THERAPEUTIC ULTRASOUND

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DEEP HEATING –ULTRASOUND

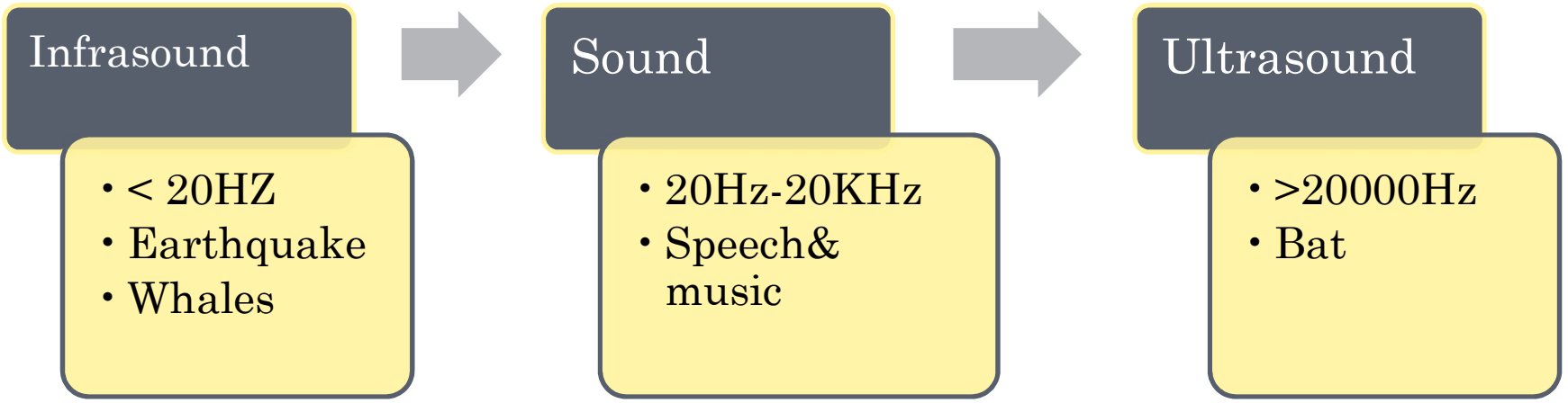
Objectives: At the completion of this lecture student must be able to:

- 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).

