Basic Ultrasound Physics and Knobology

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• A basic overview of sound

• Understanding types of transducers, and basic modes

• Understanding common controls across platforms

• Optimizing images
Sound is a Longitudinal mechanical wave
Compressions an rarefacons of molecules in gas, liquid, or solid
Sound is a Longitudinal mechanical wave
Compressions and rarefactions of molecules in gas, liquid, or solid
• **Audible sound** 20 Hz to 20 KHz

• **Ultrasound** > 20 KHz

• **Diagnostic Ultrasound** 1 MHz to 20 MHz
• **High Frequency (MHZ) gives better resolution, but limited tissue depth of view**

• **Low Frequency gives better tissue penetration**
Ultrasound Wave Interaction With Tissues

- Specular=mirror reflectors-ANGLE is CRITICAL FOR SPECULAR REFLECTORS
  (image demonstrates apparent gaps in vessel wall on sides due to lack of reflection)
- Scatter=diffuse, irregularities in surface are larger than wavelength of wound wave
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Speed and Time

Characteristics of Sound Waves

- **Period**
- **Frequency**
- **Wavelength**
- **Propagation speed**
  - 1540 m/s in soft tissue, vs. 330 in air

Period - Duration of one cycle 0.1-0.5 microsecs for US

Wavelength = Velocity (1540 m/s) X Frequency (in mHZ)
Bigness Characteristics of Sound

- Amplitude
- Power
- Intensity
Power/Intensity

• **Power**: Amount of energy transferred to tissues total

• **Intensity**: Concentration of energy

Bioeffects on tissues regulate limits of power output by medical US imaging devices.
Power/Intensity

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Bioeffects on tissues regulate limits of power output by medical US imaging devices.
Transducer Design

Uncouples internal components from case
Absorbs unnecessary sound
Piezoelectric crystal

• Piezo Electric crystals create sound when electricity applied
Energy created varies based on how fast and how strong electrical impulses are sent to crystals
• Traditional-One sending/one receiving, or stepwise (L to R)

• Phased array-smaller footprint, but triangular image to see wide area

Non-phased array- shape of beam matches shape of probe end
Phased, by timing the energy releases the combined wavefronts can be shaped
Creating an image

- Sound enters tissue

- Transducer sends sound and receives reflection, machine measures time, and since velocity known (1540) it plots distance

- Brightness=amount of reflection, acoustic characteristics of tissues
Display Modes

- A-mode
- (history)
- B-mode
- “2D”
- M-mode
Knobology Rules

- "Platform vary, but basics don’t"
- Button location will vary based on manufacturer design, so don’t worry if you cannot find them right away
- More important to know basic approach
- "Continue to learn ‘knobs’ as you scan"
- Understand basic knobology before scanning.
- Acceptable to review knobology as you are scanning
Knobology Rules

- Platform manipulation and probe handling are key to:
  - Achieving technical know-how
  - Achieving interpretation expertise
device footprinting evolving...
so know ‘pros’ & ‘cons’
device footprinting evolving... so know ‘pros’ & ‘cons’
device footprinting evolving...
so know ‘pros’ & ‘cons’

Portability

Power / Capability
Preparing to scan
Preparing to scan

Turn power on
Ensure Proper Connections
Ensure proper connections.

Ensure properly connected probe adapter.
Ensure Proper Connections

Ensure properly connected probe adapter.

Connect ECG cable, either via patient monitor or applied 3-lead ECG.
Select Your Transducer

Select 'Cardiac' transducer
Different vendors have different probes. It is important to know your vendor’s probes, their usages, limitations, etc.
# Common Transducers

<table>
<thead>
<tr>
<th>Type</th>
<th>Frequency Range</th>
<th>Width</th>
<th>Scan Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Cardiac'</td>
<td>5-1MHz</td>
<td>Phased array</td>
<td>35cm</td>
</tr>
<tr>
<td>'Linear'</td>
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<td>'Small curved'</td>
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Common Transducers

- **'Cardiac'**
  - Frequency: 5-1MHz
  - Phased array
  - Scan depth: 35cm

- **'Linear'**
  - Frequency: 13-6MHz
  - 25-mm broadband
  - Scan depth: 6cm

- **'Small curved'**
  - Frequency: 8-5MHz
  - Curved array
  - Scan depth: 10cm

**Remember:**
- ↓ Frequency = ↑ penetration = ↓ resolution.
- ↑ Frequency = ↓ penetration = ↑ resolution.
Enter patient data

Patient
Preferable to enter patient info before image storage.
Patient data entry and storage

Create patient
• Use keyboard
• HT, WT, BP to obtain indexed values.

