Therapeutic Ultrasound

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DEEP HEATING –ULTRASOUND

Objectives: At the completion of this lecture student must be able to:

- Describe how US is generated by the treatment unit
- Understand the key concepts of ultrasound and the rationale of various parameter selections such as intensity, frequency, treatment duration and duty cycle.
- Describe the thermal and non thermal effects of ultrasound based on known heating rates.
- Identify indications, contraindications and precautions associated with therapeutic ultrasound.
- Discuss techniques and efficacy of ultrasound application

Ultrasound

Ultrasound waves:-

- Ultrasound are inaudible high-frequency acoustic energy with frequency above 20.000Hz (20KHz).

Infrasound
- < 20<20HZ
- Earthquake
- Whales

Sound
- 20Hz-20KHz
- Speech& music

Ultrasound
- >20000Hz
- Bat

Therapeutic Ultrasound

Therapeutic Ultrasound (US) is inaudible acoustic high-frequency energy that produce either thermal or non-thermal physiologic effects, with following therapeutic parameters;

- Frequency range 0.75-3MHz (750.000Hz-3000000Hz)
- Intensity 0.1-3W.cm^2
- Depth of penetration 2 up to 5 cm

US is a most commonly used modalities in PT clinic

Deep heating modalities

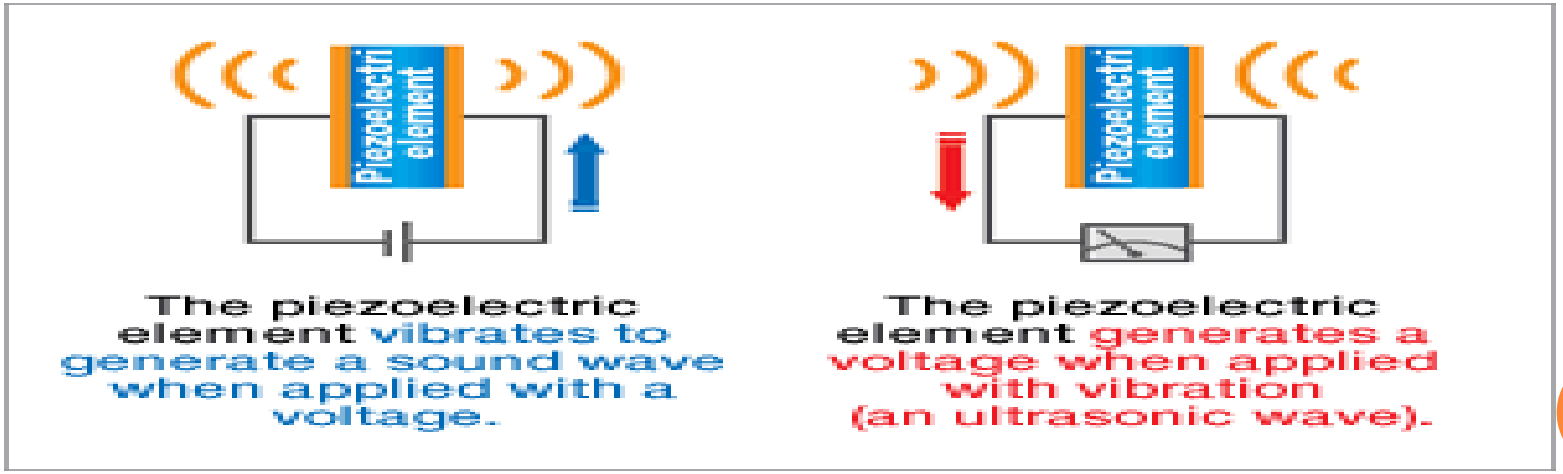
None- electromagnetic

Principle of US Production

Piezoelectricity is a natural phenomena found in many materials such natural (e.g. Quartz crystal) or synthetic (e.g.: Barium-Titanate).

Direct piezoelectric effect: creation of an electrical voltage across the crystal as it is compressed or expand

Reverse piezoelectric effect: When a high frequency alternating current is applied to the crystal causing alternate compression and expansion at each time the current changes from positive to negative. This is produce mechanical sound wave



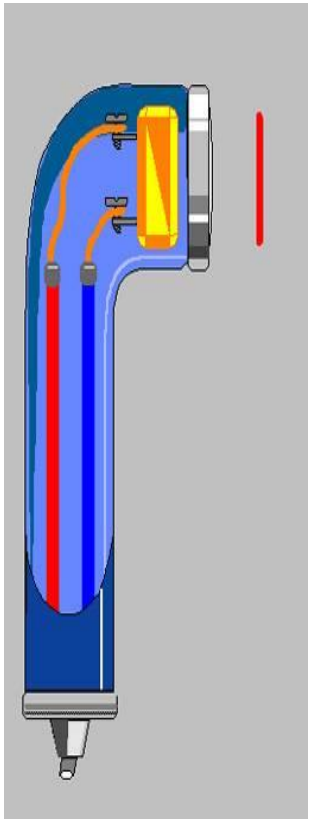
Component of US Apparatus (device)

1- Generator is rectangular box consist of

- Source of high frequency AC
- Oscillator circuit
- Transformer
- Control panel

2-Coaxial cable transmits the high frequency AC to a transducer.

