Ultrasound

Outline

- What is ultrasound?

    1. Sound wave physics
    2. Sound energy and its effect on soft tissue

- Pulsed non-thermal ultrasound – enhance tissue healing
  Cavitation and microstreaming

- Continuous thermal ultrasound

- Contraindication & precautions

- Clinical judgment and dosage

- Literature Review –with a grain of salt PLEASE!!!

WHAT IS ULTRASOUND?

- Ultrasound is a sound wave that has a frequency greater than 20 KHz.

- It is generated by applying an alternate current to a piezoelectric crystal (found in the transducer in the sound head). This crystal contracts and expands at the same frequency at which current changes polarity. The sound field generated by this crystal in turn makes the molecules in the sound field vibrate and oscillate.

- The crystal commonly used in US units is synthetic plumbium zirconium titanate (PZT).
- The quality of the crystal is what makes your US expensive.
- Crystal quality depends on the following:
  - Beam Nonuniformity ratio: ranges from 2 to 6 – the smaller the better.
  - Effective Radiating Area: as close to sound head area as possible

- Therapeutic ultrasound has a frequency range of 0.7 and 5.0 MHz.

- Most clinics will have 1 MHz and 3 MHz sound head.

Sound wave physics

- Solids and liquids consist of molecules held together by elastic forces that behave like rubber bands connecting each molecule to each of its nearest neighbors.
- If one molecule is set in vibration, then it will cause its immediate neighbors to vibrate, and in turn their neighbors, and so on until the vibration has propagated throughout the entire material. This is a wave.
- A sound wave is sound energy that is transmitted from one molecule to the next.
- A sound wave cannot travel by itself. It needs a medium for transmission (solid, liquid, gas).
- Energy contained within a soundbeam is decreased as it travels through tissue. Energy is lost to:

  Reflection or scattering of the soundbeam when it strikes a reflecting surface

  Absorption – energy lost by the sound wave as it overcomes internal friction that exists in tissue while traveling through it.

- Higher the frequency, the more rapidly the molecules are forced to move against this friction. The more they move, the more energy is consumed (absorbed); the soundbeam will therefore have less sound energy available to propagate further through the tissue.

- The velocity of the wave travel depends on the closeness of the molecules of the medium. The closer the molecules, the quicker they collide with each other and sooner they respond to disturbance, the faster they loose energy in a short distance.

$$\text{Energy}_{\text{final}} = \text{Energy}_{\text{initial}} - (E_{\text{reflected}} + E_{\text{absorbed}})$$

→ So a 3MHz sound head will affect more superficial tissues while a 1MHz sound head will affect deeper tissues.

Example:
Sound travels through air easily and can go far (yelling out in the back yard). Sound can go further because there is little energy loss by absorption. Air molecules are easily compressed.

Sound does not travel easily through a brick wall that is denser (someone yells from the outside of the house and you can't hear him from the inside). Brick molecules are a lot closer together, harder to compress. Brick therefore absorbs more of the sound energy going through it.

SOUND ENERGY AND
EFFECT ON SOFT TISSUE

So how does sound wave behave when it travels through human tissues?

From the air medium, it must enter the skin/fat which has a significantly higher density. There is 100% reflection of the sound wave at the air-skin interface. If we put a coupling medium such as gel to create a sound head-gel-skin interface, reflection is reduced to only 0.1% ; the rest of the sound energy will be transmitted through the skin barrier. As noted in the absorption coefficients table, sound energy travels through much of the soft tissue without much absorption until it reaches tissues with high collagen content, namely bone, periosteum, ligaments, capsules, fascia, tendons, and tissue interface (bursa).

Ultrasound energy is absorbed mostly in tissues with high collagen content (bone, periosteum, cartilage, ligaments, capsules, tendons, fascia, scar tissue and tissue interface i.e. bursa & synovium).

Ultrasound at high intensity near bony areas can be detrimental to the periosteum because of high energy accumulation and heating effect on the soft tissue as sound wave hits the bone (transverse or shear wave).

What happens to the tissues that absorb sound energy?

Sound energy is nonionizing radiation and therefore its use does not impose the hazards, such as cancer production and chromosome breakage, attributed to ionizing radiation.

