Knobology for Dummies

- Power On/Off
- Preset button
- Patient Information Entry
- Choose preset
- Transducer probes
- Connect and disconnect transducer
- Approach to the patient (machine placement, comfort, draping, etc.)
- U/S gel
- Explain the procedure
- Patient to screen orientation:
  1. *The top of the viewing screen is ALWAYS where the transducer is touching the patient.*
  2. *The orientation marker on the transducer and on the viewing screen ALWAYS point in the same direction.*
- Anatomical planes
- Transducer motion techniques (drag, fan, and rotate)
- Gain
- Time Gain Compensation
- Depth
- Zoom
- Freeze & Cine Loop
- Image Storage & Print
- Scanning Mode (B, CF, PW, M)
- Measurements
- “Soft Key” Modes
- Frequency
- Dynamic range
- Image rotation
- Focal position and number
- Power Doppler
### Basics of Physics and Ultrasound

#### Sound and Wave Theory:
- **Frequency** = number of cycles per second (Hz = 1/s)
- **Wavelength** = length of one complete cycle (measurable distance)
- **Velocity** of sound is constant for a given medium (330 meters/s in air; 1500 meters/s in water)
- **Velocity** = **Frequency** × **Wavelength**
  - Sound waves are a series of repeating mechanical pressure waves that propagate through a medium
  - Sound travels through tissues, causing molecules to vibrate
- **Human hearing**:
  - 20 Hz to 20,000 Hz
- **Ultrasound**:
  - >20,000 Hz
- **Diagnostic ultrasound**:
  - 1 MHz to >20 MHz
- **Most EM Ultrasound**:
  - 2.5-10 MHz

#### Sound and Wave Theory in Emergency Ultrasound:
- \( V = \text{frequency} (f) \times \text{wavelength} (\lambda) \)
- So if \( V \) is constant, then . . . . . if frequency **increases**, wavelength must **decrease** . . . . which means that with **increased** frequency, the distance the sound waves travel **decreases** (i.e. less penetration into tissue)

- **Piezoelectric (“Pressure-Electricity”) effect**: Transmission and Detection
  - There is crystalline material in the probe
  - Electrical current --> High frequency vibration --> Vibrations transmitted to adjacent tissues as ultrasound waves
  - This pulse travels at a relatively constant speed until it encounters a reflective surface, at which time a portion of the sound is reflected back toward the source
  - Sound waves in the tissues bounce back (echo) toward the probe --> Waves cause the crystals to vibrate --> Vibration generates an electrical current --> The current is then presented as the grayscale you see on the ultrasound screen

#### What You See:
- Images formed by properties of the returning echoes: **Depth** and **Direction**
- **Depth**: distance from the probe; calculated by the time elapsed between signal pulse and the received echo
- **Direction**: the crystals precisely differentiate the direction of the returning echoes
- The ultrasound crystals are arranged in an array, creating a plane of ultrasound waves; it is similar to a hand-held CT scanner
- The sound wave is calculated to be traveling through human tissue at body temperature (approx. 1540 m/sec) and the system measures the round-trip time and intensity of the returning “echo”
- The returning intensity determines (is proportional to) the grayscale assignment of the pixel (dot) of information on the screen
- The surface area of a transducer in contact with the patient is referred to as the “footprint” of the probe (small probes = small footprint; e.g. cardiac probe)
- In general, organized molecules = better image
- So, the liver is great to scan . . . .
  - Also, it is referred to as an “acoustic window”
  - In other words, the liver helps to improve visualization of other structures
  - We use the liver to see the IVC, the cardiac subxiphoid view, the gallbladder, etc.
- Fluid densities are ideal for imaging (great “through transmission”)
- Gas prohibits scanning due to the randomly distributed molecules in gas (air); signals reflected in different directions
- **Air is bad**, disrupts propagation of sound waves
- **B-mode Ultrasound**:
  - The gray-scale ultrasound you see on the screen
  - Strong echoes represented by white dots
• Absence of echoes represented by black dots
• Everything else is somewhere in-between
• Hyperechoic=bright (white) objects
• Anechoic=dark (black) objects
• Everything else is somewhere in-between=Isoechoic (same echogenicity), hypoechoic (less echoic), etc.