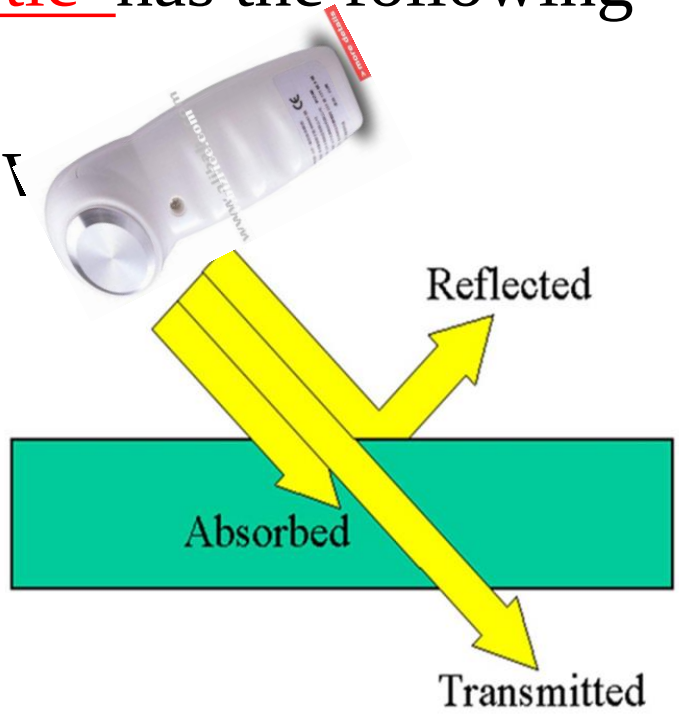
3-Transducer consists of piezoelectric crystal such as quartz, & barium titanate with one surface covered by metal plate and the other surface attached to coaxial cable that transmits high frequency AC.



Physics of Ultrasound

Ultrasound waves like electromagnetic has the following properties

- Transverse vs. Longitudinal
- Reflected/Refracted
- Absorbed and penetration
- Attenuated (loose energy)



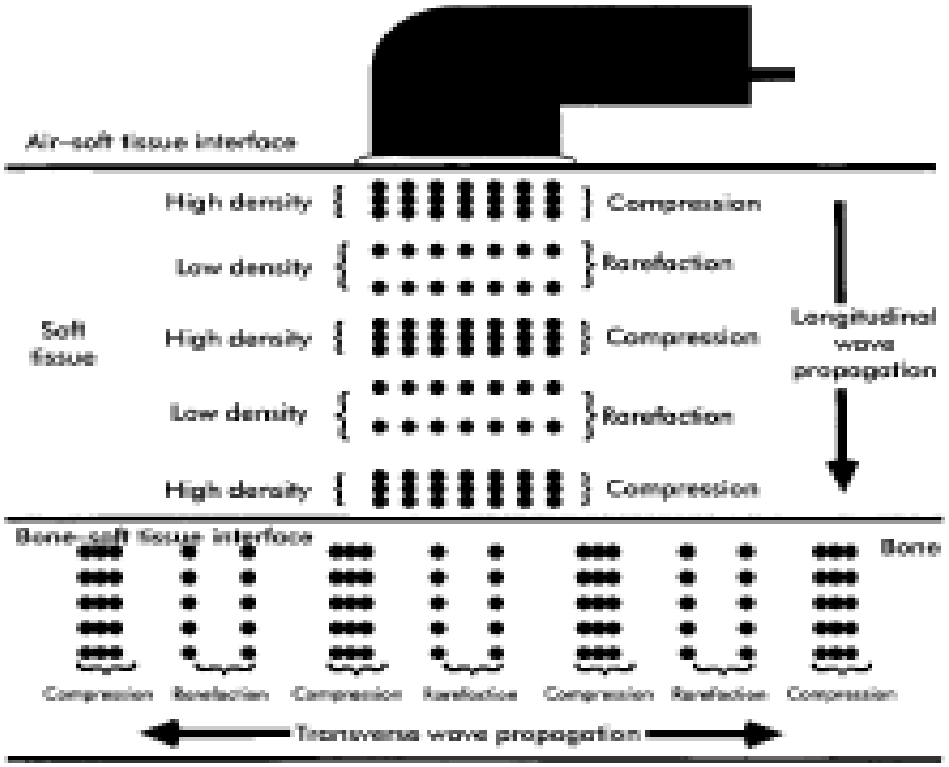
N.B.

Acoustic energy does not travel readily through space
Must travel through a medium (e.g. solid, liquid, & gas).
In PT using ultrasound gel as coupling media

Physics of US: Transverse vs. Longitudinal

Body tissue

Bone



US travels as mechanical **transverse waves** in **bone**
US travels as mechanical longitudinal wave in soft **tissue**

https://www.youtube.com/watch?v=Io-HXZTepH4

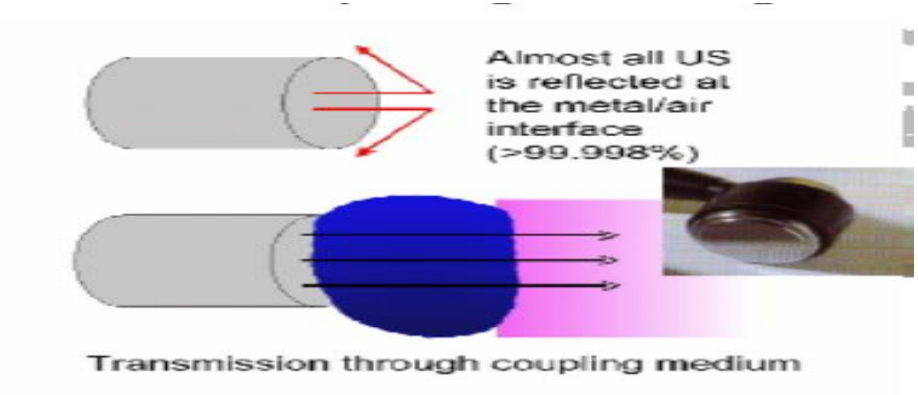
Physics of US: Reflection

The US is reflected at the interface of different tissues. This gives rise to the term acoustic impedance (Z). Acoustic impedance (Z) is the ratio between the reflected and transmitted US at an interface.

