Ultrasound Therapy

Jeff Carnett, D.P.M.

LA TROBE UNIVERSITY
www.latrobe.edu.au/podiatry

What is ultrasound?

- It is a type of sound that consists of waves that transmit energy
- The energy is created by alternately compressing and rarefying material
- The sound generated is above the audible range of the human ear
- Ultrasound has similar properties to audible sound
  - Dec in intensity with distance, cause circular motion of material and can travel through material

History of Ultrasound

- First large scale use during World War II – SONAR (Sound Navigation and Ranging)
- Ultrasound sent from submarine through water
- Echo is picked up by detector – time taken to return is indicative of distance of object
- Thus – other objects could be detected
- Problems arose – caused heating of underwater life

History

- Heating concept was developed for use of US clinically
- Can heat biological tissue – particularly those with high collagen content e.g. tendons, ligaments, fascia
- Also has NON-THERMAL effect
- This means there are measurable biological changes to tissue that are **not** as a result of heating

Therapeutic Ultrasound

- Falls into the THERMAL AND MECHANICAL categories
- Regarded as deep (3cm>) heating agent
- Can utilise the effect of ultrasound without heating of tissue also
- Used in medicine for more than 50 years
  - diagnosis (internal imaging)
  - physical therapy
  - tissue destruction (surgery)
- To use effectively must be aware of:
  - Nature of sound
  - Frequency, wavelength and velocity
  - Intensity
  - Attenuation
  - Physical and thermal tissue effects

Nature of sound

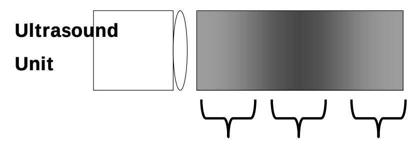
- Molecular structure of solids and liquids
- Held together by forces
- Vibration of one molecule will cause another to vibrate
- Vibration will propagate through material
- This vibration is sound
- The molecules oscillate asynchronously
- Sound waves are like traveling pressure waves which cause alternating compression and rarefaction of the particles in the medium through which they travel
- The alternating pressures cause mechanical stress to the tissue particles

Production of Ultrasound:

- Ultrasound generated by special crystals which can vibrate rapidly and display phenomenon of ‘indirect piezoelectricity’
  - contraction or expansion of crystal in response to voltage applied
  - alternating voltage makes crystal vibrate
  - used to generate ultrasound at any desired frequency
- Can use quartz but more commonly use synthetic ceramic crystals
  - sliced into 2- 3 mm thick wafers
  - mounted in applicator for protection
  - known as the ‘transducer’

Ultrasound

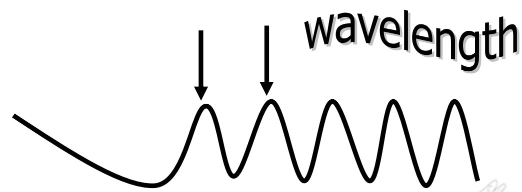
- Basically all sound travels in waves that transmit energy
- They transmit energy by alternately compressing and rarefying material in the direction of the wave



Parameters

- Frequency:
  - The number of oscillations a molecule undergoes in 1 second
  - Expressed in hertz (Hz)
  - 1 Hz = 1 cycle / second
  - 1 kHz = 1000 cycles / second
  - 1 MHz = 1 million cycles / second
- Human ear sensitive to between 16 Hz and 20,000 Hz
- Above this range is termed ULTRASOUND
- Ultrasound beams are well collimated
- Does not diverge greatly
- Common frequencies used in physical therapy are either 1 MHz or 3 MHz

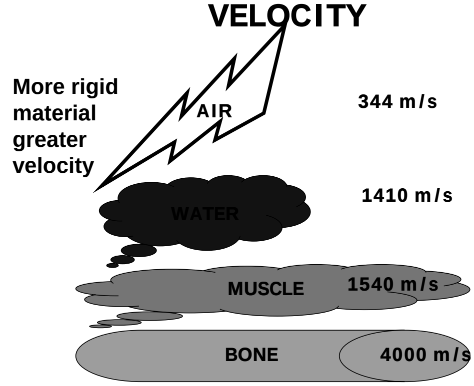
- Wavelength:
  - the distance between two successive peaks
  - wave indicates alternating compressions and rarefactions of the tissue
  - arises due to asynchronous vibration of the molecules
- Wavelength is inversely related to the frequency
- As you inc the freq the wavelength decreases