The Probes:
• The arrangement varies between the different types of ultrasound probes/transducers
• Curved array probe: crystals arranged such that the sound waves are fanned out, maximizing the scanning area; resolution is lost with increasing depth
• Linear array probe: rays are parallel, accounting for maintained resolution with increasing depth; scanning area is limited to the size of the probe (probe of choice for vascular access, venous Doppler studies)

Image Orientation:
• Longitudinal=cephalad-caudad (or sagittal) view
• Transverse=cross-sectional view similar to CT
• Oblique=views to keep organs in own axis (still considered a “longitudinal view” when in the long axis, “transverse view” in the cross-sectional axis)

What determines the quality and quantity of an echo?....

Important definitions:
• Impedance
  • The resistance to the propagation of sound, resulting in reflection of sound waves (echoes)
  • The amount of reflection is proportional to the difference in the acoustic impedance between the two media
  • Low impedance: liquid
  • Moderate impedance: liver
  • High impedance: bone, stones
  • The higher the impedance, the greater the reflected signal; this produces a brighter image on the monitor
  • If no reflection occurs, the monitor shows BLACK (echo-free)
  • In summary: Reflections occur at points where there are changes in the conducting medium’s acoustic impedance

• Attenuation
  • The loss of signal energy as it passes through tissue
  • Higher impedance=more attenuation
  • Affected by tissue impedance and scanning technique (“scatter”)
  • Attenuation of ultrasound waves occurs by:
    ➢ Reflection=as noted, the amount of reflection is proportional to the difference in the acoustic impedance between the two media; bones, stones reflect the most
    ➢ Refraction=redirection of part of the sound wave as it obliquely crosses a boundary of mediums possessing different propagation speeds; especially next to a fluid-filled structure
    ➢ Scatter=sound waves reflected away from the transducer (due to gas, skin density, scanning angle, etc.); when the ultrasound beam encounters an interface that is smaller than the sound beam or irregular in shape
    ➢ Absorption=energy is contained within the tissue (acoustic energy is converted to thermal energy), and dissipates as heat within the tissue

• Managing attenuation
  • Returning echoes, by nature, are weaker than ultrasound pulses
  • Need to amplify the signal=GAIN
  • The GAIN control amplifies the returning echoes from ALL parts of the screen
  • However, echoes from deeper structures are progressively weaker (attenuated)
  • Distant structures appear artifically less echogenic
• Need a way to adjust gain for deeper echoes: Time Gain Compensation

• **Angle of insonation (angle of incidence)**
  • The angle between the incident ultrasound beam and an imaginary line that is perpendicular to the boundary of the object of interest; important for defining the boundaries of a vessel for a vascular study
  • Translated: need to scan perpendicular to object of interest to maximize returning echoes, improve image quality

• **Resolution**
  • The ability of the sound waves to discriminate between two different objects and to generate a separate image for each
  • Basically, the “quality” of the image being produced
  • **Axial resolution**—parallel to the ultrasound beam (resolving shallower and deeper object)
    • The size of the wavelength (shorter, more resolution) is the major determinant of axial resolution; so higher frequency means better axial resolution, but more attenuation and decreased tissue penetration
    • Axial resolution is a function of Depth:Time elapsed
  • **Lateral resolution**—perpendicular to the ultrasound beam (resolving objects next to one another)
    • The width of the ultrasound beam (array of crystals, distance between individual crystal rays) is the major determinant of lateral resolution, though frequency also plays a role
    • The “focus” allows for enhanced resolution at particular depths of the scanning area, improving the lateral resolution
    • Lateral resolution is a function of the direction of the returning echoes
    • MAIN POINT: maximize your resolution

**Ultrasound Artifacts:**

• **Acoustic shadowing**
  • Anechoic signal caused by failure of the ultrasound beam to pass through an object (due high attenuation due to reflection, absorption, etc.)
  • Anechoic area distal to the reflective or attenuating surface
  • Examples are shadowing from gallstones, rib shadows, or shadowing deep to the vertebral body

• **Gain artifact**
  • When there is excessive amplification of the returning echo
  • “Black is Black” in ultrasound
  • Too much gain may obscure anechoic structures (fluid collections, vessels, etc.)

