

Prifysgol Cymru
Y Ddinas Dewi Sant
University of Wales
Trinity Saint David

THERAPEUTIC ULTRASOUND AND HEALING

SHSS6065
Semester 1 - Week 5

*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

www.uwts.ac.uk

Terms you will understand by the end of today:

- Wave
 - Frequency
 - Length
 - Velocity
 - Longitudinal
 - Compression
 - Rarefaction
 - Near field
 - Far field
 - Hot spots
 - Beam nonuniformity ratio (BNR)
- Acoustic Impedance
- Coupling medium
- Absorption
- Scatter
- Attenuation
- Half value distance
- Iontophoresis
- Thermal effects
- Non thermal effects
- Cell tickle
- Cell thump
- Contraindications

Prifysgol Cymru
Y Ddinas Dewi Sant
University of Wales
Trinity Saint David

*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Sound Waves

- U/S uses sound waves to produce therapeutic physiological effects
- Mechanical vibration at a higher frequency than audible sound wave (mechanical energy)
- Normal adult sound wave 16Hz-up to 20,000Hz (Children and adolescents)
- Above this range: mechanical vibration is known as ultrasound
- U/S frequencies 1.0-3.0MHz
- 1MHz = 1 million cycles per second

Prifysgol Cymru
Y Ddinas Dewi Sant
University of Wales
Trinity Saint David

*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Mechanics of Waveform

- Longitudinal waves containing areas of:
 - **Compression**
 - the increase in density/ pressure of molecules as a result of a source being subject to deformation ('to' or 'forwards')
 - **Rarefaction**
 - decompression of sound wave, or low pressure ('fro' or 'backwards')

Prifysgol Cymru
Y Ddinas Dewi Sant
University of Wales
Trinity Saint David

*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Longitudinal Waves: Compression and Rarefaction

- As the energy of a sound wave is passed to tissues, it will cause an oscillation of the particles that make up that tissue
- Molecular vibration = heat generation
- U/S used to produce thermal changes in the tissues
- Vibration also produces non-thermal changes

It is the non-thermal changes we are more commonly seeking to achieve.



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Sound waves → Ultra-Sound Waves

- High frequency electrical current is applied to certain crystals (Quartz or Barium Titanate).
- Produces **distortion** thus causing the crystals to **oscillate** i.e. Expand and contract at high frequency
- **Piezo-electric effect**
- Changes in the shape of the crystal cause movement of the metal end plate which in turn produces an ultrasonic wave
- Compression and rarefaction



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Ultrasound Waves

- **Frequency**
 - Number of times a particle experiences a complete compression/rarefaction cycle in 1 second
 - 1 MHz or 3MHz
- **Wavelength**
 - Distance between 2 equivalent points on the waveform in the particular medium.
 - 1MHz = 1.5mm
 - 3MHz = 0.5mm
- **Velocity**
 - Speed at which wave travels through the medium.
 - Sound waves travel faster in dense medium
 - Saline: 1500m sec⁻¹
 - Air: 350m sec⁻¹
 - Most tissue thought to be similar to saline



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Wave Frequency, Length and Velocity

- Three factors are related, but are not the same for all tissues
- Mathematical representation of relationship is:
 - **Velocity = frequency X wavelength**
 - $V = F \cdot \lambda$

More next...



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Waveform

- U/S beam is NOT uniform
- Changes in nature with the distance from transducer
- US beam nearest Rx head = **near field**/interference field/**Frenzel zone**
- US energy in parts of this field can be many times greater than the output set on machine
- As much as 12-15x greater



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Waveform

- **Near field**
 - Size (length) of near field can be calculated using
 - r^2 / λ
- Where r = radius of the crystal and λ = wavelength according to frequency (0.5mm for 3MHz, 1.5mm for 1MHz)
- E.g. Crystal diameter of 25mm at 1MHz
- Near field boundary of 10cm
- When using higher frequencies (3MHz) boundary distance is greater.



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Waveform

- **Far field/ Fraunhofer zone**
- More uniform US beam
- Gently divergent/differing
- Near field variances are noted as '**hot spots**'
- Not significant if U/S applied within safe and effective guidelines
- Therapeutic US: far field is effectively out of reach



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Waveform

- **Beam Non uniformity Ratio (BNR)**
- Indicates near field interference
- Describes numerically the ratio of the intensity peaks to the mean intensity (SD)
- Most applicators : BNR 4-6
- Theoretical best value BNR 4.0
- Some manufacturers claim BNR 1.0
- Straub et al (2008), Johns et al (2007), Pye (1996)



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Are you still awake?

The transmission of U/S through tissues

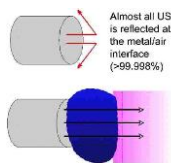
- Unfortunately, every material (interface) the U/S wave comes up against presents a barrier – an **impedance**.
- The amount of impedance is determined by two things
 - Density
 - Elasticity

The transmission of U/S through tissues

- In addition, the U/S wave has **Reflection, Refraction and Attenuation** to deal with – but we can optimize this.
- The greater the interface impedance, the more the U/S wave will be **reflected**.