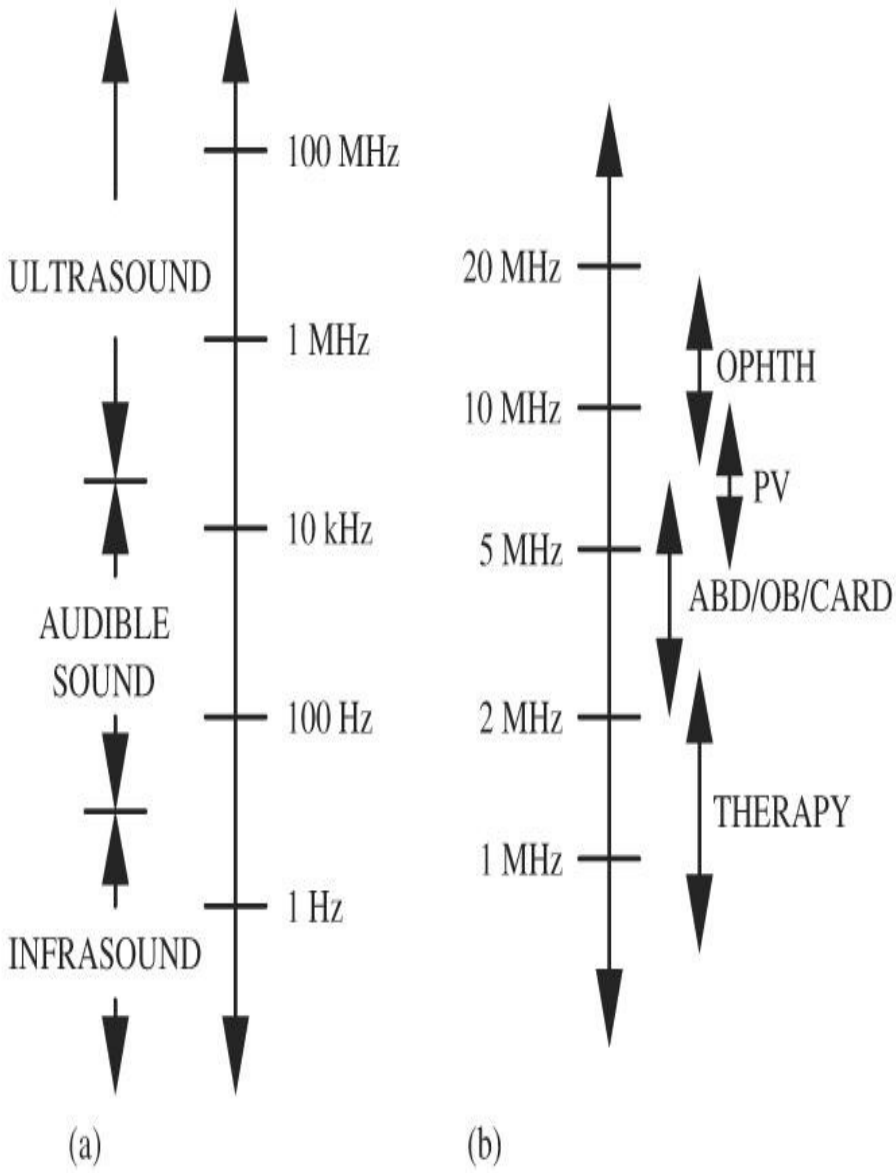


Ultrasound

Ultrasound
>20000Hz
Bat

Sound
20Hz-20KHz
Speech& music

Infrasound
< 20HZ
Earthquake
Whales



Diagnostic US
2.5 and 7.5MHz.

Therapeutic Ultrasound

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

Frequency range: 1MHz-3MHz (750.000Hz-3000000Hz)