Interface	Energy reflected
Water-soft tissue	0.2%
Soft tissue(muscles) -fate	1%
Soft tissue(muscles) -bone (Periosteum-bone)	15-70%(hot spot)
Soft tissue–air (Transducer head-skin)	99.9%

Impact of US Reflection in clinical setting

- Standing wave
  - Hotspots
  - Shearing forces



Clinical Application to Overcome Hot Spot

- keep the US transducer head perpendicular
- keep US in contact with skin (no skin-air interface)
- keeping US applicator in constant movement.
- Use of coupling media
- Using pulsed US

BEAM NONUNIFORMITY RATIO (BNR)

The beam of ultrasound is irregular (not uniform), and area of high intensity (peak) and lower intensity(valleys)

Beam Nonuniformity Ratio (BNR) is ratio between peak intensity to the average intensity with normal values 2-5

Exercises

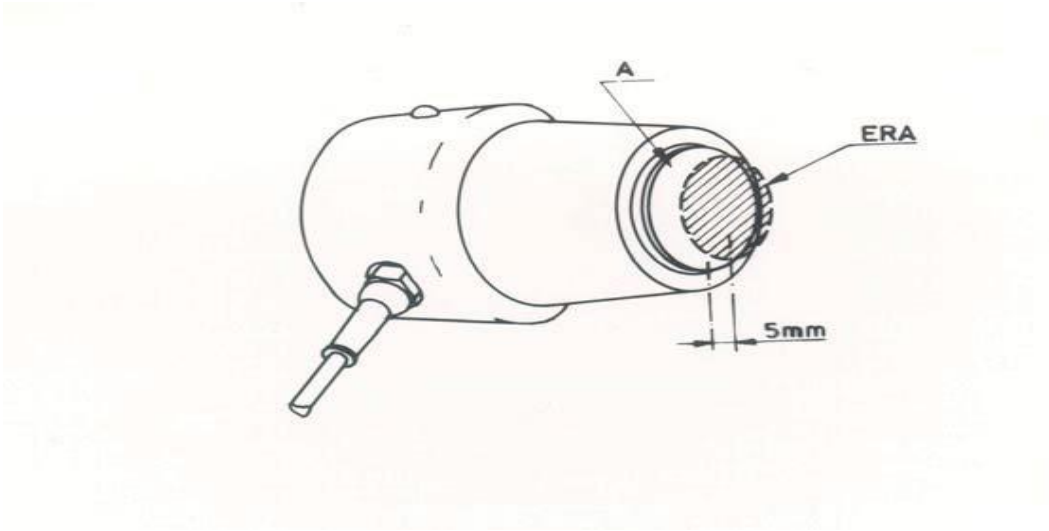
What BNR of 5:1 mean?

Lower the BNR, more uniform waves & lower chance to "hot spot"

EFFECTIVE RADIATING AREA (ERA)

ERA is the area of crystal that actually produces the sound wave.

- The ERA is smaller than treated area by half or 1/3
- The ERA is smaller than transducer face (>0.5cm^2)



BEAM AND FIELD OF US

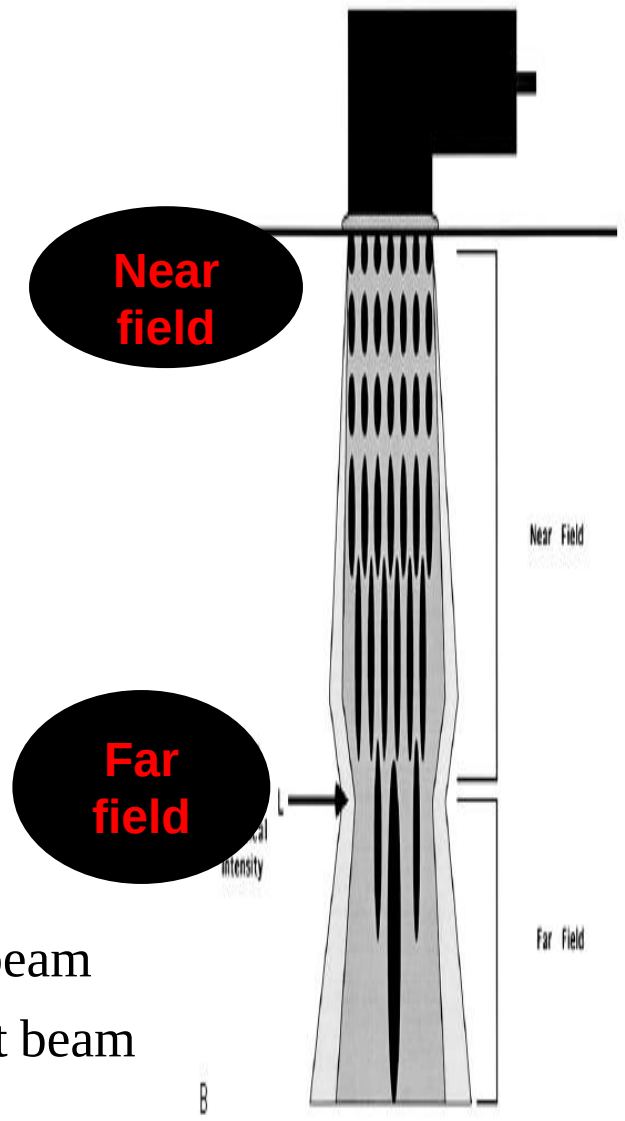
Fresnal zone (Near field): Area of the ultrasound beam closest to the transducer. (therapeutic zone),

Length of Near Field = r^2 / λ

Where:

- r is the radius of transducer head
- λ is the wave length

Fraunhofer zone (Far field): Area of the ultrasound beam immediately following near field.



