Seven Principles for Successful Emergency Sonography

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Outline:

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3. Three colors of Grayscale
4. Four sides to the Image on the Monitor
5. Five main concepts of Physics: **W.A.T.E.R**
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    b. **A**ttenuation and Artifacts
    c. **T**ransducer properties
    d. **E**nergy and Bioeffects
    e. **R**esolution
6. Knobology (**B QUIET**)
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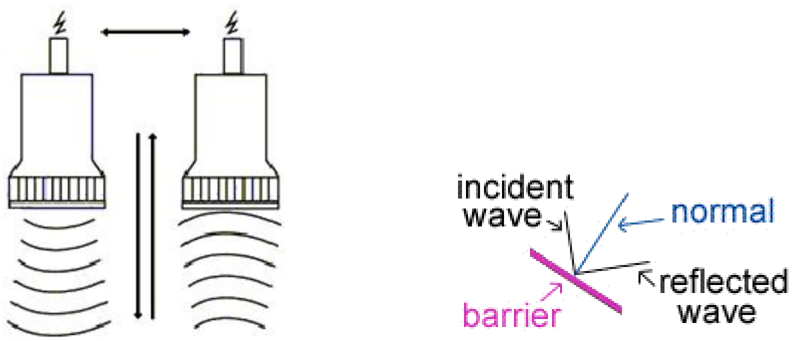
    b. Aorta
    c. Trauma
    d. Procedural
    e. Renal
    f. IUP
    g. Biliary

Introduction: Physicians have been enthralled with visualizing internal anatomy well before W. Roentgen first discovered X Rays at the end of the nineteenth century. Ultrasound in the twentieth century became commonplace in the care of the critical patient because it was portable and displayed real time images. The twenty first century will yield more skilled ultrasound operators and the need for mastery of basic principles.

Each ultrasound machine will have basic components displayed by proprietary vendors. The machines are similar in the sense that they represent technological advances in the art of echolocation. Ultrasound is a modality that is notoriously operator dependent. The skill set for acquisition and interpretation of images entails psychomotor agility combined with spatial interpretation of multi-dimensional images. Each operator should approach an ultrasound scan armed with some basic principles.

Basic Principles of Ultrasound: Every ultrasound machine has some basic components that begin with a power supply. This provides electricity to the console, monitor and transducer. The console has many knobs and buttons used to annotate the image and adjust the output from the transducer. The ultrasound machine has an interface whereby a port connects a cable to the rear of a transducer. Ultrasound is a mechanical wave that passes through tissue with very little bioeffects and a superior safety profile. Ultrasound is the principle by which wavelengths of a specific frequency are emitted from a transducer, pass through human tissue and reflect back to a transducer able to interpret the strength and distance of the signal and display it as an image (**Figure 1**). These machines can do this with ease as the digital processing power improves the pulse echo principle.

Figure 1

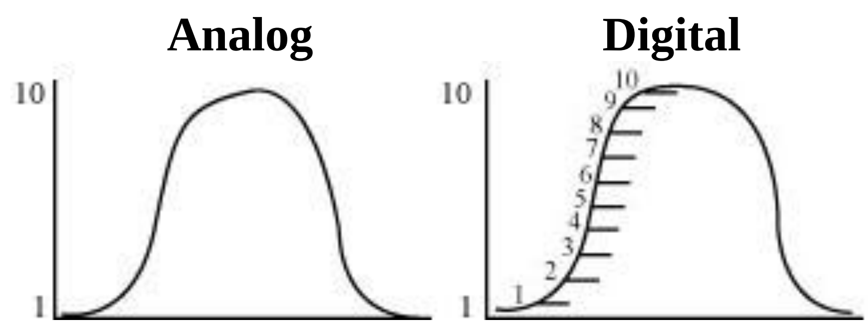


1. Overview of Ultrasound History 1794-2013

Ultrasonography comes from the Latin sonus (sound) and the Greek graphein (to write) while Ultra depicts energy outside human hearing (> 20,000 Hertz). Ultrasound outside human hearing was described by Lazarro Spallanzani when he observed bats navigating using high pitched squeals in 1794[1]. Ultrasound is based on the piezoelectric effect discovered in 1880 by Pierre Curie[1]. This principle states that electrical energy can deform certain crystals (e.g. quartz, Lead zirconate titanate-PZT) causing them to compress and expand and generate ultrasound energy. The reverse is true as returning ultrasound waves can cause a pressure deformation in the crystal and create an electrical charge. This basic principle is the foundation of every ultrasound machine. S.O.N.A.R. or Sound Navigation and Ranging became the first practical use of echolocation. Advances in industry modified the beam former to both transmit and receive sonographic data. The first medical use of ultrasound was in 1942 as Karl Dussik attempted to visualize the cerebral ventricles. As advances in technology continued, better imaging of soft tissue[2], bowel[3] and other portions of human anatomy[4, 5] were described. Ultrasound machines began to change from analog signal processing to digital processing

(**Figure 2**). As digital computing continued increasing[6], the same human anatomy was displayed with better resolution.