Enter name, dob, etc.
Ht, weight to obtain indexed values. Such as cardiac index
Same page typically accessed to export images
Before you scan... review platform

- **options**
- **keyboard**
- **gain**
- **2D Doppler**
- **M-mode**
- **Image manipulation/calculations**
Before you scan... review platform

- Keyboard
- Gain
- Image manipulation/calculations
- 2D Doppler
- M-mode
- Options
Be aware of options

Options may change with mode selection.
Adjust sweep speed
Adjust sweep speed

AV interrogation via M-mode

Slower
Adjust sweep speed

- Faster AV interrogation via M-mode
- Slower IVC collapsibility
Gain

- This is a receiving function
- Does not impact how much energy is transmitted to patient (i.e. power)
TGC allows compensation for Attenuation of signal due to absorption
Adjust gain & time gain compensation (TGC)

- Near field
- Strong reflected signals

Far field
- Weak reflected signals

Time Gain Compensation (TGC)
- Corrects varying depths of intensities in imaging field
- Adjust TGC to:
  1. Decrease in the near field
  2. Increase in the far field

TGC allows compensation for Attenuation of signal due to absorption
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- **Near field**
- **Strong** reflected signals

- **Far field**
- **Weak** reflected signals

### Gain
- OVERALL amplification of returning ultrasound signal received from ALL depths

### Time Gain Compensation (TGC)
- Corrects varying depths of intensities in imaging field
- Adjust TGC to:
  1. Decrease in the near field
  2. Increase in the far field
**Extremes in tgc & gain**

<table>
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<tr>
<th>Too bright high amplitude</th>
<th>Too dark low amplitude</th>
</tr>
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<tbody>
<tr>
<td><img src="image1.png" alt="Image of bright condition" /></td>
<td><img src="image2.png" alt="Image of dark condition" /></td>
</tr>
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</table>
Extremes in tgc & gain

Too bright high amplitude

If gain too high, noise amplified, so differentiation lost

Too dark low amplitude
graded tgc.....
Gradual near-to-far field adjustment
graded tgc.....

Gradual near-to-far field adjustment
gain affects image interpretation

Optimal gain
Optimal gain affects image interpretation.
gain affects image interpretation

Signal “blooming” vs. Signal “dropout”

↑ (‘over’) gain
↓ (‘under’) gain
gain affects image interpretation

↑ (‘over’) gain  ↓ (‘under’) gain
Gain affects image interpretation

Extent of left pleural effusion?

↑ ('over') gain

↓ ('under') gain
2D
• Two-dimensional imaging
• Most systems default to 2D at startup

Freeze
• Regulates between active and still image
2D-live vs. 2D-freeze

2D ‘live’ image

2D ‘frozen’ or ‘still’ image
2D-live vs. 2D-freeze

2D ‘live’ image

2D ‘frozen’ or ‘still’ image
M-mode

Temporal measurement of object(s) movement away and toward transducer
M-mode

IVC via 2D

IVC via M-Mode

Distance

Time

IVC collapsibility via M-Mode
M-mode

IVC via 2D

IVC collapsibility via M-Mode

Distance

time
Doppler modes: pulse wave (PW), color flow (CF), continuous wave (CW)

**CW**
- Transducer emits & receives **continuously**
- **High** velocity
- Velocity **depth indeterminate**

**PW**
- Transducer emits ultrasound in **pulses**
- **Lower** velocity
- Velocity **depth measurable**

**CF (CFM)**
- Type of PW, transducer emits **pulses**
- **Flow** direction/dynamics **color coded**
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Anatomy of Pulsed Ultrasound Beam