• **Posterior acoustic enhancement**
  • Certain media allow efficient propagation of ultrasound waves (pleural effusions, abscesses, abdominal free fluid, large vessels, etc.)
  • This increased “through transmission” (uniform transmission) causes tissue behind the media to appear more echogenic than the other surrounding tissue
  • The back wall of a cystic structure (gallbladder) will appear thicker and brighter than anteriorly: “Posterior” wall enhancement

• **Reverberation artifact**
  • When sound “bounces” between two highly reflective objects that are perpendicular to the direction of the ultrasound beam
  • The object is then imaged more than once from these repeated reflections
  • Think pinball machine
  • Recurrent bright arcs (numerous horizontal lines) are displayed at equidistant intervals from the transducer (based on the time elapsed from signal transmission)
  • Commonly occurs at the anterior aspect of the distended urinary bladder or near the layers of the abdominal wall

• **Ring-down artifact**
  • Image artifact created when an object vibrates at a characteristic resonance frequency
  • Resembles a comet tail artifact
  • Helpful in locating a needle when doing ultrasound-guided venous access procedures

• **Mirror artifact**
  • Objects appear on both sides of a strong specular reflector (e.g. the diaphragm)
• Again, think pinball machine
• Mirror image artifact is created when sound reflects off of a strong reflector and is redirected toward a second structure
• The ultrasound wave does not travel directly back to the transducer (instead may bounce between the two reflective surfaces), and the time from signal transmission to signal reception (at the transducer) is increased
• Thus, the grayscale image is displayed as artifactually deeper on the screen
• A good example is the diaphragm (strong specular reflector), and the mirror artifact of the liver on the pleural side of the diaphragm
  • **Lateral cystic shadowing (edge artifact)**
    • Sound waves encountering a rounded or curved structure
    • Results in sound waves refracted away from the original line of propagation, generating a shadow
    • Occurs with the sides of cystic structures
  • **Side lobe artifact**
    • Secondary intensity lobes displaced from the main ultrasound beam that are created by interference
    • Ultrasound beams may originate at angles to the primary beam; highly reflective interfaces return echoes via this pathway or side lobes and may introduce an oblique line of acoustic reflection
    • Especially around the gallbladder

**Other Modes of Ultrasound:**

• **M-mode:**
  • Depicts the motion or deflection of the tissue relative to the transducer on the vertical axis only; represents time on the horizontal axis
  • Helpful for IVC collapse and fetal heart tones

• **Color Doppler:**
  • Velocity information is coded into colors and superimposed on a 2D grayscale, anatomic image

• **Spectral Doppler:**
  • Allows a quantitative assessment for blood flow analysis consisting of continuous or pulsed wave technology

• **Power Doppler:**
  • Uses a different component of the returning signal and often displays a greater sensitivity for evaluation of reduced flow components, as it may be slightly less angle-dependent than spectral or conventional color Doppler technologies (esp in low flow states: testicular, ovarian torsion)

**Other Sono Functions:**

• “**Zoom**” function that allows the operator to magnify an area of interest

• “**Cine**” memory is the stored frames in a memory bank, usually 8-1000 frames; can freeze an image and go back numerous frames to choose best view

• “**Edge enhancement**” emphasizes the gray-scale differences between adjacent tissues of different densities

• **Tissue harmonics**
  • The transducer listens for sound waves returning at twice the frequency of the pulse that was emitted from the transducer (the second harmonic)
  • This “harmonic frequency” is less susceptible to distortion as compared to the traditional frequency; mainly echoes from deeper structures
  • Artifacts due to side lobes and reverberations are greatly reduced
  • Especially helpful for cardiac applications (default setting)