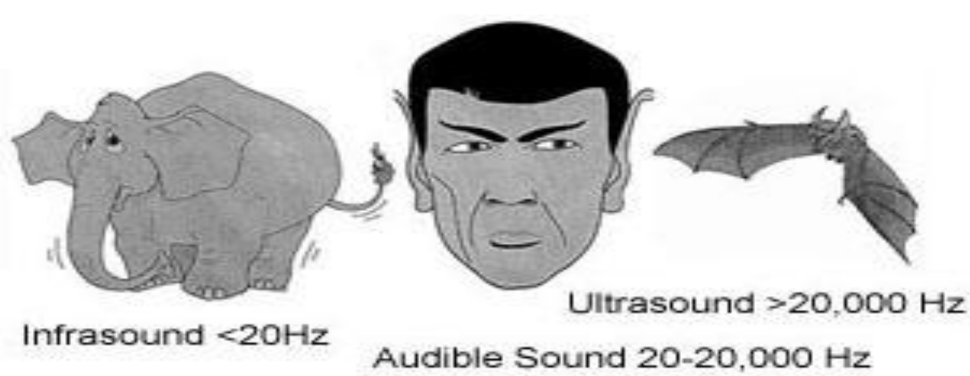
Figure 2



Emergency Medicine officially began in 1961 when a group of physicians banded together to provide emergency services for critical patients[7]. Nine years later, Barry Goldberg first described free fluid in the peritoneal cavity using A-mode (Amplitude mode) ultrasound. Kirstensen described a splenic injury using ultrasound[8] and this was followed in 1976 with a first case series describing trauma ultrasounds[9]. Subsequently ultrasound began to challenge the necessity of DPL, first described by Root in 1965[10]. Trauma ultrasounds brought to light the need for bedside diagnostics and therapeutics and ultrasound filled this need. Many papers hailed the utility of trauma ultrasound[11-20] in emergency care, and this led to more acceptance in the emergency setting. Ultrasound will continue to be a useful diagnostic and therapeutic tool in the critical encounter. The real question for the twenty first century is how "operators" are trained and how to accurately measure delivery of care. One possible solution is the focus on educational opportunities early in the course of a medical career.

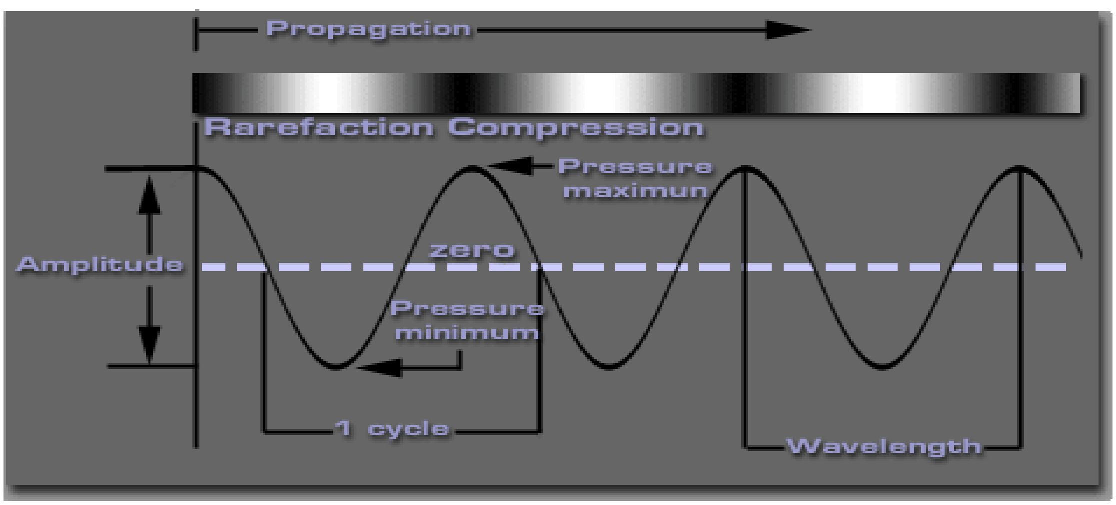
2. Sound and Ultrasound:

Figure 3



Infrasound, sound and ultrasound encompass a physical spectrum of mechanical wavelengths (**Figure 3**). The human cochlea is able to process sound frequencies in the range of 20 –20,000 Hertz (cycles/second) Human hearing is analogous to ultrasound echolocation. Both involve transmitted mechanical waves passing through a medium and processed by a receiver. Human speech begins as compressions and rarefactions (**Figure 4**) of air that rush pass the vocal cords to form words and sentences. These sound data packets travel through air at 330 m/s arriving at the ear. Genetic disposition determines the shape of the ears that channel sound waves into the external auditory canal. There, the sound waves reverberate the tympanic eardrum and transfer the energy through the bony middle ear. The malleus and incus act as a fulcrum moving the stapes back and forth. The stapes push on the oval window and forces fluid waves through the endolymph of the cochlea. The tectorial membrane of this canal is full of cilia that respond to the movement of the fluid with a resonant frequency that sends an electrical signal to the spiral ganglion and eighth cranial nerve. This energy is now perceived by the brain as sound and its location determined by the time difference perceived by both ears. The larynx acts as the transmitter and the entire ear acts as the receiver.

Figure 4



In modern ultrasound the frequencies are much higher and the ultrasound is both generated and received by the transducer. The transducer sends a pulse(waves) of data and energy and then waits 99% of the time for returning echoes. Depending on the tissue density and interfaces between tissues, the returning echoes will appear as a shade of gray between the spectrum of black and white.

3. Colors of Grayscale

B-Mode (Brightness Mode) is the image mode that displays the returning echoes in a spectrum from black to gray to white. Therefore it is important to understand that every B mode image will have a combination of these three colors depending on tissue density and water content. Biologic tissue is made up of interfaces. An interface occurs whenever two tissues of different acoustic impedance are in contact, caused by the difference between the acoustic impedance of the two adjacent tissues. The greater the acoustic mismatch between two different structures intensifies the amount of energy reflected and thus a clearer image. When an operator sees black (anechoic) on the monitor it means there are no echoes returning from this area. The differential therefore for "black" is fluid (e.g. blood vessel, urine, bile) or artifact (e.g. rib shadow). When an operator sees gray (echoic) signals on the monitor it means that echoes returning from the body are displayed at a certain depth on the screen. The differential for gray on ultrasound is soft tissue (e.g. muscle, liver, kidney) or artifact (e.g. mirror image of liver above reflective diaphragm). When an operator sees white (hyperechoic) signals on the monitor it means that there are strong echoes returning from the body. The differential for white therefore is "hard" tissue/ dense structures (e.g. diaphragm, bone, stone, fascial layers) or artifact.

Color	**US description**	**Interpretation**
Black	Anechoic/ Echolucent	Fluid or Artifact
Gray	Hypoechoic/ Echopenic	"Soft" Tissue or Artifact
White	Hyperchoic/ Echogenic	"Hard" Tissue or Artifact

Black	**Gray**	**White**
Blood	Muscle	Bone
Bile	Liver	Stone (Calcium)
Urine	Kidney	Air (Impedance Mismatch)
Transudate (Ascites)	Spleen	Diaphragm
Exudate	Pancreas	Tendon/Ligament
Cysts	Heart	Renal Collecting System

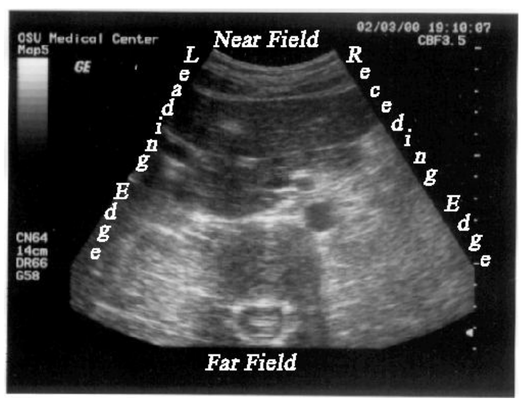
4. Sides of a Transducer/ Image:

Transducer (Probe): Which side is Up? Every transducer will usually have some palpable indentation or protuberance (indicator) that the operator can determine is the "leading edge". This mark will correspond to a symbol on the screen that displays the returning image. In most abdominal images this mark will be on the left side of the screen (e.g. a green dot). The transducer/image relationship can be remembered by LL, Left Leading. The opposite side of the probe without a distinguishing mark is the receding edge. This receding edge "follows" the pointing direction of the Leading Edge. This corresponds to the right side of the screen in abdominal imaging and can be remembered as RR, Right Receding. The probe is anchored by the power cord inserted opposite the "footprint" or "face" (the surface that contacts the patient's body). When scanning, the indicator is generally pointed to the right or toward the head in abdominal images to standardize display patterns.

