will be too dark. If amplified too much, it will be too light. The appropriate setting will vary, even according to the depth of the image. Therefore, most ultrasound machines allow the operator to adjust the gain at various depths. On portable machines there may be two dials, but on console machines there typically 8 or more sliding dials corresponding to the gain at 8 or more different depths for the image.



On this portable ultrasound machine, the dial immediately below the Red box controls the gain for the whole image. The *two dials inside the Red box separately control the gain for the upper and lower portions of the screen.*



On this console (less portable) ultrasound machine, these sliding controls allow the operator to adjust the gain on the image at 8 different levels.

If you are not seeing a useful image, it is important to decide whether you are using the right probe, one that is designed to see at the depth you are trying to see, as explained above. Then assess the amount of gel. Gel facilitates the passage of sound waves so it is good to have a lot of it, especially over an uneven surface such as the chest in a cachectic person. If you are using a sterile transducer cover (or a sterile glove), there should be adequate gel inside the cover, between the transducer and the cover. Run your finger over the transducer surface to remove any bubbles between it and the sterile cover. We discuss an easy way to make a sterile ultrasound transducer cover in "Ultrasound-Guided Interventions."

Once you have enough gel and no bubbles, if you are still not happy with the image try adjusting the gain.

Principles:

Using the ultrasound machine alone to evaluate a patient is difficult. The images are hard to comprehend, even if you use the right transducer and apply all the principles we have explained so far.

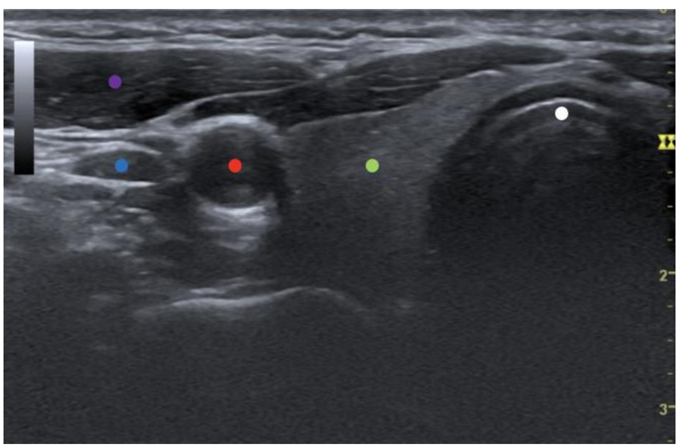
In the abdomen, begin with the liver. With the appropriate probe set to the right depth, enough gel, and the gain set properly, you should be able to see the hepatic tissue in one of the right lower intercostal spaces. Once that is accomplished, try to find the kidney, deep and inferior to the liver. Move caudally and medially towards the abdomen and continue to examine the liver, pushing the probe into the abdomen under the costal margin and pushing upwards. Move medially to find the vena cava with its vein branches entering the liver. The aorta, a pulsatile vascular structure that is farther to the left, is also easy to locate relative to the liver. When examining the pelvis, start by finding the bladder and examine the surrounding structures. Pushing downwards with the probe into the abdomen will move the bowels out of the way and allow you to find the uterus and the ovaries in a woman.

When performing ultrasound of the abdomen, start in the right intercostal spaces over the liver. Orient the probe so that it is parallel to the intercostal spaces. Adjust the gain and depth. Then slide anteriorly or posteriorly within the interspace, move to a lower interspace, or go below the costal margin and push the probe towards the dorsum to see more of the liver.

View of the liver from one of the right intercostal spaces.

In the neck, start with the linear probe oriented transversely over the lower 1/3 of the sternocleidomastoid muscle. You will see the common carotid artery, which is smaller and pulsatile, and the jugular vein, which is larger and collapses with inspiration. Move medially and you will find the thyroid gland and, in the center, the trachea, a round structure that creates a shadow, as ultrasound waves can not pass through air. Move in a cranial direction to follow the vessels upwards to the submandibular gland.

In the neck, start with a linear array probe held transversely and find the carotid artery, jugular vein, trachea and thyroid gland. These familiar structures allow you to orient yourself and then move upwards or to either side.



Looking transversely over the lower right neck just off midline, you are rapidly oriented by finding the sternocleidomastoid muscle (Purple dot,) the internal jugular vein (Blue dot,) the common carotid artery (Red dot,) the right lobe of the thyroid gland (Green dot,) and the trachea (White dot.) Case courtesy of Dr. Derek Smith, From the case https://radiopaedia.org/cases/65792?lang=us

Above all, take every opportunity you have to practice your ultrasound technique. Ultrasound can be used to diagnose many conditions and is very useful in settings like ours. Its accuracy depends on operator technique, so the more time you spend with it, the more useful it will be to you.

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