• **Acoustic power** selection refers to the transmit or output power (amplitude) employed to pulse the transducer in all modes of ultrasound
• Dynamic range
  • The range of returning echo intensities that the machine processes in forming a grayscale image (typically 30-78 dB)
  • Higher dynamic range settings tend to give more uniform-appearing images, with more subtle distinctions between tissues of different density (low contrast)
  • Lower dynamic range settings allow for greater contrast (*black is blacker, white is whiter*—high contrast)
  • Higher dynamic range for things like the liver (want to see subtle tissue findings like masses, nodules) versus lower dynamic range for applications like DVT ultrasound (want to see vessels only to assess for compressibility)
Sonography-Assisted Venous Access: Details of Technique, Pearls, Pitfalls

Ultrasound technical and knobology issues

1. Depth
2. Frequency
3. Focus
4. Gain
5. Angle of insonation

Ultrasound beams are reflected back towards the transducer with maximum efficiency if the reflecting surface is at right angles to the beam. This is especially true of highly reflective surfaces ("specular reflectors") such as a needle or a vessel wall. Therefore, to get the sharp images in sono-guided venous access, it’s necessary to rock the probe continually to optimize visualization of these structures, especially since there is usually at least a 30 degree angle between the needle and the vessel (i.e. they cannot both be imaged simultaneously with a 90 degree angle of insonation).

6. Important artifacts
   a. Shadowing
   b. Reverberation
   c. Gain ("Black is Black”)

Transverse vs. longitudinal imaging of the vessel

1. Transverse

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needle and vessel never completely out of “plane”</td>
<td>Need to keep scanning back and forth to find location of needle tip. Cannot tell path of vessel or projected path of needle above or below plane of ultrasound.</td>
</tr>
<tr>
<td>Easier with less experience</td>
<td></td>
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2. Longitudinal

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can see relationship of entire needle w vessel and progress of needle as it approaches and enters vessel. Advance needle /cath within vessel w/o contact w posterior wall under direct visualization. Favored by more experienced practitioners</td>
<td>If needle goes ‘out of plane’ of vessel, harder to determine adjustments needed to redirect</td>
</tr>
</tbody>
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Techniques

1. One person, real-time

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time hand-brain-hand information</td>
<td>Takes a bit more practice</td>
</tr>
<tr>
<td>Can watch the needle through proximal wall and advanced within lumen without damage to distal wall</td>
<td></td>
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<tr>
<td>Human resource issues</td>
<td></td>
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<tr>
<td>Can more easily use both TRV and Longi views</td>
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2. One person, localization, marking, then ‘anatomic’

Works for ascites and pleural taps, but for veins, “localization” w/o real time guidance is little better than plain LM technique
3. One person using needle guides: practical impediments in the ED: stocking and cost issues.

By far the easiest technique to master is single operator. From this point on, this is the technique that is discussed and advocated.

While starting out, especially if a preceptor is available, an assistant may be helpful to organize the space, adjust lighting, take the probe once the vein is entered, etc.

Choice of vein and location
1. Peripheral
   a. In the very obese, will often be able to locate otherwise undetectable veins in usual locations: remember courses of cephalic and basilic veins in upper extremities.
   b. In patients with damaged veins (chemo, IVDA, etc) often find the deep brachial intact: bicipital groove above antecubital fossa. Watch out for the nerve (easily identified by US).

2. Central
   a. IJ is by far the most studied and easiest. If this is absent or unavailable, experienced operators find the supraclavicular approach to the IJ-subclavian confluence preferable to the subclavicular approach to the SC.
   b. Lower IJ is more tethered, therefore more desirable access location, but closer to thorax, therefore often avoided (Denys 1993).

Issues of technique
… prepare, prepare, prepare!

90% preparation + 10% perspiration << 10% preparation + 90% perspiration!