The Beam: The physical anatomy of the beam is broken down into the near field, focal zone, and far field. From the footprint, an ultrasound beam "shines" forth and travels a set depth controlled from the "box". The beam has a near field, which corresponds to the area closest to the transducer footprint while the far field is the area farthest away from the transducer. The top of the screen corresponds to the echoes returned closest to the transducer footprint called the near field. The bottom of the image is a representation of the distal part of the ultrasound beam and is called the far field. The junction between the near field and far field is the focal zone and is the area of highest resolution.

Image: Every ultrasound image will have four sides displayed on a monitor. The ultrasound display is a key difficulty in those just learning ultrasound. Each image will have a top, a right side, a bottom, and a left side. This displayed image is generated from the transducer and is analogous to the flashlight "beam". The transducer will "shine" a sound beam into the body and the reflections that return will be displayed onto a monitor screen. This transducer can be turned in a 360-degree circle and images will be generated to the screen. Every probe acts as a vector and has magnitude and direction rather magnitude alone (scalar). This means that the transducer "points" in certain directions constantly displaying to a fixed monitor with a fixed way of displaying the image. Understanding the image display is a key principle in mastering ultrasound. (**Figure 5**)

Figure 5

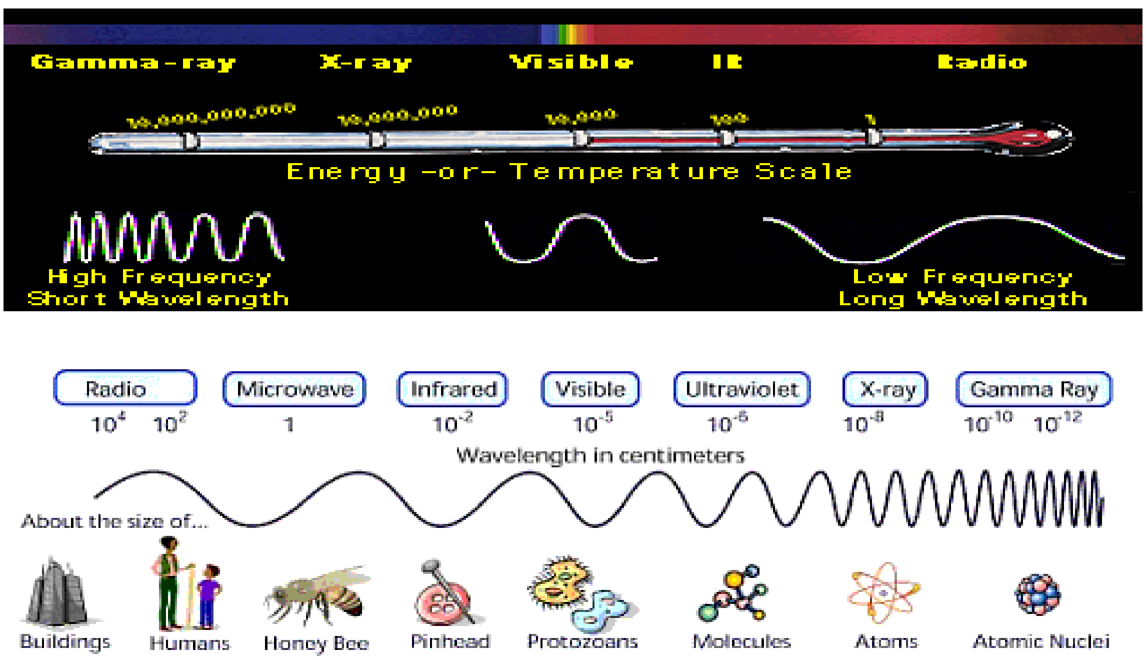


Transducer	**Image**	**Image**
Footprint	Top (12 o'clock)	Near Field
Smooth side (No mark)	Right side (3 o'clock)	Receding Edge
Beam	Bottom (6 o'clock)	Far Field
Indicator (indentation)	Left side	Leading edge

5. W. A.T.E.R.: Main Physics Concepts of Ultrasound

Wavelengths: Wavelengths are ever prevalent in the form of electromagnetic and mechanical waves. The electromagnetic spectrum is made up of transverse waves emitting energy that varies in intensity perpendicular to the direction of radiation. Sound is a longitudinal mechanical wave that vibrates air or tissue molecules in the same direction of the sound. The electromagnetic spectrum (EMS) constitutes low frequency waves (radio, microwave, infrared), waves visible by the human eye (visible spectrum ROYGBIV) and high frequency waves (UV, XRAY, Gamma Ray) (**Figure 6**). Unlike EMS waves, mechanical waves need a medium and cannot travel in a vacuum. This is why you cannot hear sounds in space (vacuum). Wavelength is described by frequency measured in Hertz. One hertz is equal to one cycle (wavelength) of sound passing 1 second. There is the spectrum by which the human cochlea can process sound 20-20, 000 hertz and then there is that energy of higher frequency greater than 20,000 hertz. This frequency represents ultrasound and most diagnostic ultrasound occurs between 1-20 MHz. Similarly for sound there are small wavelengths of sound called infrasound (elephants) below the threshold of human hearing 20 Hz.

