SOUND PRINCIPLES

Christian R. Falyar, CRNA, DNAP
Assistant Professor of Doctoral Studies
Virginia Commonwealth University
Department of Nurse Anesthesia
Introduction

• The incorporation of ultrasound into anesthetic procedures has become commonplace in recent years. Numerous studies have shown that when used correctly, ultrasound reduces the incidence of complications, as well as decrease patient recovery times and improve overall outcomes.
Objectives

- Review the physics and principles of sound
- Describe how an sound wave is generated
- Discuss the interaction between an ultrasound wave and different tissue media
- Explain how an ultrasound image is created
- Understand how Doppler ultrasound can be used to clarify an ultrasound image
- State how commonly seen artifacts impact an ultrasound image
What is sound?

- Sound is a form of mechanical energy.
- Sound travels at **different speeds through different substances, or media**.
- As sound travels through media, it can be **reflected**, **refracted**, **scattered**, **reverberated** and ultimately **attenuated**, providing information about its make-up.
- Ultrasound used in in diagnostic imaging involves frequencies greater than 1MHz.
## Propagation velocity

<table>
<thead>
<tr>
<th>Medium</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>331 m/s</td>
</tr>
<tr>
<td>Brain</td>
<td>1,541 m/s</td>
</tr>
<tr>
<td>Kidney</td>
<td>1,561 m/s</td>
</tr>
<tr>
<td>Liver</td>
<td>1,549 m/s</td>
</tr>
<tr>
<td>Muscle</td>
<td>1,585 m/s</td>
</tr>
<tr>
<td>Fat</td>
<td>1,450 m/s</td>
</tr>
<tr>
<td>Soft Tissue (average)</td>
<td>1,540 m/s</td>
</tr>
<tr>
<td>Bone (different densities)</td>
<td>3,000 to 5,000 m/s</td>
</tr>
</tbody>
</table>
What is sound?
What is sound?

- Rarefactions (low pressure)
- Compressions (high pressure)
Sound waves

- Frequency is determined by the number of cycles (compressions and rarefactions) that occur in a second.
- Wavelength is inverse to the frequency (i.e. the higher the frequency the shorter the wavelength).
- Amplitude describes the energy of the wave, and is not related to frequency.
Thoughts on frequency...

High frequency

- More cycles occur per second
- Images are higher resolution
- Greater attenuation of the sound waves limits the depth at which tissue can be imaged

Low frequency

- Fewer cycles occur per second
- Greater tissue penetration but lower resolution
- Less attenuation allows for imaging of deeper structures
Thoughts on frequency...

High frequency

Low frequency
Generation of sound waves

- A wave is generated when an ultrasound system applies an electrical field to crystals located on the transducer.
- These crystals convert the electrical energy to mechanical energy; this is known as the **piezoelectric** effect.
- The sum of the waves is an ultrasound beam.
- These beams are emitted in pulses, with each beam being two to three cycles in length.
Generation of sound waves

- outer housing
- backing material
- alternating current to create potential difference
- piezoelectric crystals
- matching layer
- acoustic insulator
- power supply

Diagram:
- Alternating Current
Transducers

- Transducers are the link between the ultrasound system and the tissue.
- Most transducers used for regional anesthesia are either linear or curved array transducers.
- Transducers use the **piezoelectric effect** to create an image.
- Axial and lateral resolution are determined by the characteristics of the transducer.
Sound wave properties

Focal Zone

Fresnel Zone
(Near Zone)

Fraunhofer Zone
(Far Zone)
Generation of sound waves

• The echoes interpreted by ultrasound result from the different acoustic impedances of tissues
• The amount of reflection, refraction, scattering, and attenuation is dependent on the degree of difference
## Acoustic impedance

<table>
<thead>
<tr>
<th>Body Tissue</th>
<th>Acoustic Impedance (10^6 Rayls)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.0004</td>
</tr>
<tr>
<td>Lung</td>
<td>0.18</td>
</tr>
<tr>
<td>Fat</td>
<td>1.34</td>
</tr>
<tr>
<td>Liver</td>
<td>1.65</td>
</tr>
<tr>
<td>Blood</td>
<td>1.65</td>
</tr>
<tr>
<td>Kidney</td>
<td>1.63</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.71</td>
</tr>
<tr>
<td>Bone</td>
<td>7.8</td>
</tr>
</tbody>
</table>
Sound/Tissue interaction

Reflection

Refraction

Scattering

Attenuation

Incident Wave

Reflected Wave

Impedance $Z_1$
Impedance $Z_2$

Incident Wave

Reflected Wave

Impedance $Z_1$
Impedance $Z_2$

Incident Wave

Refracted Wave

Transducer

Attenuated Wave
Reflection

Specular vs. Diffuse Reflection

- Specular Reflection: The wave is reflected in a predictable, direct path. Impedance $Z_1$.
- Diffuse Reflection: The wave is scattered in multiple directions, with transmitted waves also present. Impedance $Z_2$. 
Reflection

Specular

Diffuse
Refraction

- Incident Wave
- Reflected Wave
- Refracted Wave
- Impedance $Z_1$
- Impedance $Z_2$
Rayleigh scattering

- Rayleigh scattering occurs at interfaces involving structures of small dimensions (such as a red blood cell).
- This creates a relatively uniform average amplitude in all directions.
Rayleigh scattering