Parameters

- Velocity:
  - speed at which vibratory motion is propagated through material – measured in metres per second (m.s-¹)

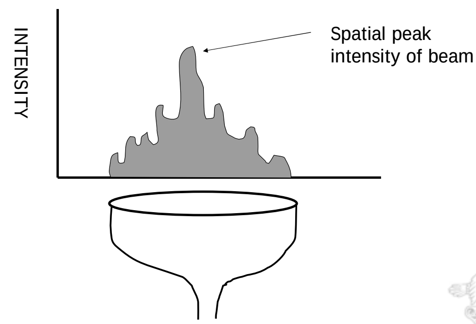
VELOCITY



Parameters:

- Intensity:
  - rate at which energy delivered per unit area
  - expressed in watts per cm^2 (W/cm^2)
  - physical therapy common use
    - 0.25 to 2.0 W/cm^2
- Intensity derived by measuring total output power of applicator and dividing by the surface area of the applicator face
- Intensity can be varied depending on whether the machine is used in PULSED or CONTINUOUS mode
- Heating of tissue depends on intensity
- World Health Organisation limits use to:
  - 3.0 W/cm^2
  - Above 10 W/cm^2 - tissue is destroyed
  - Below 0.1 W/cm^2 - used for diagnostics

Intensity



Spatial average intensity

- The average intensity of the ultrasound output over the area of the transducer
- The ratio of the peak and the average intensity is known as the:

  BEAM NONUNIFORMITY RATIO
- Most units this figure is approx 5:1 or 6:1
- Creates an uneven intensity within the beam
- BNR Must be specified on the machine

Pulsed mode

- Delivery of ultrasound during only a portion of the treatment period
- Ultrasound is <u>on</u> then <u>off</u>
- Proportion of time the US is on is referred to as the 'DUTY CYCLE'
- Expressed as percentage or ratio:
- 20% or 1:5 – ultrasound is on for 20% of the time
- PULSED ULTRASOUND WILL HAVE MINIMAL THERMAL EFFECTS

Continuous mode

- Ultrasound is delivered for the whole period of the treatment time
- The greatest heating of tissue is achieved using continuous mode

Absorption

- Absorption:
  - transfer of energy from the sound beam to the surrounding tissue
  - as frequency increases so will the internal friction in the tissue and hence absorption will increase
- Amount of absorption is expressed as its 'absorption coefficient – they are tissue and frequency specific
- Absorption is highest in tissue with highest collagen content

ABSORPTION COEFFICIENTS IN DECIBELS/CM AT 1 AND 3 MHz

TISSUE	1MHz	3MHz
Blood	0.028	0.084
Fat	0.14	0.42
Nerve	0.2	0.6
Muscle	0.28	0.84
Skin	0.62	1.86
Tendon	1.12	3.36
Cartilage	1.16	3.48
Bone	3.22	

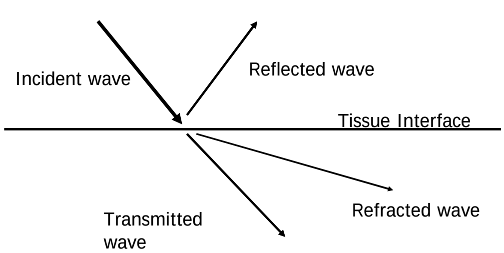
Reflection

- REFLECTION:
  - The redirection of an incident beam away from a reflecting surface at an angle equal and opposite to the angle of incidence.
  - Ultrasound is REFLECTED at tissue interfaces
  - Highest at sites of greatest difference between acoustic impedance
  - Most reflection occurs at the soft-tissue / bone interface
  - MUST KEEP TREATMENT HEAD MOVING TO AVOID BURNS

Refraction

- REFRACTION
  - The redirection of a wave at an interface
  - Ultrasound enters tissue at one angle and part of the energy is refracted to another angle

ULTRASOUND REFLECTION AND REFRACTION



Attenuation

- Absorption, reflection, refraction all contribute to the ATTENUATION of the ultrasound beam
- Attenuation is a measure of the decrease in US energy as it passes through the tissue
- Absorption accounts for approx 50% of attenuation
- This attenuation can be measured and is referred to as "half depth" – or half value thickness….