Sound energy has two physiological effects:

1. Enhance inflammatory response and tissue repair
2. Heat soft tissue

PULSED NON-THERMAL ULTRASOUND ENHANCE INFLAMMATORY RESPONSE AND TISSUE REPAIR

Ultrasound energy produces a mechanical pressure wave through soft tissue. This pressure wave causes:

1. generation of microscopic bubbles in living tissues

2. Distortion of the cell membrane, influencing ion fluxes and intracellular activity.

Three mechanisms of cell membrane distortion:

1. Acoustic streaming

2. Bubble formation

3. Microstreaming

Three mechanisms of cell membrane distortion:

1. Acoustic streaming.
   - The compression phase of an ultrasound wave deforms tissue molecules (cell membrane). This deformation is called radiation force.

2. Bubble formation – cavitation.
   - Radiation force affects gas bubbles in the tissue fluids. Under this pressure wave (compression and rarefaction), these bubbles expand and contract which add further stress to cell boundaries. When bubbles expand and contract, without growing to critical size, the activity is called stable cavitation. Unstable cavitation does not occur in therapeutic range (pulsed 20% @ 0.1 to 3 W/cm2) in normal tissues except in air-filled cavities such as lungs and intestines.

3. Microstreaming.
   - Cavitation sets up eddy currents in the fluid surrounding the vibrating bubbles and the eddy currents in turn exert a twisting and rotational motion on nearby cells. In the vicinity of vibrating gas bubbles intracellular organelles are also subjected to rotational forces and stresses. This microscopic fluid movement is called microstreaming.

   - Bubble activity augments the mechanical effect of a pressure wave. The scale of cavitation depends on the ultrasound characteristic; bubble growth is limited by low-intensity, high-frequency, and pulsed ultrasound. Higher frequency means shorter cycle duration, so that the time for bubble growth is restricted. Pulsed ultrasound restricts the number of successive growth (excessive energy accumulation) and allows the bubble to regain its initial size during the off period.

What is the physiological effect of cell membrane destabilization?

Cell membrane destabilization results in an increase in the permeability, therefore many molecules travel into the cell, precipitating secondary effects:

1. Increase skin and cell membrane permeability
2. Increase intracellular calcium -- known as second messenger for cell function including protein synthesis
3. Increase mast cell degranulation
4. Increase histamine and chemotactic factor release by granules from mast cells and circulating platelets –influences circulation and protein synthesis.
5. Histamine is released by the degranulation of mast cells. The rate at which this occurs is proportional to the intensity. It is possible to form too much histamine at a high intensity which could prolong the inflammation instead of stimulating healing. The inflammatory response may be prolonged with the application of any heat modality in the inflammatory stage.

In summary cell membrane destabilization is thought to enhance the inflammatory response from the inflammatory phase (Days 1- 6) to the proliferative phase (Days 3-20)
Refer to chapter 2 in your book.

Common use for pulsed non-thermal ultrasound

- Facilitate healing in the inflammatory and proliferative phase following soft tissue injury (tendonitis, bursitis, acute soft tissue injuries)
- Bone healing (1.5 MHz, pulsed 20%, 0.15w/cm2, 20 minutes, daily)

CONTINUOUS ULTRASOUND
THERMAL APPLICATION

Continuous, high intensity ultrasound increases the temperature of the soft tissue by:

- increasing kinetic energy of tissue molecules (ie.rubbing the hands together fast enough will generate heat on your skin)
- increasing the production of unstable cavitation

Ultrasound kinetic energy when absorbed by tissues can also be converted into heat.
Unstable cavitation occurs when the bubbles collapse violently under the pressure due to excessive energy accumulation, after growing to critical size. This implosion produces large, brief, local pressure and temperature increase and causes the release of free radicals.

Heating tissues between 40-45degrees using ultrasound has the following physiological effects:

- Increase the extensibility of soft tissue
- Decrease the viscosity of fluid elements
- Decrease pain perception by slowing nerve conduction velocity
- Increase metabolic rate
- Increase blood flow which assists in the reduction of swelling
- Stimulate the immune system

<u>Common use for continuous ultrasound</u>:

- Prior to stretching at tight structure (tendon, capsule, ligaments, fascia, scar)
- Pain control in chronic pain
- Chronic inflammatory conditions

CONTRAIDICATION

- Undiagnosed pain
- Cancer
- Active tuberculosis
- Psoriasis
- Decreased circulation
- Infection
- Pregnancy
- Central nervous system tissue
- Joint cement (cannot use continuous mode, but may use pulsed mode 50% or less)
- Plastic components
- Pacemakers
- Thrombophlebitis
- Uncontrolled bleeding or blood-thinning medication (coumadin)
- Eyes
- Reproductive organs
- Heart