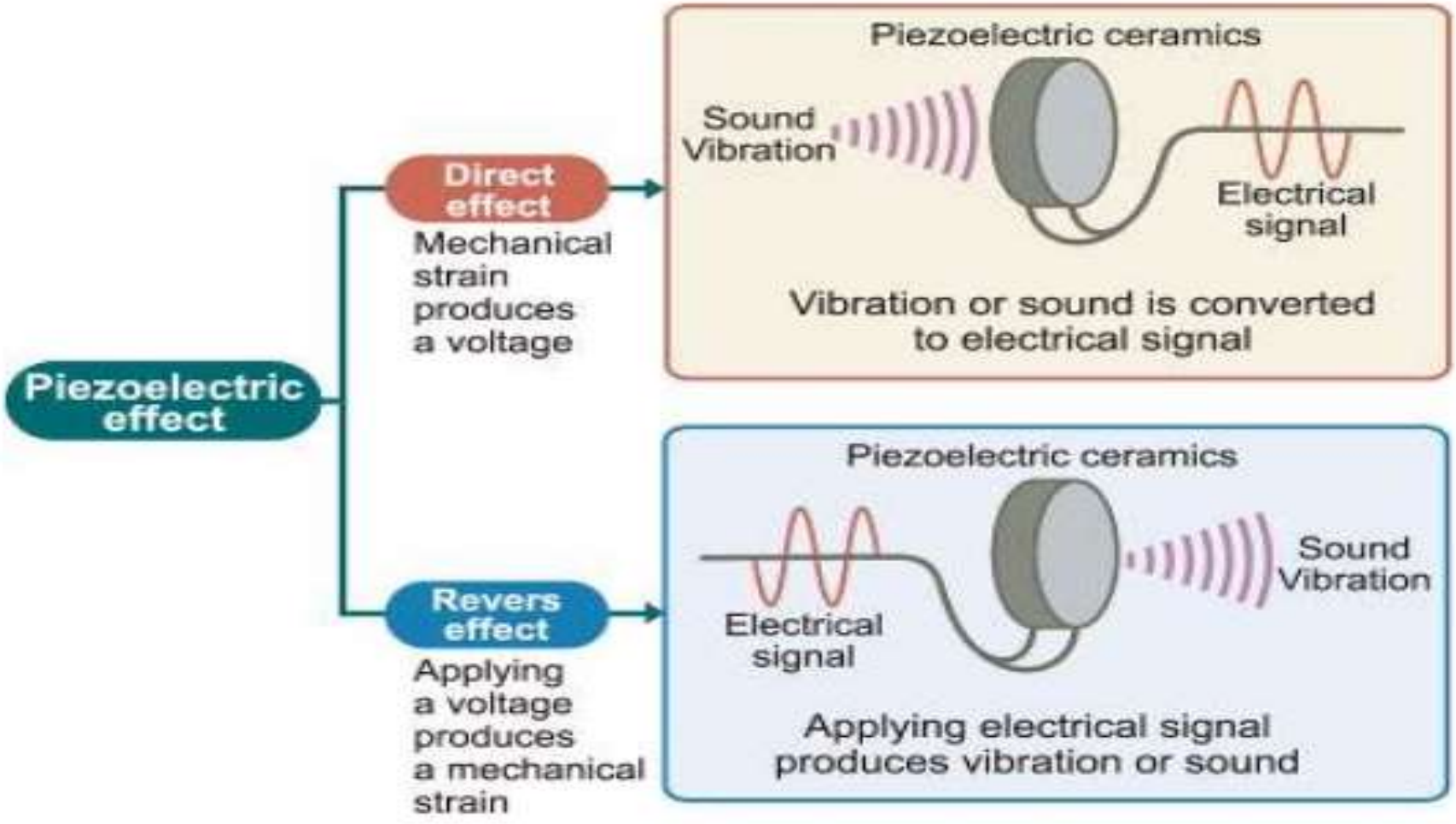
Intensity: 0.1-3 W.cm^2

Mode of energy: continuous /pulsed

Depth of penetration: 2 up to 5 cm

Principle of US Production/generation

Piezoelectricity is a natural phenomena found in many natural materials (e.g. Quartz crystal) or synthetic such as plimbium zirconium Titanate-(PAT).



Component of US Apparatus (device)