- **Receive Time**
- **Listening Time**
- **Off Time**

- **Transmit Time**
- **Talking Time**
- **On Time**

- **Pulse repetition period**
- **Pulse repetition frequency**

- **Pulse Duration**
- **Pulse Length**

**Duty Factor** = \( \frac{\text{Pulse Duration}}{\text{Pulse repetition period}} \)
Pulse Wave Doppler
Pulse Wave Doppler
Place your 'sample volume box' over area of interest.
Pulse Wave Doppler
Pulse Wave Doppler

Trace LVOT VTI + adjust HR using trackball.
By convention, Blue is Away from transducer—watch for “invert”
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Color Flow Doppler

Adjust 'Region of interest' for color display

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Color Flow Doppler

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Color Flow Doppler
Color Flow Doppler

![Color Flow Doppler Image]
Color Flow Doppler

Adjust "Color scale": range of velocities displayed
Color Flow Doppler

Detecting low velocities requires lower color scale.
Continuous Wave Doppler
Continuous Wave Doppler
Continuous Wave Doppler
Continuous Wave Doppler

Move cursor using `trackball` mark with `Set` button.
Continuous Wave Doppler

\[ V = 4.20\text{m/s} \]
\[ P = (4v^2) = 70.67\text{mmHg} \]
Adjust depth, sector size, zoom...

**Trackball & Set**
- **Ball** controls cursor movement, sector size, window rotation.
- **Set** locks & unlocks.

**Zoom**
Live image amplification of defined area.

**Depth**
Controls the maximal imaging display distance.
Effects of Imaging Depth

- **Image size**
  - Depth change affects reduction/enlargement of displayed structures ➔ affects evaluation

- **Frame rate**
  - Time per second an image is updated
  - ↑ Depth of structure = ↑ US penetration needed = ↑ wait-time between pulses = ↓ frame rate
Effects of Imaging Depth

- Temporal resolution
  - Ability to evaluate rapidly moving structures
  - Directly related to frame rate
  - For optimal temporal resolution keep imaging depth just beyond region of interest

- Lateral resolution
  - Ability to evaluate structures perpendicular to US beam
  - \[ \text{Depth of structure} = \frac{\text{lateral resolution}}{} \]
Effects of Imaging Depth

- **Sector size**
  - Usually starts with ‘wide & deep’ sector for broad view
  - Wide sector size = ↓ frame rate & ↓ temporal resolution
  - If fast moving structure, narrow your sector or consider M-mode

- **Zoom**
  - Magnification without change in resolution
Real-Time Imaging

- **Frame rate**
- **Temporal resolution**
  - line density
  - sector size

- Absolute amount of info returning slows procession
- Depth of viewing determines frame rate
- USE THE NARROWEST AND SHORTEST WINDOW YOU CAN
Sector Width
Sector Width
Calculations

Worksheet
- Compiles data & calculations.
- May edit, delete, save.

Measure
- Brings up cardiac calculations folders.
- Some devices, use 'trackball,' 'cursor,' and 'set' to access.
Calculations & Measurements

Cardiac calculation
• Open folder
• Using 'cursor,' select specific measure or calculation.
Calculations & Measurements

**Cardiac calculation**
- Open folder
- Using 'cursor,' select specific measure or calculation.
LVOT Measurement

Measurements parallel to beam are most accurate, try to orient imaging to obtain this, example measure LVOT from PSLAX not Apical view.
LV 2D Measurements
Options: image optimizing techniques
Options: image optimizing techniques

- Frequency (freq)
  - ↑ freq = ↓ penetration = ↑ resolution of proximal structures
  - If deep structures, will need ↓ freq.
  - If superficial structures, will need ↑ freq.
  - For example, obese patient may need ↓ freq.

Higher Frequency=greater attenuation in tissues
Frequency

↑ freq = ↓ penetration

↓ freq = ↑ penetration
Frequency

↑ freq = ↓ penetration

↓ freq = ↑ penetration

Freq 3.6 MHz

Freq 1.5 MHz
B-color

Grey color scale
B-color

Grey color scale
B-color

Blue color scale

Orange color scale
Summary

- Remember how to choose an **appropriate ultrasound transducer**
- Apply the basics of an **ultrasound platform** to any echocardiography device
- Practice basic **image optimizing techniques**
• Ultrasound beam reflection is the basis for the image

• High frequency=high resolution but low penetration depth

• Image quality and temporal resolution are at odds

• Optimizing gain and imaging settings is essential for interpretation
Questions?