Ultra-effective Ultrasound

Why, when, and how to effectively use therapeutic ultrasound!

But where did it come from?

brief history of ultrasound
Ultrasound

- Isn’t that what they used to take a picture of my baby when I was pregnant?
Ultrasound

- Historical Perspective:
  - 1920s
    - acoustical energy for underwater detection
  - 1930s
    - Low intensity US in physical medicine to produce heat in treatment of soft tissue injuries
• Physical Principles
  ◦ Sound is produced by the vibration of a medium
    • If a column of air is vibrated, the human ear may be able to perceive the disturbance.
      ◦ Only if it is in an audible range!
        • That range is from 20 to 20,000 Hz
Think of the beating of a drum...

- Sound exerts pressure on the medium it travels through
  - Compressing and then releasing pressure
  - Sound cannot travel in a vacuum
Ultrasound
• We hear the disturbance of the air particles because of the frequency or pitch of the sound is:
  ◦ 20 - 20,00 cycles per second
  ◦ US is either 1MHz or 3 MHz

• Even he can’t hear it!
<table>
<thead>
<tr>
<th>Species</th>
<th>Frequency Range (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>human</td>
<td>64-23,000</td>
</tr>
<tr>
<td>dog</td>
<td>67-45,000</td>
</tr>
<tr>
<td>cat</td>
<td>45-64,000</td>
</tr>
<tr>
<td>cow</td>
<td>23-35,000</td>
</tr>
<tr>
<td>horse</td>
<td>55-33,500</td>
</tr>
<tr>
<td>sheep</td>
<td>100-30,000</td>
</tr>
<tr>
<td>rabbit</td>
<td>360-42,000</td>
</tr>
<tr>
<td>rat</td>
<td>200-76,000</td>
</tr>
<tr>
<td>mouse</td>
<td>1,000-91,000</td>
</tr>
</tbody>
</table>

How well do they hear?
<table>
<thead>
<tr>
<th>Species</th>
<th>Frequency Range Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>gerbil</td>
<td>100-60,000</td>
</tr>
<tr>
<td>guinea pig</td>
<td>54-50,000</td>
</tr>
<tr>
<td>hedgehog</td>
<td>250-45,000</td>
</tr>
<tr>
<td>raccoon</td>
<td>100-40,000</td>
</tr>
<tr>
<td>ferret</td>
<td>16-44,000</td>
</tr>
<tr>
<td>opossum</td>
<td>500-64,000</td>
</tr>
<tr>
<td>chinchilla</td>
<td>90-22,800</td>
</tr>
<tr>
<td>bat</td>
<td>2,000-110,000</td>
</tr>
<tr>
<td>beluga whale</td>
<td>1,000-123,000</td>
</tr>
<tr>
<td>elephant</td>
<td>16-12,000</td>
</tr>
</tbody>
</table>

How well do they hear?
<table>
<thead>
<tr>
<th>Species</th>
<th>Frequency Range Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>porpoise</td>
<td>75-150,000</td>
</tr>
<tr>
<td>goldfish</td>
<td>20-3,000</td>
</tr>
<tr>
<td>catfish</td>
<td>50-4,000</td>
</tr>
<tr>
<td>tuna</td>
<td>50-1,100</td>
</tr>
<tr>
<td>bullfrog</td>
<td>100-3,000</td>
</tr>
<tr>
<td>tree frog</td>
<td>50-4,000</td>
</tr>
<tr>
<td>canary</td>
<td>250-8,000</td>
</tr>
<tr>
<td>parakeet</td>
<td>200-8,500</td>
</tr>
<tr>
<td>cockatiel</td>
<td>250-8,000</td>
</tr>
<tr>
<td>owl</td>
<td>200-12,000</td>
</tr>
<tr>
<td>chicken</td>
<td>125-2,000</td>
</tr>
</tbody>
</table>

**How well do they hear?**
References:

Sound energy is transmitted as a wave. Each vibrating particle collides with and displaces its neighbor, transferring momentum and losing some energy along the way.
Newton’s Cradle

Some what “if”s?