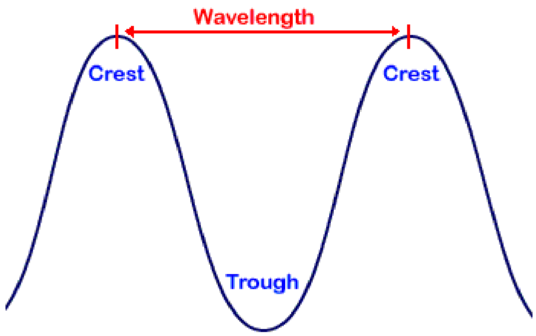
Figure 6



When ultrasound waves are emitted from a transducer the emitted waves appear as a plane wave front. The anatomy of a beam consists of a near field, a far field and a focal zone. In the near field the intensity of the beam varies from wave front to wave front. The far field is where the beam diverges and has a more uniform intensity. The best spatial resolution occurs at the near/ far field junction called the focal zone. Ultrasound energy is made up of waves of compressions and rarefactions - pressure that travels through tissue and follows Huygen's principles. The general wave equation is that velocity equals frequency multiplied by wavelength.

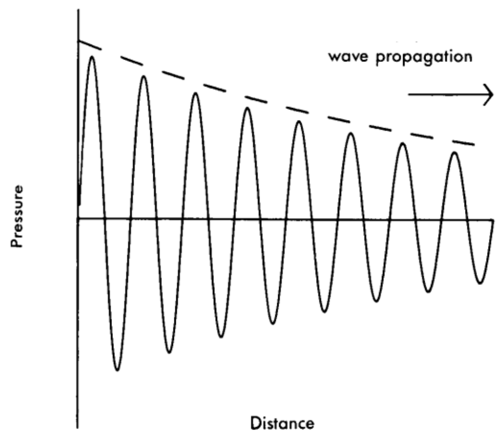
Wavelength: Length of space over which a cycle occurs

Cycle: One complete variation of a measured variable
Hertz (Hz): Unit of frequency
Frequency: Cycles per second
Pulse: A short burst of waves; a few cycles
Pulse duration: Time from beginning to end of pulse
Pulse repetition frequency: Pulses per second
Continuous wave: A wave that cycles indefinitely; not pulsed



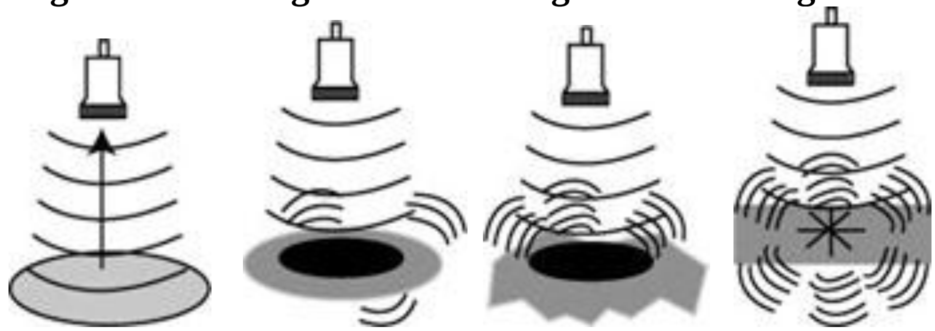
Attenuation: Energy is diminished as it travels from the probe through the body (**Figure 7**). This loss of energy can take many forms. Absorption is the highest component of attenuation and directly removes energy from the ultrasound beam. Absorption of the energy occurs at the level of each cell and is manifest as thermal heating of tissue. At diagnostic levels the ultrasound dissipates heat to the tissue at 1 dB/cm2. Refraction is a form of scatter and occurs when ultrasound crosses a tissue interface at oblique angles. Reflection is a desired form of attenuation that allows signals hitting the organ perpendicular to return to the probe and display clearly on the monitor. The purest form of reflection is specular reflection that occurs with very smooth surfaces (e.g. diaphragm). Finally scatter occurs with objects smaller than the individual wavelength such as blood cells or air. As frequency increases the ultrasound waves are less stable and more prone to attenuating effects. This means that the waves break up and the energy is lost in the tissue rather than returning to the probe.