Guess what...

- steel-air interface = greatest impedance
 - so we use a **Coupling Medium**.

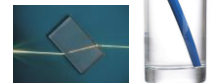


Almost all U/S is reflected at the metal/air interface (>99.998%)

Refraction and Attenuation

- If the U/S wave is not administered perpendicular to the tissue then wave **refraction** will occur
- A degree of refraction occurs at each interface that we cannot control – **acoustic impedance** – the ratio of reflected and transmitted.

↓ acoustic impedance = ↑ transmission



Half Value Distance

- Soft tissue reduces the beam as it is absorbed
- The depth at which the beam has been halved from the surface value is the **Half Value Distance**.
- We must consider the attenuation rates of differing tissue when justifying our frequency selection

	1 MHz	3MHz
Muscle	9.0mm	3.0mm
Fat	50.0mm	16.5mm
Tendon	6.2mm	2.0mm

Absorption Characteristics of Ultrasound Energy

Blood Fat Nerve Muscle Skin Tendon [Cartilage Bone]



Increasing Protein Content gives Increasing Absorption

**Best absorption in TENDON, LIGAMENT, FASCIA
JOINT CAPSULE and SCAR TISSUE**

BREAK

- Next up – TUS and tissue healing..

Effects of TUS on Healing Process

- Increase speed of healing
- Enhance quality of repair
- **Thermal** and **Non-Thermal** effects

Thermal Effects of TUS

- High intensity (0.5 W/cm²)
- Continuous mode
- Heat dense collagenous tissues: periosteum, ligament, tendon, fascia, fibrotic muscle
- If temp of damaged tissue raised to 40-45°C then a hyperaemia will result which will be therapeutic in its effect



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Non-Thermal Effects of TUS

- Attributed to a combination of **Cavitation** and **Acoustic Streaming** (& Micromassage?)
- **Cavitation** is the formation of gas filled voids
 - **Stable** – formation and growth of bubbles. These bubbles are an accumulation of dissolved gas and enhance **acoustic streaming**
 - **Unstable** – formation of gas bubbles but at the low pressure part of the US cycle – collapse and release large amount of energy = cell death.



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Non-Thermal Effects of TUS

- **Stable cavitation** enhances **Acoustic Streaming**
- Acoustic streaming is the small scale eddying of fluid near the vibrating structures
 - i.e. cell membranes and stable cavitation gas bubbles.
 - Affects diffusion rates and cell permeability
 - Sodium ion permeability altered = cell membrane potential change
 - Calcium ion transport modified = altered enzyme controlled mechanisms
 - i.e. protein synthesis and cellular secretions.
 - Cell membrane becomes excited = increase cell activity



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Non-Thermal Effects of TUS

- **Micromassage**
 - Mechanical effect of sound wave cause molecule vibration
 - Reported to increase tissue fluid interchange, in turn affecting tissue mobility – think back to nutritional affects of joint mobilisations?!



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Contraindications to TUS

- Do not expose embryo or foetus
- Malignancy (disease, tumour, melanoma etc)
- Tissue which is bleeding or could be reasonably expected (healing)
- Significant vascular abnormalities including DVT, emboli, severe athero/arteriosclerosis
- Haemophiliacs not covered by clotting factor replacement
- Application to eye; stellate ganglion; cardiac area in Pt with heart disease or pacemaker; active epiphyses in children



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

Contraindications to TUS: Precautions

- Always use lowest intensity which produces a therapeutic response (**cell tickle not cell thump**)
- Ensure applicator is moved throughout Rx (Standing wave: reversible blood cell stasis)
- Ensure Pt is aware of Rx nature and the expected outcome
- If a thermal dose is intended, ensure contraindications for heat Rx apply
- Caution advised in vicinity of pacemakers or other implanted electronic devices
- Continuous U/S not advised over metal implants



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

TUS and Healing: Inflammatory Process

- **Inflammation**
 - TUS has stimulating effect on the **mast cells, platelets, white cells** with phagocytic rolls and the **macrophages** (Watson, 2008. ter Haar, 1999)
 - **Acoustic streaming** changes **platelet membrane permeability** releasing **serotonin & wound factors**
 - TUS induces the **degranulation of mast cells** causing the release of **arachidonic acid** which is a precursor for synthesis of **prostaglandins** and **leukotriene** (Leung et al 2004)
 - Degranulation may be caused by the **increase in Ca ion permeability**
 - Overall influence of TUS is **pro-inflammatory** NOT anti- inflammatory
 - 'inflammatory optimiser' Watson (2007, 2008)