http://commons.wikimedia.org/wiki/Newton%27s_cradle

Sound, not mass....
http://www.lhup.edu/~dsimanek/scenario/cradle.htm
• Waves travel through media in three modes:
  ◦ Longitudinal-
    • compression and decompression
  ◦ Transverse
    • Shear (solids, bone)
  ◦ Standing
    • Source of the waves is kept stationary opposite a boundary and the path of the incident and reflected wave coincide
So why should you care?
Ultrasound

- Transverse Waves
  - Ultrasound loves heterogenous surfaces
    - These are areas between tissues of different tissue types with different densities
      - These create reflective surfaces and the sound waves bounce off and reflect back into the surrounding soft tissue in these areas similar to light bouncing off of a mirror
Ultrasound

- Waves
  - Standing Waves
    - To prevent the formation of standing waves and the resultant high peaks in energy the transducer must continuously be moved.

- http://www.physicsclassroom.com/Class/waves/u10l3b.cfm
How is Ultrasound used today?

“Ultrasound is a commonly used therapeutic modality that can increase temperature in deep tissue. The thermal effects of ultrasound can accelerate healing by increasing metabolism and blood flow and by decreasing chronic inflammation. Heat also reduces muscle spasm and pain, and vigorous heating can improve the range of motion by increasing the elastic properties of collagen.”

How is Ultrasound used today?

- “Draper et al. measured the rate of temperature rise in human muscle with a range of ultrasound intensities. Their study was the first to measure temperature increases at frequencies of both 1 and 3 MHz. This work provided clinicians with guidelines regarding the intensity, frequency, and duration of treatment necessary to raise tissue temperature at a given depth to a level necessary to achieve therapeutic effects.”

How is Ultrasound used today?

- To increase temperature in deep tissue
- To accelerate healing by increasing metabolism and blood flow
- To reduce muscle spasm and pain
- To reduce chronic inflammation
- To help improve the range of motion by increasing the elastic properties of collagen.


Ultrasound Characteristics

• Frequency:
  ◦ Number of events that take place within a set time frame
    • Sound = # of cycles per second
      ◦ Higher pitch = higher frequency
      ◦ Lower pitch = lower frequency
Ultrasound Characteristics

- Frequency:
  - Higher frequency sound waves vibrate air molecules more rapidly
    - expend energy more quickly
    - Travel a shorter distance
Ultrasound Characteristics

- Frequency:
  - Lower pitch sounds vibrate air molecules more slowly
    - Expend their air more slowly
    - Travel greater distances
So, what does this have to do with Ultrasound?

- Therapeutically, we use 2 different frequencies
  - 1MHz & 3MHz
    - The indications for the different frequencies are based upon the depth of penetration
• **Woofer**
  ◦ 1 MHz
  ◦ deep, depending upon the underlying tissue and homogeneity
  ◦ slower response due to less absorption

• **Tweeter**
  ◦ 3 MHz
  ◦ superficial, at a palpable depth, depending upon the underlying tissue
  ◦ quick results for absorption
Fill in the blanks:

- The higher the ______ the shallower the depth of penetration.
- The lower the ______ the deeper the depth of penetration.
Duty Factors

- Pulsed Ultrasound
  - It is only producing ultrasound when it is ON
  - This is a fixed function of the unit
  - Lower duty factors help to stimulate tissue healing due to changes in cell membrane permeability
    - Greater mechanical compression and relaxation effects
The _____ the percentage of ON time, the more thermal the effects will be.