Figure 7



Attenuation: Decrease in amplitude/intensity as waves travel through a medium
Absorption: Conversion of sound energy into thermal energy (heat)
Reflection: Portion of sound returned from an interface; echo (**Figure 8**)
Refraction: Change of sound direction when passing from one medium to Another (**Figure 9**)
Scatter: Redirecting sound in several directions because of small size or surface roughness (**Figure 10**) (**Figure 11-Diffuse Scatter**)

Figure 8 **Figure 9** **Figure 10** **Figure 11**



Artifact: Artifacts are displayed portions of the image that do not correspond to representative anatomic structures. Artifacts occur because of ultrasound physics and how waves interact with tissue interfaces. One of the most common is posterior acoustic shadowing. Any strong reflector will leave a shadow such as gallstones, metal foreign bodies, calcifications and bone. Posterior shadowing artifacts are commonly seen at the ribs. As the ultrasound encounters strong reflectors, the waves cannot penetrate the deeper structures and leaves a shadow. To solve this problem, rotate the probe in between the ribs and shine the beam through the window of the intercostals muscle (gray). Repositioning, applying pressure, and imaging from another plane are some ways to avoid artifacts. Common artifacts are listed below.

Comet Tail: Series of closely spaced reverberation echoes

Mirror Image: Artifact image appearing on the opposite side of a strong reflector (e.g. diaphragm)

Ring Down: Extreme form of reverberation artifact that occurs when a long series of echoes resulting from a continuous stream of sound emanate from a single site

Shadowing: Decrease in echo amplitude from reflectors that lie behind a high attenuating structure

Enhancement: Increase in echo amplitude from reflectors that lie behind a weakly attenuating structure

Edge Artifact: Refraction or interference from a fluid filled structure adjacent to soft tissue

Beam Width: As the beam widens the image loses clarity and images can be projected into areas where they do not physically reside.

Contact Artifact: Air shadowing because of too little gel.

Gain: Too many signals from the tissue causing whiteout.

Reverberation: A near field artifact that results from a strong echo returning from a large acoustic interface to the transducer.

Transducer: A transducer is a device able to convert one form of energy into another. In medical ultrasound, piezoelectric elements (PZT, quartz, ceramics) have the unique ability to change electrical energy into mechanical sound energy. When the machine is powered, an electrical signal is transmitted to the monitor, keyboard and the probe connector. Energy travels through a connecting cord to the probe. The probe houses a transducer element that utilizes the piezoelectric effect and responds to the powered energy to send out ultrasound waves at specific frequencies (1-20 MHz). The footprint of the probe consists of a matching layer that allows a smooth transition of the sound to and from the body. This matching layer is an intermediate acoustic impedance between the soft tissue and the hard piezoelectric crystal. Behind the matching layer is the transducer with active crystals that when electrically stimulated emit ultrasound waves at frequencies based on the thickness and shape of the element. Behind the transducer crystal is the damping material made of epoxy resin and tungsten powder that works to shorten the returning wavelengths and prevent "ringing" Just as a bell continues to resonate after being struck, returning ultrasound would continue to distort the image if there was no backing material. This damping increases bandwidth and improves resolution. The probe is made of an epoxy casing to limit wear and tear.
Ultrasound probes come in various shapes and sizes depending on their intended use with transducer frequency based on the element's shape and thickness. In general smaller probes usually have higher frequencies (e.g. 7.0 MHz) for imaging closer structures (Thin element→ High Frequency); while lower frequency (3.0 MHz) probes have better penetration (Thick element→ Lower Frequency). The transducer both transmits and receives sound waves transmitting approximately 1% of the time and listening the rest of the time. Wherever you place the probe on a patient an image will be generated from the reflected signals. The following is a list of the types of ultrasound probes.

Annular Array: Array of ring shaped elements arranged concentrically
Phased Array: An array that steers and focuses the beam electronically
Linear Array: Array of piezoelectric crystals in a line
Curvilinear Array: Array arranged in a sloping curve footprint.

All transducers have the four following components:

1. **Epoxy:** casing to protect against wear and tear
2. **Matching layer:** Material at the front face of transducer to reduce the reflections from the soft tissue piezoelectric element interface. and prevent ringing
3. **Piezoelectric crystal**: Conversion of pressure to electrical voltage**.**
4. **Damping material:** Backing material used to dampen the returning US pulses.

Energy:

X-rays are images made from radiation transmitted through the human body
Magnetic resonance images are made from radiation emitted by the human body
Ultrasound images are made from radiation reflected within the body. [21].