Larger diameter + higher frequency = More focused beam

Smaller diameter + lower frequency = More divergent beam

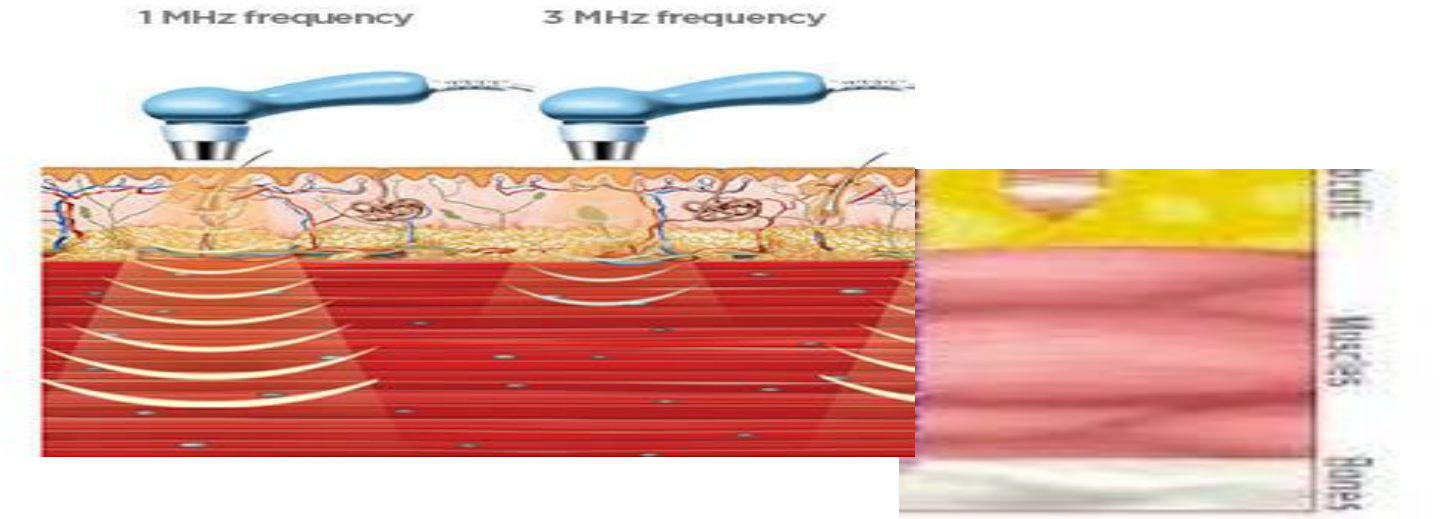
Penetration & Absorption of US

- What is the relationship between penetration and absorption?

  Penetration (5cm) = ↓ Absorption = Frequency (1MHz).

  Penetration (2.5cm) = ↑ Absorption = Frequency (3MHz).

- Tissues with higher water content have low absorption rate and high penetration rate.
- Tissues with higher protein content have high absorption rate low penetration rate.



Tissue characteristics, frequency, duty cycle, intensity duration of treatment

Relation between Absorption &Penetration of US

Medium	Absorption	Penetration
Water	1	1200
Blood	23	52
Whole blood	60	20
Fat	390	4
Muscle	663	2
Nerves	1193	1

- Tissues with higher water content has low absorption rate and high penetration rate.
- Tissues with higher protein content has high absorption rate (peripheral nerve, bone) and low penetration rate

Attenuation of US

Attenuation is a gradual reduction in the intensity of the ultrasonic beam once it has left the treatment head and it depends on absorption rate and scatter.

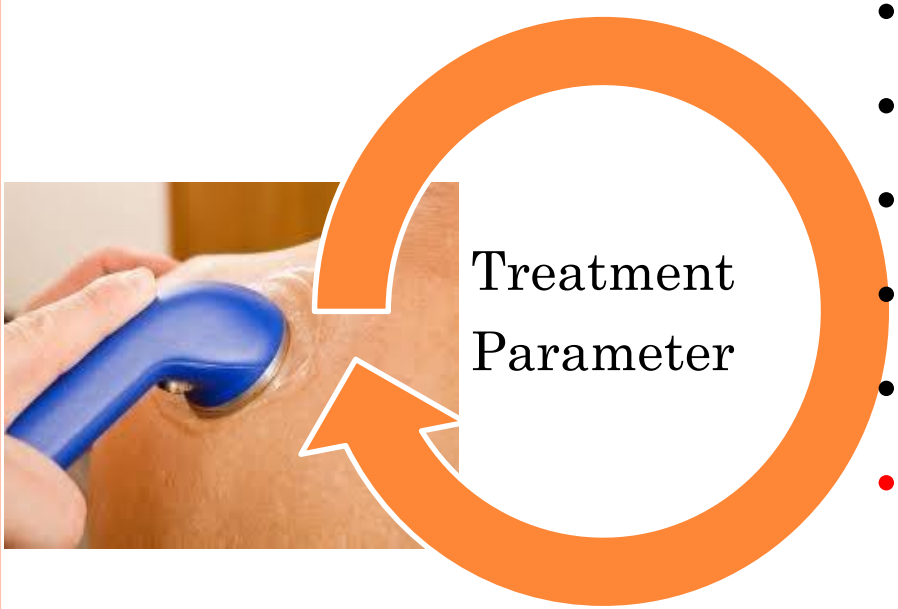
- The higher the tissue with H_2O content, the less the attenuation.
- The higher the tissue with protein content, the more the attenuation.