PRECAUTIONS

- Acute inflammation (use non-thermal settings only)
- Epiphyseal plates (use pulsed, low intensity <0.5w/cm2)
- Decreased sensation (esp. with thermal US)
- Over implanted materials
    - ✓ metal reflects 90% of incident US
    - ✓ plastic respond like periosteum and it absorbs a large % of US
    - ✓ generally safe if the sound head is kept moving

DOSAGE PARAMETERS

Questions to ask yourself:

- Is there any contraindications?

- What is my injured and tissue? (muscle, tendon, ligament, bursa, fascia, bone, periosteum, capsule, synovium, cartilage, joint, nerve)

- What is the nature of the injury :
  1. Traumatic (date & event of injury noted for stage of healing)
  2. Cumulative Repetitive Trauma (tendonitis/bursitis/strain/sprain)
  3. Degenerative (disc disease, chronic tendonitis, arthritis)

- Is there any inflammation in this tissue?
  1. If yes, you would want to consider ultrasound to enhance the inflammatory response and promote healing.
  2. If no, then is this injured tissue short and scarred down?
  3. If tissue shortness and scarring is your problem than you can also consider US to heat up the tissue so you can stretch it after to improve flexibility.
  4. If neither inflammation nor tissue scarring or shortening is an issue then US is not the modality of choice.

- Will ultrasound irritate the injured tissue?

US directly over nerves tend to irritate the nerve.
US over bony areas can cause periosteum over heating as most of the sound energy is absorbed here, you may need to reduce the intensity to 0.5 w/cm2 or less to avoid irritation.

- Can you effectively deliver ultrasound energy to the target tissue or is the structure too deep or inside a joint?

- What are your treatment goals?
  - Thermal or non-thermal?

- If non-thermal, at what is the healing stage (inflammatory, proliferative, maturation), acute or chronic?

- Does the injured tissue have high, moderate, or low irritability (use pain scale)?

  If high irritability, you may treat is as acute (inflammatory phase day 1 to 3)

  If moderate irritability, you may treat as sub-acute (proliferative phase)

  If low irritability, you may treat as sub-acute towards resolution (proliferative to maturation)

Frequency:

1 MHz – US energy will penetrate to a depth of 2.5 to 5 cm
3 MHz – US energy will penetrate to a depth of 1.5 cm

The higher the frequency, the more likely most of the energy will be absorbed superficially, leaving little energy to penetrate further into the tissue (inverse relationship of attenuation/absorption and frequency).

Mode:

Continuous – to heat tissue/scar breakdown
Pulsed (50%, 20%) – to heal tissue
Duty cycle is 1:1 for 50% and 1:4 for 20%. Time is in milliseconds.

Intensity:

To heal:

- **0.05 – 0.2 W/cm2** (the lowest you can go on the machine)
  - **Goal:** Debridement, increase cell membrane permeability (electroporation), and increase cell energy level.
  - **Application:**
  - Day 1 to 7-10 - inflammatory phase following a traumatic event
  - High irritability – pain 8-10/10 – little ROM with severe impairments of function.

- 0.2 to 0.5 W/cm2
  - **Goal:** Increase cell membrane permeability (electroporation) and increase fibroblastic activity
  - **Application:**
  - Day 7-10 - early proliferative phase after a traumatic event
  - Moderate irritability – pain 6-8/10 in an acute/chronic/degenerative non-traumatic condition

- 0.5 – 0.80 W/cm2
  - **Goal:** Aid collagen deposition and tissue healing
  - **Application:**
  - Day 7-10 to 21 - Proliferative phase after a traumatic event
  - Moderately low irritability- pain less than 4-6/10 (start with 0.5 and increase with subsequent treatments as healing takes place and irritability decreases)

To heat: 0.8 w/cm2 – 1.0 w/cm2 for superficial tissues
Greater than 1.5 w/cm2 for deep tissues (hip)

- Patient may report a sensation of warmth but not burning or pain.
- If pain is felt, it is a sign of excessive periosteal heating; the intensity should be reduced immediately or the transducer head should be moved more quickly.
- It is possible to burn with ultrasound.
- When using 3MHz in continuous mode near bony areas, you may have to reduce the intensity due to periosteum overheating.