Attenuation

- Using 3MHz - the intensity will be reduced to half that applied to skin when the beam penetrates to 1.5cm
- Using 1MHz – the intensity will be reduced to half that applied to skin when the beam penetrates to 5cm
- Known as ‘half-value thickness’ (d)

Biophysical effects

- Thermal and non-thermal (physical)
- THERMAL effects refer to those effects generated by the production of heat in the tissues….
- NON-THERMAL effects are thought to be related to the mechanical events produced in the tissues

THERMAL EFFECTS

- Ultrasound can inc. tissue temp. to depths of 5cm or more
  - Usual effects of heating of tissue e.g.
  - Blood flow changes,
  - Increase in metabolic rate,
  - Pain reduction,
  - Increased enzyme activity
  - Increased tissue extensibility
  - Reduction of muscle spasm
  - Changes to nerve conduction velocity

THERMAL EFFECTS

- Extent of heating will depend on:
  - intensity, frequency, duration, size (area) and type of tissue sonated
  - generally use **3MHz** for tissue up to 1 to 2cm deep
  - use **1MHz** for tissue deeper than 2cm
- Ultrasound is particularly useful for heating tissue with high collagen content such as tendons, ligaments, joint capsules and fascia
- Remember - pulsed ultrasound will have little thermal effect

NON-THERMAL EFFECTS

- NON-THERMAL (physical)
- Cannot be explained by thermal means
- Cavitation:
  - Production of gas bubbles in tissue by US beam vibration
  - bubbles expand and collapse
  - no increase in amplitude = stable cavitation
  - if they violently collapse can cause tissue damage = unstable or transient cavitation – this is very unlikely with therapeutic intensities
- TRANSIENT CAVITATION MUST BE AVOIDED:
  - use intensities below 4 W/cm^2
  - use pulsed ultrasound if appropriate
  - move treatment head during therapy

NON-THERMAL EFFECTS

- Increase in cell wall and vascular permeability
  - may be useful in reducing inflammation
- Stasis of blood flow:
  - blood cells can congregate at half wavelength with standing wave
  - MUST move treating head during therapy
- Prevention of collagen binding:
  - ? due to prevention of bonding process which takes place in forming scar tissue
- Analgesia

Indications:

- Commonly used in rehabilitation
  - Periarthritis
  - Sesamoiditis
  - Plantar fasciitis
  - Bursitis
  - Tenosynovitis
  - Tendonitis
  - Myalgia
  - Contusions
  - Damaged ligaments
  - Scar tissue
- Very beneficial in joint contracture and scar tissue - 'heat and stretch' concept
- Heating increases visco-elastic property of collagen - improves and facilitates stretch

Components and use:

- Components:
  - power supply, oscillator circuit, transformer, coaxial cable and applicator
- Couplants:
  - water soluble gel often used - eliminate air
  - must be in good contact with skin
  - immersion in water for small or bony parts
  - hold transducer 0.5 - 3cm from body

Components and Use

- Moving versus stationary applicator:
  - nonuniformity of sound beam = uneven energy distribution - hot spots (indicated by BNR – beam nonuniformity ratio – should be below 8)
  - stasis of blood blow
  - blood vessel damage
  - AVOID STATIONARY APPLICATOR - KEEP APPLICATOR HEAD MOVING
- Move in concentric overlapping circles
- Not too rapidly - approx. 4 cm / s

Pulsed versus continuous:

- Energy can be delivered via a pulsed (on/off) or continuous mode
- Pulsed:
  - intermittently interrupted wave
  - intensity will be zero when sound is off and maximum when on e.g. 50% (5ms on and 5ms off)
    or 20% (2ms on and 8ms off)
  - by pulsing the intensity is decreased and less heating of tissue will occur
  - good option when non-thermal effects required or heating to be kept to minimum

Pulsed v's Continuous

- Continuous:
  - continuous wave form
  - energy being produced all the time
  - large increases in tissue temp. can be achieved at various depths
- Must consider:
  - aims of therapy, area to be treated, depth of tissue, stage of tissue repair etc

Contraindications:

- Do not apply ultrasound to:
  - eye region
  - over heart area / pacemaker
  - during pregnancy
  - reproductive organs
  - malignancy
  - impaired pain / temp perception
  - impaired circulation
  - thrombophlebitis
  - epiphyseal areas of bone in children
  - sepsis
  - if receiving radiotherapy
  - Plastic / metal joint components

Treatment planning

- Assess patient and set the goals of treatment
  - If tissue or joint is restricted, your goal may be to increase joint ROM
  - If pain due to injury or arthritis – goal is to reduce pain
- Determine if ultrasound is appropriate
- Check for contraindications
- Design a treatment schedule that will be reviewed at each appointment