Half value thickness (mm): is the depth of the soft tissue at which the US beam reduces to 1/2 of its intensity. It depends on frequency and types of tissues

	Fat	Muscle	Bone
@ 1 MHz	50mm	10-20mm	15mm
@ 3 MHz	16mm	30-60mm	5mm

Treatment parameters with Ultrasound

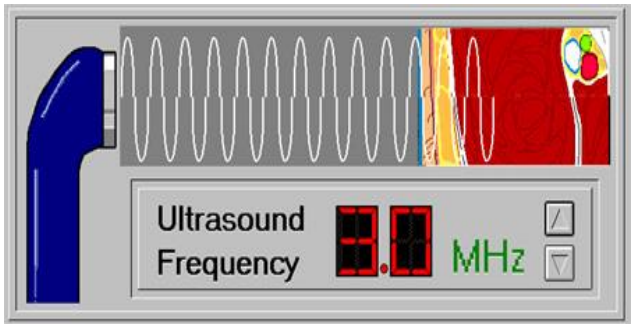
The treatment parameters depend on the desired effects of US (thermal/ non-thermal), However, the following parameters have to be considered



- Frequency
- Intensity
- Mode and Duty cycle
- Treatment duration
- Conducting media
- **Technique of applications**

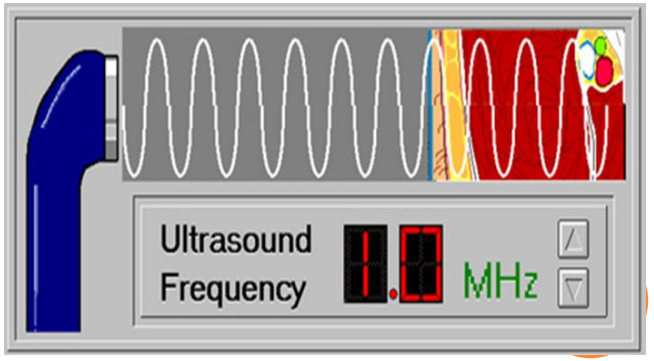
1-Frequency of US

- 3MHz:The higher the frequency, less depth of penetration and more absorption in superficial tissues.
- **3MHz** is appropriate for superficial lesions (2-3cm) such as planter fasciitis, Achilles tendinitis , tennis elbow.



1MHz: The lower the frequency (1MHz), the greater is the depth of penetration into deeper tissue

1MHz is effective for deeper lesion (3-5cm).



2-ULTRASOUND INTENSITY (1-3W/CM²)

Intensity (1-3W/cm^2): the rate of energy (Watts) is being delivered per unit of area (cm^2).

Spatial average intensity (SAI) is the average intensity of US output over the area of transducer (W/cm^2)

$$\text{SAI} = \frac{Total\ watts\ (W)}{effective\ raduating\ area\ ERA(Cm^2)}$$

If ultrasound is produced at a power of 8 W and the ERA of the soundhead is 4 cm2, the SAI would be 2.0 W/cm^2.

According to the World Health Organization's guide-lines;

SAI of 3.0 W/cm^2 is the safe limit for therapeutic treatment.

SAI of 10 W/cm^2 are used to surgically destroy tissue,

SAI below 0.1 W/cm^2 are used for diagnostic purposes.

2-ULTRASOUND INTENSITY (1-3W/CM²)

There are no definite guidelines for selecting specific ultrasound intensities during treatment; however,

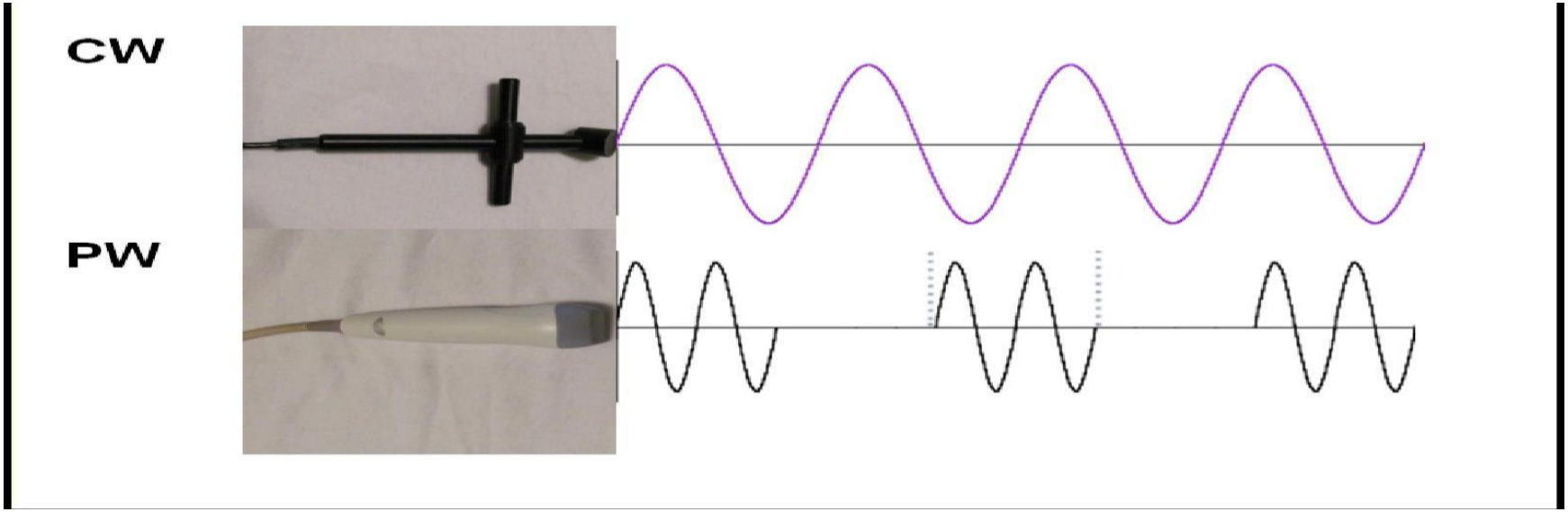
- Too high intensity causes tissue damage (>2.5-3W.Cm^2)
- Lowest intensity achieves a desired therapeutic effect (≤1.5W.Cm^2)

The intensity required at the lesion can be determined from the following table :

Tissue State	Intensity require(W/cm^2)
Acute	0.1 - 0.3
Sub Acute	0.2 - 0.50
Chronic	>0.3-0.8

3-Mode of US Delivery and Duty cycle

Continuous mode of US is the continuous delivery of US energy over time that induce thermal effect, used for chronic condition.