The _____ the percentage of OFF time, the more thermal the effects will be.
Cavitation

- **Friend or Foe?**
- Violent collapse of bubbles within the target treatment area tissue
- Tissue damage occurring internally first
- Tissue implosion
• can be caused by
  ◦ stationary head technique
    • continuous or pulsed ultrasound
  ◦ low ERA
  ◦ high BNR
  ◦ inappropriate frequency selection
- increased cellular activity
- diffusion changes along the cell membrane
- oscillatory movement of cells
  - influencing inter and intracellular fluid levels
  - stimulation of mechanoreceptors for pain relief
Beam Non-uniformity Ratio

- BNR
  - homogeneous beam
    - predictable pattern
    - no spot heating
    - smaller chance of creating hot spots that exceed safe levels
Beam Non-uniformity Ratio

- BNR
  - high ratio
    - non-homogeneous
    - hot spots
    - difficult to reproduce results
    - potential dangerous to cells
• BNR refers to which of the following?
   ◦ a. the quality of the beam
   ◦ b. the beam non-uniformity ratio
   ◦ c. the intensity of the beam as set on the unit
   ◦ d. a fixed attribute of the crystal
   ◦ e. a parameter on the unit that can be adjusted
   ◦ f. Body Not Ready to take a quiz on ultrasound yet.
Effective Radiating Area

- ERA
  - high percentage
    - reproducible results
    - predictable treatment area
  - shorter, more effective treatment time than with a low percentage transducer
Effective Radiating Area

- ERA
  - low percentage
    - hot spots
    - longer Rx time
    - less reliable
weekly
- equipment
  - transducer
  - cellophane tape
  - water
  - steady hand
  - ability to move hands independently and simultaneously while looking at a dial... *(a skill that all clinicians learn when first learning how to apply ultrasound)*
to phores means “to push through”

- Iontophoresis - pushing or repelling like ions of a medication via the application of direct current, 2 electrodes, an ionized medication, a patient, and.....electrical energy
• What about phonophoresis?
  ◦ how deep?
  ◦ molecular push, not ionic push
  ◦ what are you trying to phores?
  ◦ how is it made up?
  ◦ what is the strength of the mixture?
  ◦ do you need a coupling agent?
Coupling Media

• Purpose
  ◦ to exclude air from in-between the transducer and the skin
  ◦ to transmit ultrasonic energy
    • aquasonic gel  72.6% transmission
    • distilled water  59%
    • petroleum jelly  0%

• http://www.electrotherapy.org/modalities/ultrasound%20basics.htm
Acoustical Streaming

- a unidirectional flow of tissue components, which occurs at the cell membrane level
  - increased cell membrane and vascular wall permeability
  - increased ion fluxes and cellular activity
  - increased capillary density and improved blood flow
  - increased protein synthesis with enhanced wound healing
Duty Factor

- actually refers to the % of ON time
- lower duty factors produce less heat, but are more biostimulative
- Less may be better.... *(would you rather be sharply nagged or gently nudged?)*
Dosage

- There is more to dosage than...
  - “1.5W/cm² for 5-7 minutes”
  - Dosage is dependent upon the treatment goals and the depth of the tissue that is being treated

http://www.electrotherapy.org/modalities/ultrasound%20doses.htm
Treatment Time

- not every treatment needs to be “5 - 7 minutes”
  - it is dependent upon
    - the treatment goal
    - the size of the transducer
    - the size of the treatment area (which should not exceed two times the size of the transducer)
“Compiling the treatment dose. The final compilation of the treatment dose which is most likely to be effective is based on the principle that one needs to deliver 1 minutes worth of ultrasound energy (at an appropriate frequency and intensity) for every treatment head that needs to be covered.”

http://www.electrotherapy.org/modalities/ultrasound%20doses.htm 2010
What does BNR have to do with intensity?

(by multiplying the BNR times the intensity, you will determine what the maximum potential intensity would be)

BNR x W/cm² = worst case scenario
What does ERA have to do with the movement of the transducer?

If your ERA is a high % of the surface area of the transducer, then you are producing US under a higher % of the transducer.
How large should the treatment area be, relative to the size of the transducer?

no more than two times the size of the transducer
(as long as the transducer has a high ERA)
Can manual skills be combined with ultrasound?

**WHY NOT?**

ultrasound produces cellular changes during insonation...
How many treatments would be considered too many?

if the ultrasound is **not** producing sustained relief for the patient, it should be discontinued

THERE IS NO MAGIC NUMBER!!
Why do some patients complain of an achy feeling about an hour after ultrasound?

Your intensity was too high and/or the crystal was of poor quality.
Is underwater treatment effective?