In biological systems such as human beings the distribution of energy is central to the care of a patient. Exposing a patient to unnecessary energy is the rationale for the **ALARA** principle.

ALARA: Acronym for As Little as Reasonably Achievable. This represents the theory that operators should use ultrasound to obtain diagnostic information in as little exposure as possible to the patient.

Acoustical Output Power of ultrasound waves is measured by the following:

SPTA Spatial Peak-time Average intensity: the resultant measure of intensity when averaged for a pulsed repetition period for a stationary beam at the location in the field where this quantity is the largest.
SPPA: Spatial Peak-pulse average intensity: The average intensity in an acoustic pulse, measured at the location where this quantity is the largest
SATA: Spatial average-time average intensity

There are two known bioeffects of ultrasound:

Thermal effects: Thermal Index (TI)
Raises tissue temperature due to the absorption of energy.

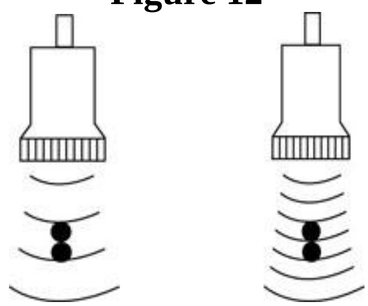
Nonthermal (Mechanical) Effects: Mechanical Index (MI)
Cavitation: Production and dynamics of bubbles in sound.

Resolution: Resolution is the ability to distinguish echoes in terms of space (detail), time (temporal), and strength (contrast grayscale). In general resolution is improved with higher frequency probes. The tradeoff is that higher frequencies have higher levels of attenuation and the signal is unstable. Therefore penetration is sacrificed for resolution. One technology called tissue harmonics identifies the spectrum of harmonic frequencies from an ultrasound signal, digitally subtracts the returning fundamental harmonic, and “listens” selectively for the second higher frequency harmonic. In this manner the signal can be transmitted at a lower frequency for better penetration and receives at a higher frequency for better resolution[22].

Spatial resolution: minimum distance between two distinguishable reflectors

- **Axial:** Vertical axis resolution to distinguish separate echoes (**Figure 12**)
- **Lateral:** Horizontal resolution perpendicular to the axis of the US beam to distinguish separate echoes
- **Slice Thickness:** Dependant on beam size, echoes perpendicular to the image plane rather than within the image plane (lateral resolution)

Figure 12



6. Knobology (B QUIET, see appendix):

The Console: All ultrasound machines have standard features of a console and a monitor to display the image. The track ball is a good place to focus your attention as this device is the navigation for the machine and allows the operator to select software options, move the cursor, and measure structures. Each machine is different but the consoles share many of these same controls. The major ones are **depth**—adjusts the length of the US beam, **gain**—adjusts the intensity of the returning signal, and **application**—adjusts the software for specific investigation of anatomy (e.g. Obstetric vs. Cardiac). It is important to adjust depth and make the image as large as possible to improve recognition of key anatomy. It is important to think about where in the body structures are located and "shine" the ultrasound beam to the appropriate depth. When using gain it is important to identify structures that are supposed to be black and adjust gain accordingly. The "slide pots" or time gain compensation (TGC) are usually to one side of the console and consist of 8 knobs that slides from the left (dark) to the right (white). These controls change the segmental gain from the top of the image to the bottom. Another knob usually controls the overall gain and adjusts the returning signal for the entire image. Gain sets the tone for the rest of the image and if set too high becomes the proverbial "polar bear in a snowstorm" image.

Newer machines have color and pulsed Doppler. These functions focus on moving structures based on velocity and direction. The resultant colors correspond to a pre set color wheel with hues of red and blue representing velocity. In general these functions can identify the presence of direction of flow in regards to the transducer while pulsed

Doppler gives an audio and visual display of the flowing waveform. Both forms of Doppler provide physiologic data that coupled with the anatomic data from grayscale gives the operator a better understanding of the patient. The best way to understand the nuances of the machine is to practice and become familiar by scanning.

7. Major Emergency Indications (ACEP 2001 Guidelines)

One major organization within Emergency Medicine endorses the following indications for performing ultrasound exams and the focused questions they answer[23]. These questions are not the only ones that can be answered by the emergency practitioner yet represent the major indications supported by the College at the beginning of the twenty first century.