Pulse mode of US is interrupted delivery of US energy over time, that induce non-thermal effect, used for acute and subacute condition. (Why?)

4-Duty cycle: In Pulsed Modes US

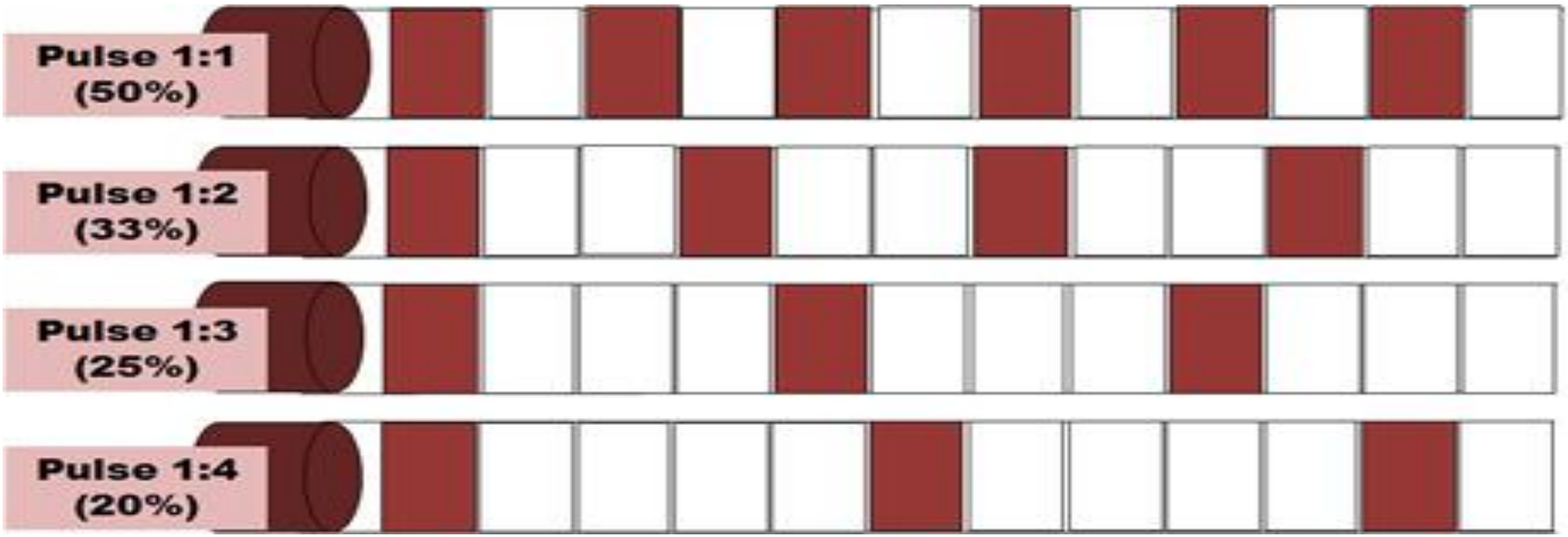
Mark : Space Ratio $\frac{Pulse\ duration(on-time)}{inter\ pulse\ \ interval\ (oof-time}$

Duty Cycle $= \frac{Pulse\ duration(on-time)X100}{pulse\ peroid(\ on-time+off-time)}$

Commonly "on time" is 2msec, & "off time" varies from 2-8msec

Pulse	Interval	Mark:space ratio	Ratio of pulse to total period	Duty cycle
2 ms	2 ms	1:1	1 in 2	50%
2 ms	8 ms	1:4	1 in 5	20%

4-Duty cycle In Pulsed Modes of US



- Pulse of 1:9 produced no heating, (10%duety cycle)
- Pulse of 1:4 minimal heating, (20%duety cycle)
- Pulse of 1:3 mild heating, (25%duety cycle)
- Pulse of 1:2 moderate heating, (33%duety cycle)
- Pulse of 1:1moderate heating (50%duety cycle)

Pulse of 1:3 & 1:4 are used for treatment of acute lesions.

5-Treatment Duration

Dependence on Frequency, intensity, size of treatment area and thermal/non-thermal effects

- 3MHz at 1.5W/cm^2 is sufficient to achieve a 4^0 C increase in local temperature of muscles per minutes (4-5minutes)
- 1MHz at 1.5W/cm^2 is sufficient to achieve a 0.4^0 C increase in local temperature at per minutes (12 minutes)
- 1MHz at 2W/cm2 is sufficient to achieve a 0.40 C increase in local temperature at per minutes (10 minutes)