...don’t water bubbles collect on the surface of the skin?

Hmmmm
What is the difference between the external dimensions of a transducer and the ERA?

the crystal is mounted inside the transducer, AND
the ERA is a % of the crystal that produces US
How would we know what the ERA and BNR were for the units in our department?

It should be labeled on the unit or you should be able to call and ask the manufacturer.

*(you need to provide the serial #)*
Ultrasound

- One of the variables that can be adjusted is referred to as the duty factor or ON time.
  - This “parameter” determines whether or not the ultrasound is continuous or pulsed.
  - Continuous ultrasound produces more heat than pulsed ultrasound
    - Duty factors that are higher are considered more thermal than those that are lower.
    - You could compare them to a nudge versus a nag....
POP Quiz!!!

- The lower the BNR, the more _____ the delivery of the acoustical energy will be to the target treatment tissue.
- The higher the ERA %, the more _____ the treatment effects will be.
- The more efficient the crystal, the _____ the % of the surface area is the ERA.
POP Quiz!!!

Which of the following parameters controls the depth of penetration for ultrasound treatments?

- a. intensity
- b. duty factor
- c. transducer size
- d. frequency
- e. I don’t know and I don’t understand this
POP Quiz!!!

If you were treating a patient with chronic lateral epicondylitis to produce a heating effect in the joint capsule, approximately how long would it take if you used a 5cm$^2$ transducer?

- 5 minutes, 8 minutes, 1.5-2 minutes......
- I don’t have a clue!
- Physicians prescribe the treatment time, not PTs or PTAs. Doesn’t the physician tell the clinician everything they need to know?
POP Quiz!!!

Why would treating the paraspinal lumbar musculature with ultrasound be an inappropriate utilization of the modality? (10cm² transducer)

- a. you would be there forever if a thermal effect was desired, and perhaps never achieve the temperature elevation desired anyway.
- b. It would be appropriate, I have seen it many times before.
- c. Ultrasound is a better spot heater or spot treatment modality.
- d. Aides do ultrasound, so what’s the question?
- e. The treatment area is better suited for another heating modality other than ultrasound.
POP Quiz!!!

- If the ERA of a transducer was 10 square centimeters, and the intensity was set at 1 W/cm² what would the total power be?
  - a. 0.1 Watts/cm²
  - b. 10 Watts
  - c. 100 Watts
  - d. What’s a Watt got to do with it?

1W
Ultrasound: Indications

- pain (musculoskeletal in origin)
  - Elevating tissue temperature
- muscle guarding
  - Increasing local circulation
- What about
  - tissue healing?
  - edema reduction?
  - biostimulation?
Ultra-effective Ultrasound

- not an oxymoron
- doesn’t have to be monotonous
- doesn’t have to be the least interesting modality that can be applied
- ...and you too, can understand how technology has changed the way it is administered

http://www.youtube.com/watch?v=hLKBad8BQTo
Ultrasound: Indications

- Since 1964, ultrasound has been used as a therapeutic agent in the treatment of soft tissue injuries. These include:
  - ligaments, joint capsule, tendon & muscle
  - inflamed tendon sheaths
  - scar tissue sensitivity, neuromas
  - pressure sores, varicose ulcers
  - fascitis
Arndt-Schultz Law

- “weak stimuli excite physiologic activity, moderately strong ones favor it, strong ones retard it, and very strong ones arrest it.”
The big question....

- Why is ultrasound most commonly applied @ 1 MHz CW 1.5W/cm² for 5-7 minutes, regardless of the chronicity or depth of the target tissue?
Are technical skills and manual skills incongruous?
Could a monkey effectively apply Ultrasound?
...some have
...and they are the ones who do not feel that ultrasound does anything beneficial...
do you see a pattern here?
Ultrasound in Clinical Practice...

We will discuss and demonstrate:

- the biophysics of ultrasound
  - physical principles
    - sound propagation
    - frequency
    - penetration
    - absorption
    - types of waves
    - intensity
Ultrasound in Clinical Practice…

- Therapeutic Equipment
  - generators
  - transducers
  - durability/safety
- Biophysical effects
  - thermal effects
    - tissue absorption
  - non-thermal effects
    - stable cavitation

![High Frequency Wave](image1.png)

![Low Frequency Wave](image2.png)

The high frequency wave sounds higher than the low frequency wave.
Ultrasound in Clinical Practice...