Generator is rectangular box consist of

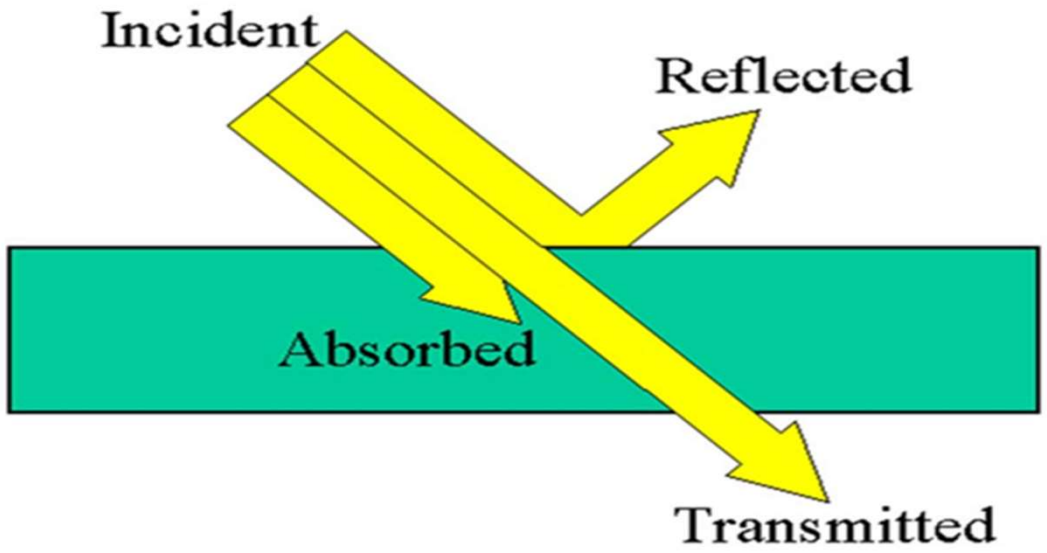
Transducer

Coaxial cable

Physics of Ultrasound

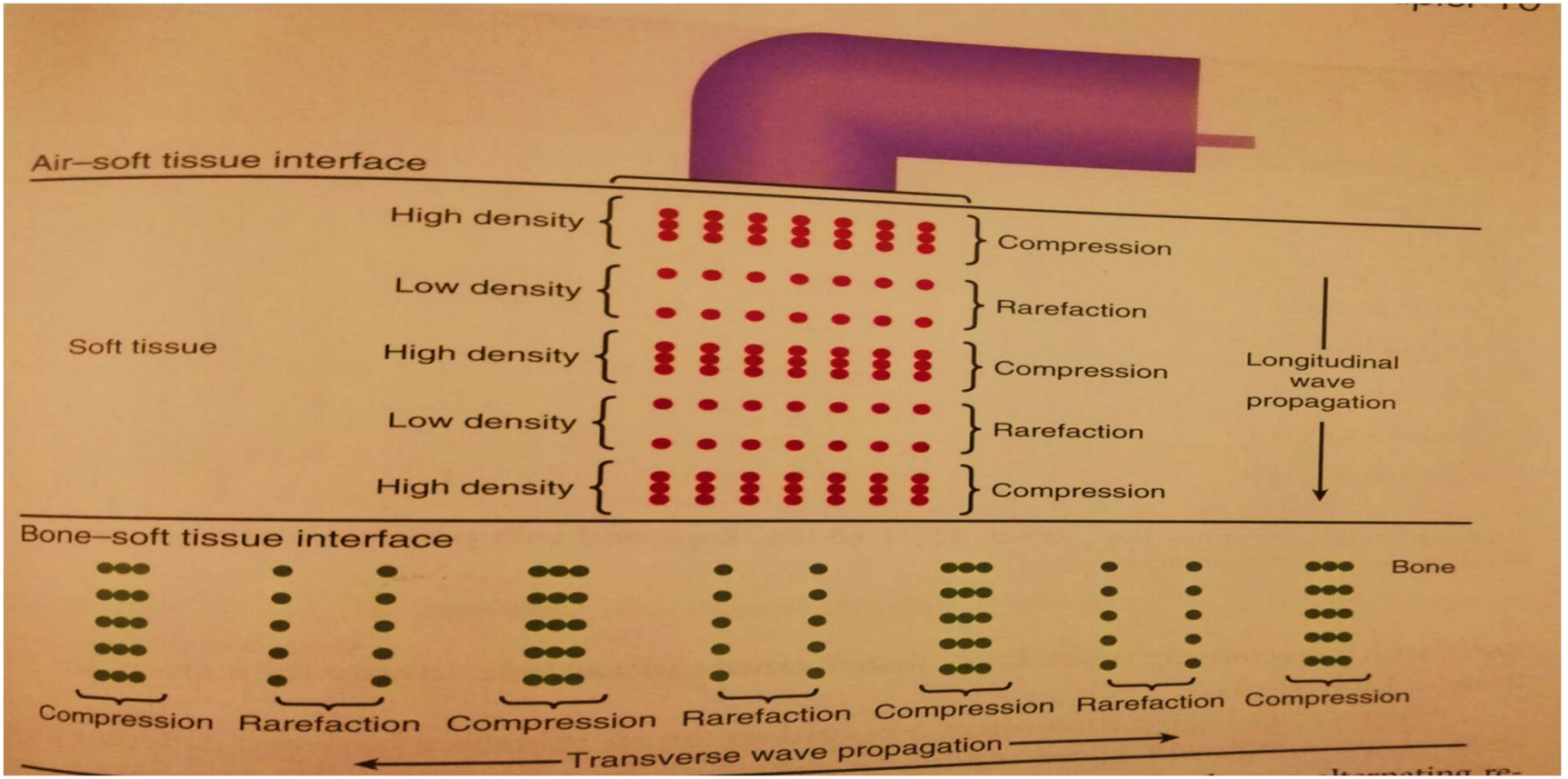
Ultrasound **likes electromagnetic** has the following properties

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



US Wave Transmission

Transverse, Longitudinal, Standing

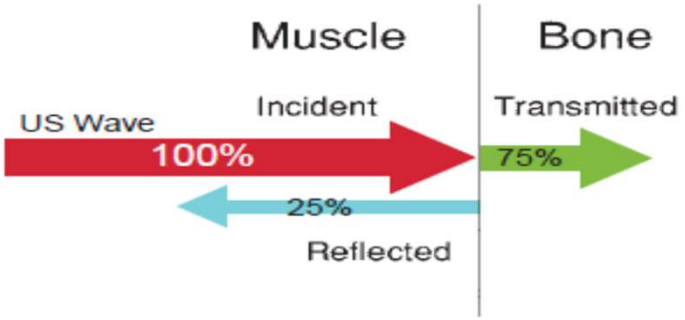


https://www.youtube.com/watch?v=Io-HXZTepH4

Reflection/Refraction of US

The US is reflected at the interface of different body tissues. The amount of the energy reflected is proportional to the difference in acoustic impedance between the two media