Treatment duration

Average 7 minutes

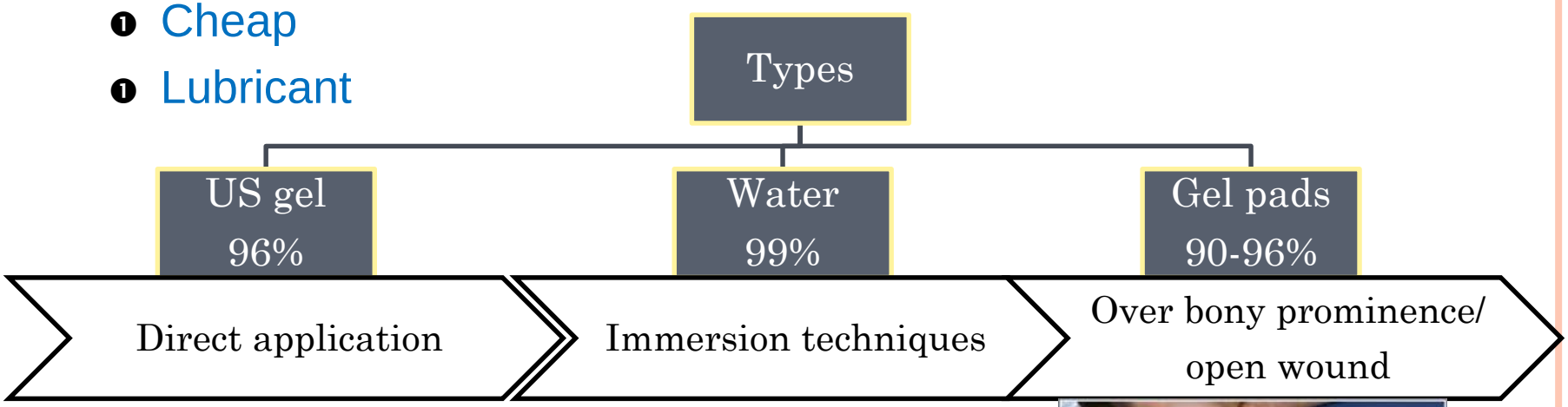
Range 5-15 minutes

6-Conducting Media

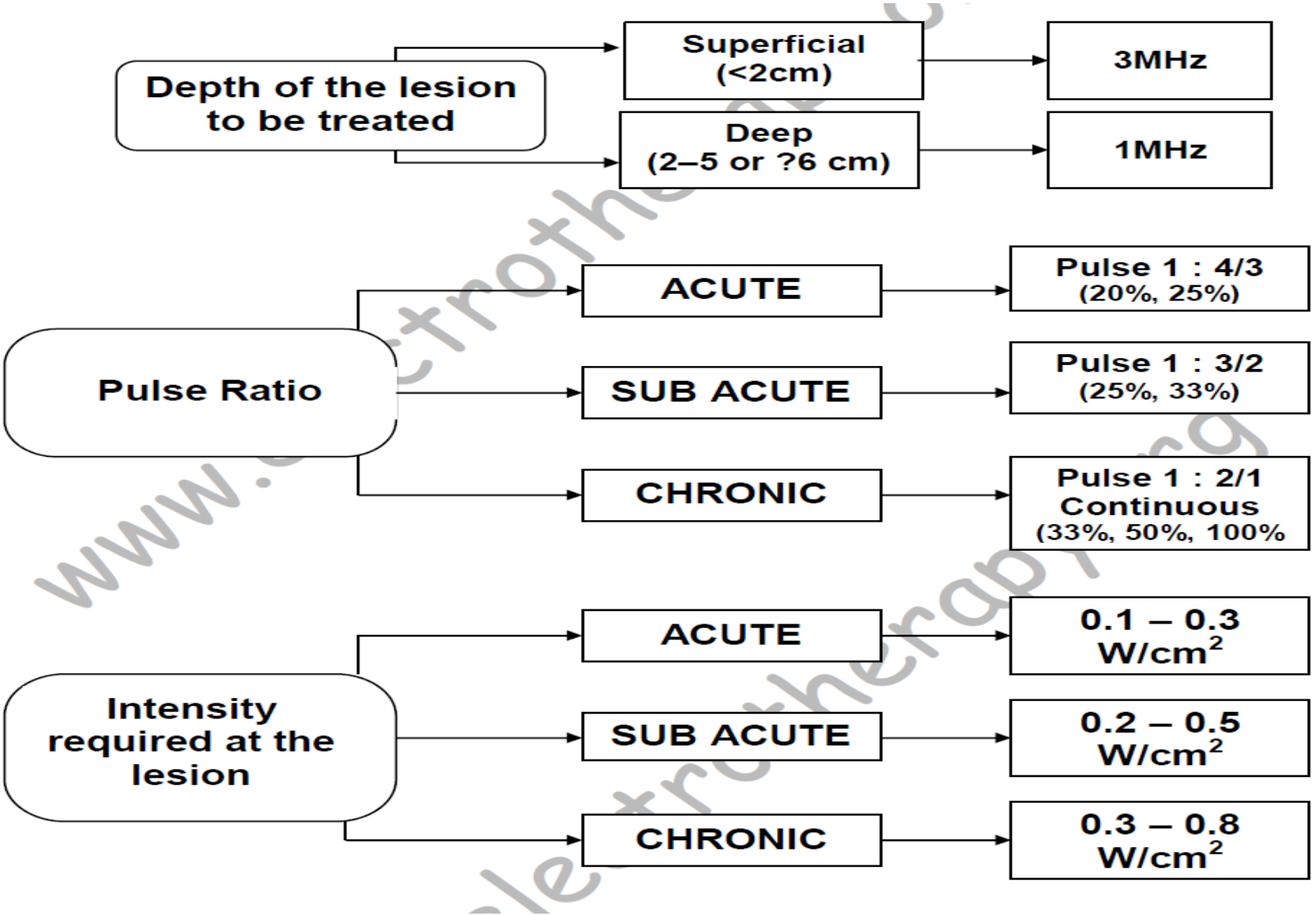
A substance that facilitates the transmission of ultrasound energy by decreasing impedance at the air-skin interface

Characteristics of Good Coupling Media

- High viscosity and transmissivity for US
- Hypo-allergic character
- Acoustic impedance similar to human tissue
- Cheap
- Lubricant



Ultrasound Dose Calculation



Physiological Effects of Ultrasound

Thermal effects:- {continuous mode US of 0.5-3w/cm^2)

Those effects of ultrasound result from a temperature increase (40-45^{0}C) due to friction among molecules) in the tissues.

1° C	Increase metabolic rate
2-3°C	Reduce pain and spasm and increased blood flow
4 °C	Increase tissue extensibility& decrease joint stiffness

- Increased pain threshold (reduction of pain& muscle spasm).
- Increased blood flow.
- Increased extensibility and deposition of collagen tissue
- Increased enzyme activity
- Increased tissue perfusion (oxygenation)
- Decreased nerve conduction velocity

Physiological Effects of Ultrasound

Non-thermal effects

Using a pulsed mode: Duty cycle of 20-25%, with normal intensity

Using a continuous mode with intensities lower than 0.5 w/cm^2.