- Therapeutic Application Techniques
  - coupling techniques
    - media
    - to phores or not to phores...
  - parameter selection
    - Rx time, intensity, duty factor
    - frequency selection
    - transducer selection
Ultrasound in Clinical Practice…

- Treatment goals
- patient positioning
- therapeutic protocols
- the truth about the contraindications
  - “what’s not hot about ultrasound, ...pun intended”
  - Just for review...
Tissue Elasticity and Ultrasound

how, what, when and where?
What should we do now? How will we know which Ultrasound units are best for what we want to do?

Water test all the units.

Check to see how the phoresing agents are made.
Will you really be able to cause palpable Differences with Ultrasound in one treatment? *We’ll see in lab!*

**Parameters**
- 3 MHz @ 0.5 W/cm²
- pulsed @ 20%
- treat only the palpable nodule
- Treatment time = 2 minutes using a head the same size as the nodule

**Parameters**
- 1 MHz @ 1.5 W/cm²
- continuous
- the entire upper trap
- 5-7 minutes using the larger sound head
How about stretching with US?

“I’ll bet the depth and pt position make a difference...”

- 3 MHz @ 1W/cm²
- continuous
- small Rx area
- treat for 1 minute in neutral, then apply stretch and treat while stretching

- 1 MHz @ 1W/cm²
- continuous
- “regular” Rx area
- treat for 5 minutes
- let patient rest
- then stretch
How do you determine Dosage Levels?

- Questions to ask yourself:
  - is it superficial or deep? - frequency
  - is it acute or chronic? - duty factor
  - is there much soft tissue in the area? - W/cm²
  - how large is the treatment area, and how large is the transducer? - Rx time

http://www.electrotherapy.org/modalities/ultrasound%20doses.htm
What about the contraindications for Ultrasound?

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>metastasis?</td>
<td>Yes, if it’s in the Rx area</td>
</tr>
<tr>
<td>metal implants?</td>
<td>NO</td>
</tr>
<tr>
<td>epiphysis of growing bone?</td>
<td>Yes</td>
</tr>
<tr>
<td>joint replacements?</td>
<td>Yes for 1 MHz but No for 3MHz and No if you are using pulsed modes</td>
</tr>
<tr>
<td>fractures?</td>
<td>Typically, patients with unstabilized fractures are not treated in PT. NO</td>
</tr>
<tr>
<td>acute inflammatory processes?</td>
<td>Only continuous modes, it may be helpful in promoting healing in pulsed modes.</td>
</tr>
</tbody>
</table>
What do we have here?

I see the epiphysis of growing bone, what do you see?
Thank you, now Insonate to your heart’s content!

“May both you and your patients enjoy the results!”
Depth of the lesion to be treated

- Superficial (<2 cm) → 3MHz
- Deep (2–5 or >6 cm) → 1MHz

Pulse Ratio

- ACUTE
  - Pulse 1:4/3 (20%, 25%)
- SUB ACUTE
  - Pulse 1:3/2/1 (25%, 33%, 50%)
- CHRONIC
  - Pulse 1:2/1/Continuous (33%, 50%, 100%)

Intensity required at the lesion

- ACUTE
  - 0.1 – 0.3 W/cm²
- SUB ACUTE
  - 0.2 – 0.5 W/cm²
- CHRONIC
  - 0.3 – 0.8 W/cm²

Area to be treated in relation to the treatment head size

- e.g. 1x 2x 3x etc

Aim for 1 minute of US per treatment head area

http://www.electrotherapy.org/modalities/ultrasound%20doses.htm
not every treatment time with ultrasound needs to be “5 -7 minutes”
• it is dependent upon
  • the treatment goal
  • the size of the transducer that you are using
  • the size of the treatment area *(which should not exceed two times the size of the transducer)*