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

TUS and Healing: Inflammatory Process

- **Proliferation**
 - Stimulative effect via **cellular up-regulation**
 - Primary targets for TUS are **fibroblasts, endothelial cells, myofibroblasts** (Watson and Young 2008)
 - TUS **pro-proliferation**: maximises its efficiency
 - Produces required **scar tissue in optimal fashion**
 - Harvey et al (1975) low dose pulsed TUS increases protein synthesis, **enhancing fibroplasia and collagen synthesis** (Warden et al 2006)
 - Growth factors are positively affected by TUS (McBrier et al 2007) as a are Heat Shock Proteins (Nussbaum and Locke, 2007)



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

TUS and Healing: Inflammatory Process

• Remodelling

- Generic scar tissue **adopts functional characteristics**
- TUS enhances appropriate orientation of newly formed collagen fibres and **promotes profile change from type III to Type I** : increasing tensile strength and enhancing scar mobility
- TUS enhances functional capacity of scar tissue (Yeung et al 2006)
- TUS may have capacity to influence **collagen fibre orientation** (Byl et al 1996)



*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Machine Settings

- Frequency
 - 1MHz = Deep
 - 3MHz = Superficial
- Pulse Ratio
 - 10%, 20%, 50%, 100%
- Intensity
 - Average 0.6 W/cm2
- Time
 - No of Rx Heads x Pulse ratio



*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Machine Testing

BEFORE the patient arrives

- House keeping
- Plugging it in
- Tx head
- Set the machine
- Water bath/bowl
- THE Tx HEAD MUST BE IN THE WATER
- Direct it upwards
- Press start
- Increase intensity



*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Patient Checks

- Contraindications
- Precautions
- Thermal Skin Test



*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Patient Explanation

- What will this do for the patient?
- What effects will it have?
- What should they feel?
- What shouldn't they feel?

INFORMED CONSENT:

- Do you understand the treatment?
- Do you have any questions?
- Are you happy for me to proceed?



*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Application: Types of Output

Continuous

- Sub-acute and chronic injuries (11 days +)
- Deep tissue lesions

Pulsed (duty cycle)

- Acute or early sub acute stages (2-10days)
- Over bony prominences
- Over metal implants
- Failed thermal skin test ?
- If unsure
- 1:9/ 10% Acute (5 days)
- 1:4/ 20% Sub Acute (6-21 days)
- 1:1/ 50% Chronic (21 days)



*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Application: Duration

- 1 minute per cm^2 as the time
- Thus a 5cm^2 head will cover 5cm^2 in 1 minute on continuous beam
- For a pulsed output: multiply by the duty cycle:
- 5cm^2 on 1:1 = 2 minutes Rx
- 5cm^2 on 1:4 = 5 minutes
- 10cm^2 on 1:4 = 10 minutes
- Area of 15cm^2 at 1:9 = 30 minutes



*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Practical Application

Keep Rx head moving:

- NO STANDING WAVES
- When a U/S wave hits interface of 2 tissues with different acoustic impedance
- Reflected wave meets and incident wave
- Can cause unstable cavitation



*Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives*

Recommended Rx Per Week

- Acute: daily up to 5/7
- Sub acute 3-5/7
- Chronic 2-3/7



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

NOTE TAKING

- Machine
- Machine settings:
 - Frequency
 - Intensity (W/Cm2)
 - Rx time (mins)
 - Pulse Parameters/Duty cycle (ratio or %)
- Area treated (size and location)
- Any immediate or untoward effects
- Rx progression
- Coupling medium



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives

TUS Protocol

STEP	STAGE	NOTES
	Equipment Checks (test machine, check connections/leads)	Done BEFORE patient arrives Check output using bowl of water
	Pt Checks (CI, Thermal Skin test)	Check all contraindications Perform thermal skin test (hot/cold test)
	Clear Pt explanation (Benefits & Dangers, IC)	What will this do for the patient? What effects will it have? What should they feel? What shouldn't they feel? INFORMED CONSENT
	Identify Rx area, target tissue, aim of Rx (palpate & inspect)	Expose, obs, palpate
	Client positioning (comfort & access)	Get them comfortable
	Application of coupling medium	10 pence piece average (2 Rx heads)
	Select: Frequency	3.3MHz Superficial (under 2cm) 1 MHz Deep tissue (2-5cm)
	Select Duty Cycle	Continuous (100%), 50%, 25%, 20%, 10%
	Select Intensity	0.1-0.8 W/cm ²
	Select Rx Duration	1 Rx head (5cm) is 1 minute of treatment Calculate against duty cycle
	Recommended Rx per week	Acute: daily up to 5/7 Sub acute 3-5/7 Chronic 2-3/7
	Practical Application	Keep Rx head moving: avoid standing wave
	Ending Rx, note taking	Note machine make, model, settings, CM pre and post, Pt comments



Trawsnewid Addysg; Trawsnewid Bywydau
Transforming Education; Transforming Lives