Treatment time:

1. Based on 3-5 minutes of continuous application for and area that is twice the ERA of the sound head.
2. Treatment time depends on the duty cycle and treatment surface area.

To heal:

- Pulsed 50% on an area that is 2 x ERA = 6 - 10 minutes
  (3-5 min. X 2)

For non-thermal effect, intensity of a PUS 50% must be less than 0.5 W/cm2. Thermal effect begins at intensity greater than 0.5 W/cm2.

- Pulsed 20% on an area that is 2 x ERA = 15 - 25 minutes
  (3 min. X 5)
- Pulsed 20% on an area equal to ERA = 7 - 13 minutes

N.B. The preferred duty cycle for clinicians is 50% as it delivers the full dose in a shorter time period while conserving the non-thermal effect as long as intensity is less than 0.5 w/cm2. A duty cycle of 20% may be used if the clinician finds sound reason; delivery of the full dosage may take more time. Controversy exists between text books as to which duty cycle is physiologically advantageous.

To heat:

- Continuous on an area that is 2 X ERA = 6-10 minutes
- Continuous on an area that is equal to ERA = 3-5 minutes
- Underwater application can be longer to 10-12 minutes

<u>Sound head / transducer size (controversy):</u>

1. Small – deeper
2. Large - superficial

It is due to beam divergence of the small sound head and that sound head size in inversely proportional to depth of penetration.

- Large 1 MHz good for shoulders (capsule) and hip
- Large 3 MHz is good for shoulder (superficial structures) elbows and wrist
- Small 3 MHz is good for finger and toes

Latest news: sound head size does not affect depth penetration. Try to use a sound head size that is appropriate for the part treated (SH with ERA that is 50% of the part being treated).

<u>Contact media: gel</u>

Sound head movement:

- Never stay stationary
- Keep it moving, slow and gentle with constant pressure.
- This will minimize the risk of creating unstable cavitation and standing waves that is detrimental / damaging to soft tissue.

Treatment frequency

- Ultrasound has cumulative effects
- Daily for 10 days – low irritability and scar
- 3-4 times/week – moderate irritability for 3-4 weeks
- 2 times /week – high irritability 4-5 weeks
- If no change after 3-4 sessions, change settings or discontinue.
- Stop after 10-15 treatments

Chronic inflammatory conditions

Thermal application may be indicated in initial stages (if chronic inflammation is perpetuated by significant scarring)

Non-thermal application later stages (scarring is less of an issue and inflammation reduction and debridement is your goal)

Progressions of parameters

Intensity can be increased over the healing time
Percentage of pulsation can be increased over healing time

Your lecturer's notes serve as a general guideline based on research evidence, book reviews and clinical experience. You will find many controversies in the literature about dosage and parameters. Use the above guideline with good judgment and adjust dosage as needed on an individual basis, depending on your patient's condition and response to ultrasound.

ULTRASOUND LABORATORY

Determine if US is appropriate for the following cases and write down the appropriate parameters if applicable.

1. Patient sprained her thumb 3 days ago and is seeing you for treatment. O/E: marked swelling of the thenar and moderate swelling of the hand, minor echymosis and moderate pain.
2. Patient sprained his ankle 10 days ago.
   O/E: moderate swelling of the ankle, minor tenderness to lateral malleoli. Patient is PWB with crutches.
3. Patient reports sleeping the wrong way and woke up with pain in the R. shoulder 3 wks ago and pain persists
   O/E: C-spine scan is –ve, ROM R. shoulder is limited. Marked tenderness to palpation noted inferior to the acromion.
4. Patient had been playing golf for years and is now developing a golfer's elbow. It started 6 months ago for no apparent reason.
5. Patient reports sitting in a chair and got up the wrong way injuring his back 6 wks ago. Pain continues to persist.
6. Patient reports having hip pain on/off for 6 months now but it's gotten worse in the past 2 wks after a trip to the country side with a lot of walking on uneven terrain. Pain is found to posterolateral hip. Dr's note says hip bursitis.
7. Patient had a cyst removed from his index 3 months ago and the area is still "lumpy" and sensitive to touch.
8. Patient had a hysterectomy for benign cyst growth 1 year ago. She c/o numbness is the area and thickened scar, making her feel uncomfortable during intercourse.
9. Patient has a THR 1 year ago and developed a hip bursitis recently. Pain began 6 wks ago.
10. Patient with diabetic neuropathies fell down the stairs 3 months ago and fractured his distal tibia. He went to ER and had ORIF. He continues to c/o pain to the ankle especially when he walks. Tenderness is found around the ankle joint.
11. An 8 y.o girl sprained her R. knee while playing soccer 2 wks ago. She is still having pain when she bends her knee past 120 degrees and a bit of pain to touch around MCL.
12. 65 y.o male with pacemaker has a shoulder tendonitis to the L. shoulder that is 3 months old.
13. 70 y.o female has frozen shoulder. It started 6 months ago and now she cannot use her arm. She has a cardiac history and is on coumadin.
14. 40 y.o female came out of radiation for breast cancer and now developed scarring in the breast tissue and limited ROM in the shoulder. She had been too fearful to move her shoulder for 2 months and developed a frozen shoulder.