Interface	Energy reflected %
Gel/water-soft tissues	0.1%-0.2%
Soft tissue(muscles) -Fate	1%
Soft tissue(muscles) -Bone (Periosteum-bone)	Average 35% (15-70%)/Hot spot
Soft tissue–air (Transducer head-skin)	99.9%



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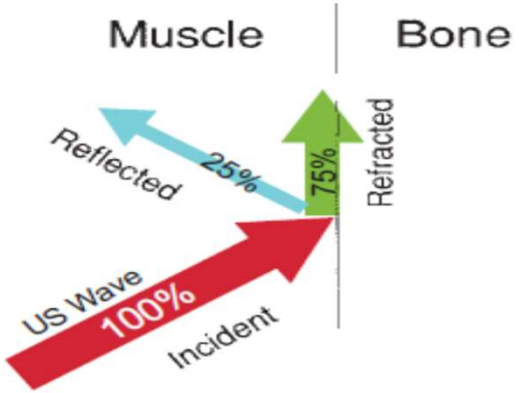

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Impact of US Reflection in clinical setting

- **Standing wave**
  - Hotspots
  - Shearing forces

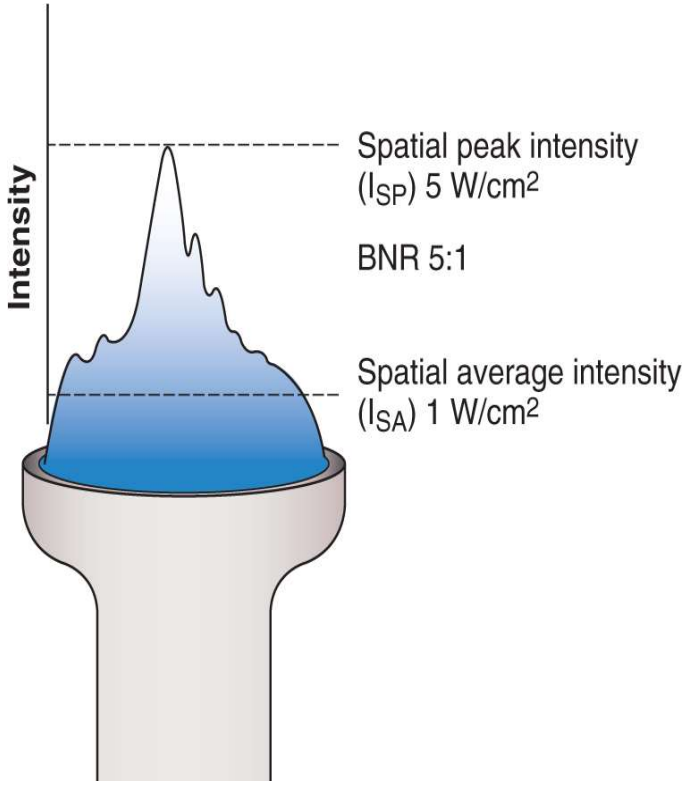
Clinical Application to Overcome Hot Spot

- 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 NON UNIFORMITY RATIO (BNR)

BNR is the amount of variability of intensity within the beam of US

$$BNR = \frac{Spatial\ peak\ intensity}{spatial\ Average\ intensity} = 2\text{-}5$$



Exercises

What BNR of 1:1 mean?

What BNR of 5:1 mean?