- Who/What is Mickey?
Attenuation

- The decreasing intensity of a sound wave as it passes through tissue
- In medical ultrasound, attenuation is the result of the interaction of sound with tissue
- The attenuation coefficient is the relation of attenuation to distance, and is dependent on the tissue traversed and the frequency of the ultrasound wave
- Higher frequency waves are attenuated to a higher extent than lower frequency waves
## Attenuation coefficients

<table>
<thead>
<tr>
<th>Body Tissue</th>
<th>Attenuation Coefficient (dB/cm at 1MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.002</td>
</tr>
<tr>
<td>Blood</td>
<td>0.18</td>
</tr>
<tr>
<td>Fat</td>
<td>0.63</td>
</tr>
<tr>
<td>Liver</td>
<td>0.5-0.94</td>
</tr>
<tr>
<td>Kidney</td>
<td>1.0</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.3-3.3</td>
</tr>
<tr>
<td>Bone</td>
<td>5</td>
</tr>
</tbody>
</table>
Attenuation
What creates my picture?

• It’s all in the math!!!
• The computer assigns a color in a grey scale based on the strength of returning echoes to form the image.
• This process repeats itself hundreds of times a second resulting in real-time imaging.
What do tissues look like?

- **Nerves** – in cross section appear as round “honeycomb” structures
- **Tendons** – appear similar to nerves, but become flat and disappear when followed proximally along an extremity
- **Vascular Structures** – typically appear as anechoic circular structures in cross-section. Will appear tubular in longitudinal view
- **Fat** – appears hypoechoic with streaks of irregular hyperechoic lines
- **Fascia** – appears linear hyperechoic structures marking tissue boundaries
- **Muscle** – appears feather-like in longitudinal view; appears as a “starry night in cross-section, more hypoechoic than nerves
- **Pleura and Air** – pleura appears hyperechoic, with the lung appearing hypoechoic underneath
- **Cysts** – similar appearance to vascular structures, cysts will also appear as hypoechoic in longitudinal view
- **Bone** – appear as hyperechoic linear structures with hypoechoic regions underneath (shadowing)
Not all nerves look the same...

Peripheral Nerves

Roots of the Brachial Plexus
Nerves vs. Tendons

- Nerves and tendons can both appear as hyper-echoic circles in the periphery.
- They can be differentiated by following their course proximally along the extremity.
Adipose tissue

- Adipose tissue appears hypoechoic with streaks of irregular hyperechoic lines
- It is the most superficial layer imaged
Arteries, veins and cysts

- Arteries, veins, and cysts all appear as anechoic structures.
- Arteries are pulsatile, while veins can be easily compressed.
- Arteries and veins will appear as tube-like structures in long view, cysts will remain round.
Muscle

- Muscle appears heterogeneous on ultrasound because of the varying acoustic impedances between the cell structures, the water content within the cells, and the intertwined fascia.
Lung tissue appears as a thin hyperechoic line with “tails” (areas of reverberation) beneath it.
Bone

- Bone is a significant specular reflector, creating a hyperechoic area with shadowing beneath it.
The Doppler effect

"Über das farbige Licht der Doppelsterne und einige andere Gestirne des Himmels - Versuch einer das Bradleysche Theorem als integrierenden Theil in sich schliessenden allgemeineren Theorie"

Christian Andreas Doppler
1803-1853
Doppler effect

- Animals use Doppler in nature and it has been adapted by man for many purposes
- Doppler is dependent on the angle of insonation
- Either the sender or receiver must be moving
- Doppler is used to create an image
Doppler effect

\[ \cos 0 = 1 \quad \cos 90 = 0 \]

negative shift

sound frequency decreased (< 300 Hz)
siren emits a sound at 300 Hz

positive shift

sound frequency increased (> 300 Hz)
Doppler effect

- The Doppler effect compares the transmitted to the received signal.
- The transducer emits a pulse into tissue. When the pulse comes in contact with a moving object (RBC), it is reflected back to the transducer; the difference between the transmitted and received signals is the Doppler effect.
Doppler effect

Arterial

Venous
Doppler effect

Phasic

Non-phasic
Doppler effect
Doppler effect

Which picture is correct?
Know you Doppler physics...

http://www.medison.ru/uзи/eng/all/vessels.htm
Artifacts

• An artifact is any phenomenon that affects the acquisition or interpretation of an ultrasound image

• Artifacts can occur because of properties within the tissue itself, or created by the anesthetist

• The most commonly seen artifacts are air artifact, shadow artifact, acoustic enhancement, and reverberation
Air artifact

- Air artifact occurs when the transducer does not fully contact the skin.
- This is commonly seen when imaging smaller anatomical structures.
- Applying sufficient gel to the transducer and applying even pressure will correct this.
Shadow artifact

- Shadow artifact (red arrows) results from the severe amount of attenuation when an ultrasound wave comes in contact with bone or other tissue with a high attenuation coefficient.
Acoustic enhancement

- Acoustic enhancement occurs when a beam passes through tissue with low acoustic impedance into tissue with a much higher impedance, causing it to look more echogenic than it actually is.
Reverberation

- Reverberation occurs when sound reflects off strong specular reflectors such as this block needle, creating an illusion that there are "multiple" needles below the actual one.
Questions?
References

References