Answers to the Ultrasound Lab.

1. Target tissue: ligament/capsule

Pulsed 50% , small 3MHz, 0.05 W/cm2, 5 min. Inflammatory phase, US to debride excessive inflammatory products, and promote healing.

2. Target tissue: ligament / strained tendons surrounding the area

Pulsed 50%, large 3MHz, 0.5 W/cm2, 5 min. if no bruising and low irritability.
Pulsed 50%, large 3MHz, 0.3 W/cm2, 5 min if bruising present and a bit irritable.

3. Investigate for other causes possible, if clear then can US.
   If Rotator cuff tendonitis, bursitis, then:
   Pulsed 50%, large 3MHz, 0.5 -0.8 W/cm2, 5 min with shoulder in slight extension and internal rotation to expose the tendon.
4. Medial epicondylitis don't usually respond well to US and so is not the first modality of choice to treat this condition.
   - If the pain is diffuse around the area and we choose to use US then we might US the ulnar nerve (we might irritate it).
   - If the pain is truly localized well above and away from the ulnar nerve then maybe we'll consider US using a small sound head, pulsed 50%, 0.5 w/cm2, 5min.
5. Need to evaluate properly to determine if it's a muscular strain, a disc problem or a facet problem.
   - If it's a true strain, then may consider US, continuous, 1MHz, 0.8 to 1.5 w/cm2 to break down scar tissue present.
   - If it's a disc problem, with nerve irritation, US probably won't do any good. Your best bet is to use McKenzie protocol and traction to reduce nerve irritation.
   - If it's a facet problem then US won't do any good either because sound energy will most likely reflect off the bones and will not penetrate to the facet joint.

6. Target tissue: bursa

Pulsed 50%, large 1 MHz, 0.5 -0.8 W/cm2, 6 min

7. Target tissue: scar

Continuous, small 3MHz, 0.5 to 1.0 W/cm2, 5 min

- The treated area is small and superficial so we start a bit lower than 0.8 w/cm2 to avoid overheating the first time and can increase gradually over the treatment period. You should also massage the area to increase elasticity.

8. Continuous 3 MHz, 0.8 to 1.2 w/cm2, 5 min. to break down scar.
   - If you're concerned about the benign tumour you should.
   - However in this case you can administer US because the uterus was removed and your US will only penetrate to a depth of 1.5 cm which is not far enough to affect internal organs. You should massage and stretch the scar after US application.
9. Target tissue: bursa.

Pulsed 50%, large 1 MHz, 0.5 -0.8 W/cm2, 6 min

- It's OK to US over the implants as long as you keep the sound head moving.

10. Find out the pain location.

- If it is around the fracture site with screw and plate, NO US.; the fracture is still fresh.
- If the pain is distal to the fracture site and away from the plates and screws then it's ok, i.e. around the talo-fibular ligament is fine.
- Use Pulsed 20%, large 3 MHz, 0.5 -0.8 W/cm2, 5 min to target irritable inflamed tendons or synovial sheath in the tender area.

11. Target tissue: ligament

Pulsed 50%, large 3 MHz, 0.5 W/cm2, 5 min

- OK on growth plate if pulsed less than 0.5 w/cm2.

12 Target tissue: tendon.

Pulsed 50%, large 3MHz, 0.5- 0.8 W/cm2, 5 min

- You can use US if you are not directly over the pacemaker or it's wires. Wires and pacemaker are often visible under the patient' skin.

13. US is contraindicated

14. US is contraindicated