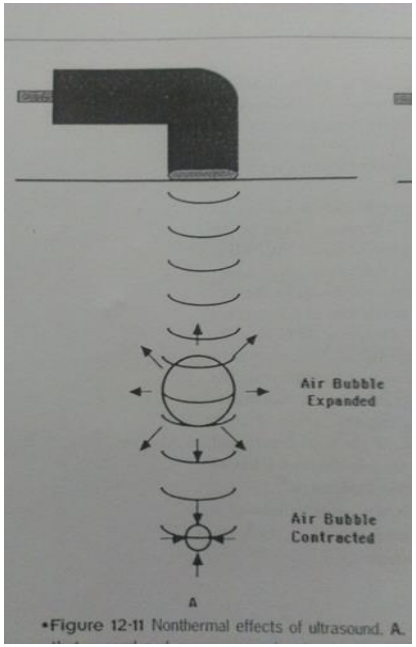
Cavitation

Acoustic micro-streaming

Micro-massage

1-Cavitations is the formation of tiny gas bubbles in the tissues fluid as a result of US energy due to molecular agitation.

Stable cavitation occurs when the bubbles oscillate to and fro within the US pressure waves, creating faster transmigrations of ions at cellular level, and associated with acoustic streaming, to induce therapeutic effects .



1-Cavitations

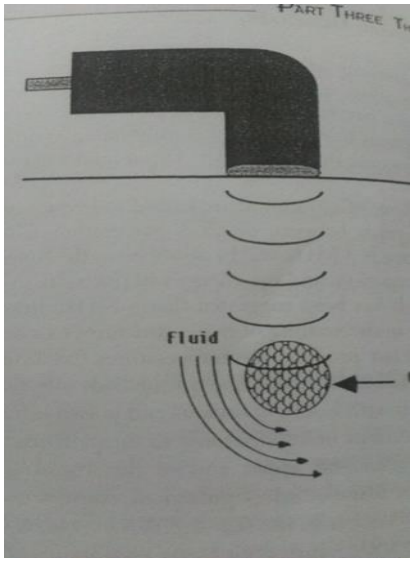
2-Unstable cavitation occurs when the gas bubbles pick up too much US energy causing them to expand rapidly and then collapses causing high pressure and temperature changes and resulting in gross damage to tissues. (low frequency/high intensity US)

Clinically: Unstable cavitation is minimized by:

- ✓ Using space-averaged intensities below 4W/cm^2
- ✓ Using a pulsed source of ultrasound
- ✓ Moving the treatment head

2-Acoustic Microstreaming:

Acoustic microstreaming is localized, unidirectional fluid movement around the vibrating bubble.



- ✓ Altering cell membrane permeability
- ✓ Enhance protein synthesis
- ✓ Enhance repair process

3-Micromassage effect:

- This occurs where the longitudinal waves of the US beam produces compression and rarefaction of the cells, and affect the movement of the tissue fluid in the interstitial space .
  - ✓ Sclerolytic effects in soft tissue
  - ✓ Release of contracture and adhesion

Non-thermal Effects of Ultrasound

- ↑ Cell membrane and vascular permeability
- ↑ Blood flow
- ↑ Fibroblastic activity
- Secretion of chemotactics
- Stimulation of phagocytosis
- Production of granulation tissue
- Synthesis of protein
- ↓ edema
- Diffusion of ions
- Tissue regeneration

Indications (Therapeutic US)

- Acute and sub-acute traumatic and inflammatory conditions
  - 1-Soft tissue injuries (sprain, strain)
  - 2-Painful shoulder
  - 3-Bursitis
- Chronic rheumatoid and arthritic conditions
  - 1-Rheumatic conditions
  - 2-Osteoarthitis
  - 3-Rheumatic nodules
- Wound healing
  - 1-Venous ulcer
  - 2-Pressure sores
  - 3-Surgical wound
  - 4-Burn

Indications for Therapeutic US

- Scar tissue and contracture
  1-Scar tissue (surgical and post burn)
  2-Dypuytren's contracture
  3-Plantar fascities
- Pain relief
  1-Low back pain
  2-Neck pain
  3-Rheumatic pain
  4-Phantom pain
  5-Herpes zoster

Contraindications for therapeutic US

1-Rapid dividing tissues: Encourage neoplastic growth and provoke metastases. Therefore, treatment over tumours should be avoided.

2-Pregnant Uterus: Not applying treatment over the pregnant uterus.

3-Epiphyseal Plates: Avoid giving ultrasound on cartilaginous epiphyseal plates because growth of the bone is impeded.

4-Spread of Infection:

- Bacterial or viral infection could be spread by US ,
- The low-grade infections of venous ulcers,

5-Tuberculosis: Risk of reactivating encapsulated TB.

6-Radiotherapy: Areas that have received radiotherapy in the last 3 months should not be treated because of the risk of encouraging pre-cancerous changes.

7-Nervous System: Where nerve tissue is exposed, e.g. over a spina bifida or after a laminectomy.

8-Specialized Tissue:

- The fluid-filled eye -retinal damage could occur.
- Treatment over the gonads is not recommended.

10-Implants: Smaller and superficial implants, low dose can be used

11-Vascular Problems: **:** Circumstances in which hemorrhage might provoke should not be treated. Such as

- *Haemarthrosis*
- *Haematoma*
- *Uncontrollable haemophilia.*

- Severely *ischaemic tissues* should be avoided because of the poor heat transfer and possible greater risk of *arterial thrombosis* due to stasis and endothelial damage.
- Recent *venous thrombosis* might extend the thrombus or disrupt its attachment to the vein wall forming an *embolus*.
- Areas of *atherosclerosis* are best avoided for the same reason.