1. Ergonomics.
   a. Have the screen facing you at the patient’s shoulder level. Make sure you have the probe oriented so that the transverse section demonstrated on the screen is spatially in the same orientation as the patient’s anatomy (i.e. the left side of screen will refer to patient’s right when doing peripheral, but patient’s left doing IJ).
   b. Be comfortable: this has a major impact on your chance of success!
      i. For IJ, the patient needs to be in Trendelenburg. If they are on a civil war era gurney without this adjustment, change gurneys unless precluded by extreme exigency (i.e. need STAT access). Would you want a central line started on your dehydrated family member subjecting them to increased risk of multiple sticks, venous trauma, and complications, just because their doctor couldn’t be bothered to put them on the right stretcher?
      ii. Adjust the height of the stretcher.
      iii. For peripheral vein cannulation, find a stool with wheels. This allows for maximal mobility with stability and comfort.
   c. Reconnoiter prior to draping and prepping.
      i. Is the vein present and compressible through it’s entire length?
      ii. Are there valves present?
      iii. Does it take sudden turns?
      iv. Are you sure you’re not looking at an artery in a hypotensive patient (also compressible: use color flow if in doubt).
      v. Especially important for peripheral access: you need to know where the vein runs in someone’s arm to position yourself, to position the arm, and to position the machine.
   d. Again: check compressibility: avoid the multiple sticks I inflicted on 1 patient culminating in “failed” central venous access 2/2 venous thrombosis.
2. Use probe cover and semi-sterile technique even with peripheral lines.
   a. Patient protection
   b. The value of the IV site and your time
   c. Use tegaderm coverage for peripheral lines.
   d. Widely prep the skin as if for blood cultures.

3. Analgesia: USE IT! This is a WIN-WIN PROPOSITION for you and the patient. With peripheral lines, as with central lines, squirt 1-3 cc of 1% lido (TB syringe often works) into the venous access site. This has several advantages:
   a. Patient comfort: many of these pt’s have already had many painful attempts, and the brachial vein is deep and painful to reach.
   b. Operator comfort: if your puncture site is in the wrong place, or your approach to the vein is off-line, spare yourself the pressure of an anxious and irritated patient! They don’t need to feel this, and you’ll be a hero when you “got the line in one shot ... and I didn’t feel a thing!”
   c. Patient cooperation … patient stays still

4. Needle and catheter length
   a. Especially with brachial vein in obese patients, the standard 1.25” IV catheter is too short: the first time they shake their arm or bend it, the tip of the catheter is out of the lumen, in the subQ tissues.
   b. Use at least 1.75 inch catheters
   c. Consider use of 15cm catheters (pending Service Center supply)
   d. If necessary, use A-line kits or long caths in central venous access kits w Seldinger technique.

5. Artery vs. vein vs. nerve
   a. In the upper extremity and neck all 3 are present.
      i. Artery: pulsatile, usually not collapsible [careful w/ hypotension!], color flow + if available
      ii. Veins usually not seen w/o tourniquet or Trendelenburg. Thinner walled, collapsible, larger than arteries.
      iii. Nerves: can see stipple d fascicular appearance when angle of insonation right. Non compressible. After application of tourniquet, veins do not show color flow.
   b. Very light touch not to collapse veins.
   c. In hypotensive pts, arteries may become collapsible w probe pressure.

6. Probe manipulation
   a. You will hold the probe in your non-dominant hand (the one normally used to stabilize the skin and-or palpate the vein).
   b. Hypothenar surface of hand against pt skin to stabilize probe and avoid slippage, maintain correct pressure.

7. Angle of needle advance
   a. May need to be steeper than for subcutaneous vessels: 30 degrees often optimal. This is both because the vessels are often deeper, and one doesn’t want several inches of subcutaneous tunnel (and can’t afford it with normal length catheters), and because a steep angle is needed to pierce the venous wall.
   b. Steep angle of advance makes puncture of distal wall more likely. Use real-time sonographic visualization of proximal vessel wall entry and advance of needle within lumen.

8. Vein entry
   a. Watch the screen.
      Don’t bother to look for flash-back unless you’re really unsure whether you’re in the vein … this is a sono-guided procedure … you’re probably in a darkened room anyway.
   b. Once you have entered the vein, the job is only half done!
      Continue to watch the needle as it is advanced far enough for the bevel and/or catheter to be completely through the vessel wall and inside the lumen. Lower inserting hand toward pt’s skin: this raises the tip of the needle to avoid catching the back wall of the vein. Advance needle another 1 cm in vein under direct sono visualization.
   c. Put the probe down in a place where it can’t fall on the floor (preferably in its holster on the machine). With your free 2nd hand advance the catheter as for traditional access technique. Secure line as per usual.