Cardiac Imaging- Is there cardiac activity? Is there depressed cardiac activity? Is there normal cardiac activity? Is there presence of pericardial fluid?
Aorta—Does this patient have a dilated abdominal aortic aneurysm?
Trauma- Is there free fluid in potential spaces of the abdomen and thorax?
Procedures- Can Ultrasound directly visualize the anatomy for this procedure?
Renal—Does this patient have Hydronephrosis?
Intrauterine Pregnancy—Does this patient have a normal pregnancy in the uterus? Does it have a heartbeat?
Biliary—Does this patient have gallstones? Is there signs of cholecystitis?

Conclusion: Ultrasound is a complex skill set requiring knowledge of basic physics, the psychomotor skills to acquire an image, and the spatial knowledge to interpret its meaning. If a systematic approach is taken each time and standard images are obtained, the operator dependency of ultrasound is lessened. The technology of ultrasound will continue to improve and the sonographic resolution of anatomy will sharpen. The twenty first century will measure the skill of a critical care clinician on how well they can utilize bedside diagnostics such as ultrasound in the care of the patient. Basic principles of ultrasound are founded in historical developments and emerge to display echoes onto a screen. These images reflect human anatomy and pathology and constitute major variables in the medical decision making of emergency care. There may come a day as our profession continues to improve its safety record while delivering quality health care, that ultrasound confirmation of anatomy proceeds any invasive procedure. One thing is certain, ultrasound units continue to decrease in size and improve resolution that allow the trained practitioner a tool that can "look into" the body and make decisions based on real time images. This alone will drive all future uses of ultrasound as physicians hone their ultrasound skills.

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Appendix

B QUIET

Brightness mode Quality Ultrasound Imaging Examination Technique

1. Identification/Orientation

1.0 Date/Time (Machine Default)

1.1 Patient Name/MRN/Sonographer	1	2	3	4
1.2 Body Marker	1	2	3	4
1.3 Comments (Image Title, Labeled structures)	1	2	3	4

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2. Technical

2.1 Resolution-- Application/Focal Zone	1	2	3	4
2.2 Depth -- Field of view	1	2	3	4
2.3 Gain (Segmental, Overall)	1	2	3	4

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3. Image Anatomy

3.1 Near Field (Top of Screen)	1	2	3	4
3.2 Receding Edge (Right Side)	1	2	3	4
3.3 Far Field (Bottom of Screen)	1	2	3	4
3.4 Leading Edge (Left Side)	1	2	3	4

Total ________________

1: Unacceptable
2: Needs Improvement
3: Acceptable
4: Optimal

Exam Difficulty **1 2 3 4**

1= Difficult Exam (poor windows, inappropriate preparation)
2= Challenging exam
3= Acceptable exam
4= Optimal exam (Good windows, clear anatomy)

Likert Standard Scoring Explanatory Numeric

Identification/ Orientation

1.1 ***Identification*** **1 =** All absent **2 =** One present, one accurate
3 = Two present, two accurate **4** = All present, all accurate (*Sign the image*)

1.2 Body Marker **1 =** Absent **2 =** Wrong marker, wrong probe position
3 = Correct marker, wrong probe position **4 =** Correct marker, correct probe position

1.3 Comments **1 =** No comments **2 =** Title present, inaccurate or no labels **3 =** Image title + minimal labels (1-2 structures) **4 =** Title + multiple labels (>2)

Technical

2.1 ***Resolution*** **1 =** Wrong application, wrong focal zone **2 =** Correct application, wrong focal zone **3** **=** Wrong application, correct focal zone **4** = Correct application, correct focal zone

2.2 ***Depth*** **1** = Image too small (<half of screen) **2 =** Image cut off or not maximized at present depth (>4 cm from ideal depth) **3 =** Adequate depth (within 1 –3 cm) **4 =** Optimal depth (*Intended image fills the screen*)

2.3 ***Gain*** **1 =** Inappropriate (*too white, too dark throughout the image*) **2 =** Poor gain setting in near or far field **3** = Adequate gain settings (*Minimal echoes in fluid filled structures, all structures contrasted*) **4 =** Optimal gain settings and grayscale (*No internal echoes in vascular or fluid filled structures, appropriate tones to soft tissue*)

Anatomy

3.1 ***Near field*** **1 =** Unclear representation **2 =** Image partially distorted
3 = Adequate visualized anatomy **4** = Optimal near field anatomy representation

3.2 ***Receding edge*** (*Right side image*) **1 =** Unclear representation **2 =** Image partially distorted
3 = Adequate visualized anatomy **4** =Optimal anatomy representation

3.3 ***Far field*** **1** = Unclear representation **2 =** Image partially distorted
3 = Adequate visualized anatomy **4** = Optimal far field anatomy representation

3.4 ***Leading edge*** ***(*** Left side image) **1** = Unclear representation **2 =** Image partially distorted
3 = Adequate visualized anatomy **4** = Optimal anatomy representation