Ultrasound application

- Use ultrasound transmission medium such as aqueous gel – need to eliminate air
- Or use ultrasound under water
- Select best treatment parameters for
  - Frequency
  - Intensity
  - Duty cycle
  - Duration of treatment

Frequency

- Select frequency according to depth of tissue to be treated:
  - Use 1 MHz for tissue up to 5cm deep
  - Use 3 MHz for tissue 1 – 2 cm deep
- Remember the depth of penetration is lower in tissue with high collagen content or areas of increased reflection

Intensity

- Select intensity according to treatment goal:
  - Inc tissue temp – pt should feel warmth in 2-3 mins of application
  - At 1 MHz intensity of 1.5 – 2.0 W/Cm2 will usually create warmth
  - At 3 MHz intensity of 0.5 W/Cm2 is usually sufficient to create warmth
- Can adjust intensity as needed during treatment on pt reports of warmth
- If superficial bone in area may need to dec intensity due to quick absorption by bone

Intensity

- For non-thermal effects – using a pulsed format:
  - Intensities between 0.5 – 1.0 W/Cm2 appear to be beneficial

Duration of treatment

- Will depend on goal of treatment, size of the area, the ERA of the treatment head
- Generally ultrasound applied for 5-10 mins for each treatment area that is twice the ERA of the transducer
  - Eg – ERA = 10cm2
  - Treatment area = 20cm2
  - Treatment time = 5-10 mins
- Also inc time when lower intensities or lower frequencies are used

Application

- Must keep transducer head moving
- Can use overlapping circles or zig-zag technique
  - Will reduce risk of burning
  - Standing wave
  - Cavitation etc

Documentation

- Area, freq, intensity, duty cycle, duration
  - Eg

Achillies tendon superior to calcaneus, 1.5 W/Cm2, continuous, 3 MHz, 5 minutes.

Case studies:

- 40 yr - male - lat. ankle sprain 24 hours ago
- Initial - rest, ice, compression, elevation
- Problem
  - swelling and bruising
  - pain
  - decreased ROM
- Ultrasound:
  - low dose to decrease oedema and inc. cellular activity
  - Days 1 - 5
    - 3MHz / 0.5 Wcm^2 / p 20% / 5 mins
  - Days 6 - 14
    - 3MHz /1.0 Wcm^2 / p 20% / 5 mins
- Home program of rest, ice, compression and elevation

Case studies:

- 38 male - lateral epicondylitis - 6 weeks duration
- Initial - rest and ice
- Problem
  - temp. pain relief only
  - aggravation with renewed activity
- Ultrasound
  - 3MHz / 1.0 Wcm^2 / CW / 3 mins
- Home program
  - stretching
  - gradual exercise program

Is it Effective?

- Very conflicting results in research
- Cochranes reviews:
  - OA of knee – no benefit over placebo
  - Patellofemoral pain syndrome – no clinically important effect on pain relief
  - Acute ankle sprain – no support for the use of ultrasound in ankle sprains
- These reviews must be taken in the correct context – have very strict criteria and many studies do not meet this criteria

Difficulty with Research

- Difficulties include:
  - Different populations
  - Different parameters of treatment
  - Additional treatments with ultrasound
  - Many studies do not state the dose, length of treatment or other important parameters
  - Difficult to compare when different dosages are used

Further Reading

- Micholvitz, S. L. *Thermal Agents in Rehabilitation*. 3rd Ed. F.A. Davis Company, Philadelphia, 1996.
- Belanger, A. *Evidence-Based Guide to Therapeutic Physical Agents*, Lippincott Williams & Wilkins, Philadelphia, 2002.
- Welch V, Brosseau L, Peterson J, Shea B, Tugwell P, Wells G. *Therapeutic Ultrasound for Osteoarthritis of the Knee* (Cochrane Review. In: The Cochrane Library, Issue 2, 2002.
- Brosseau L, Casimiro L, Robinson V, Milne S, Shea B, Judd M, Wells G, Tugwell P. *Therapeutic Ultrasound for Treating Patellofemoral Pain Syndrome* (Cochrane Review). In: The Cochrane Library, Issue 2, 2002.
- Van der Windt D, Van der Heijden G, Van den Berg S, Ter Riet G, De Winter AF, Bouter LM. *Ultrasound therapy for acute ankle sprains*. (Cochrane Review) In: The Cochrane Library, Issue 2, 2002.

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