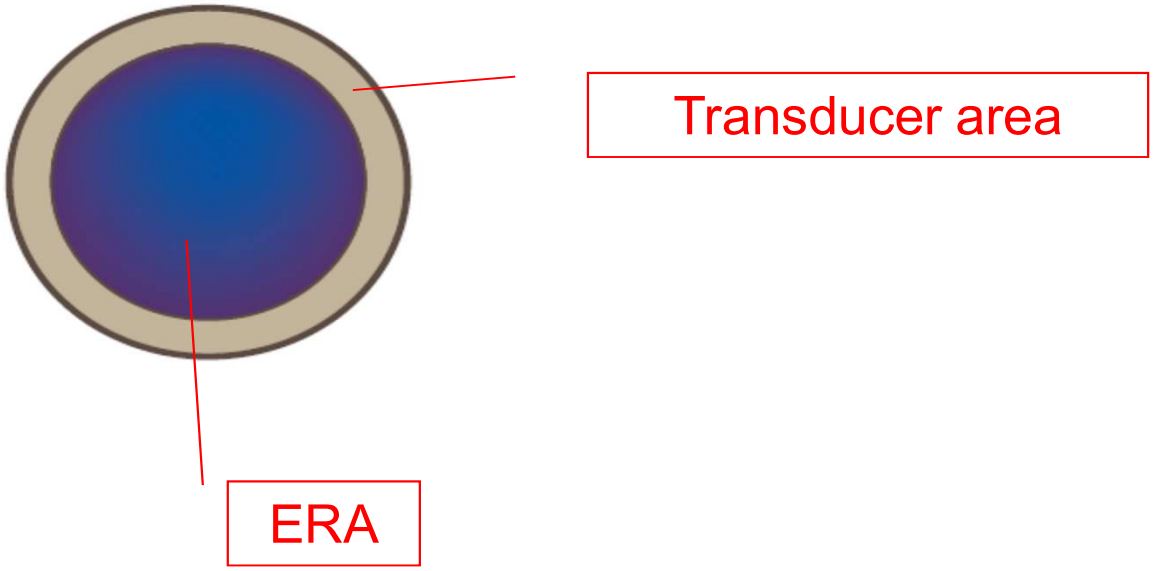
Lower the BNR,

- ❖ 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 < 0.5cm^2 from transducer face



- **Poor quality US has small ERA and higher BNR**

FIELDS OF US

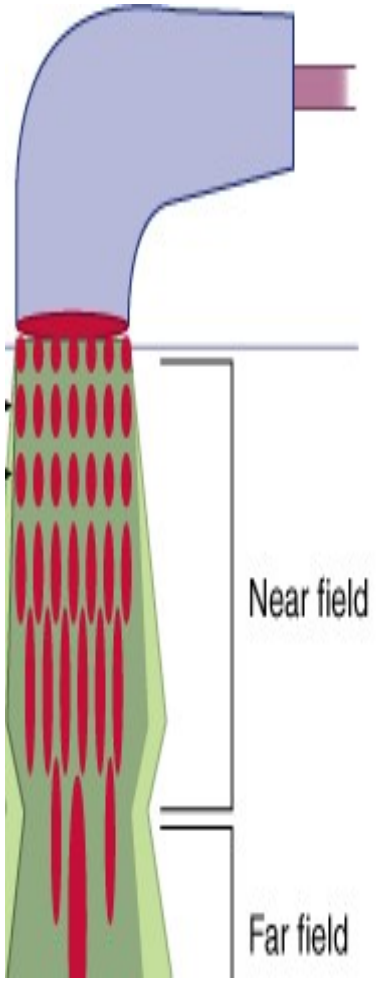
Fresnal zone (Near field): Area of the ultrasound beam closest to the transducer. (therapeutic zone) head ,less divergent.

Length of Near Field = r^2 / λ

Where:

- Square of r is the radius of transducer head
- Wavelength λ of US

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

Frequency	ERA	Length of near field
1	5	11
3	5	33

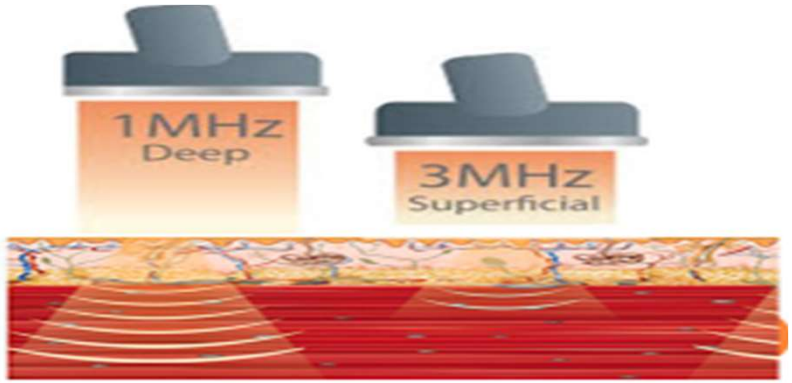
Absorption and Penetration of US

Dependents on

- Acoustic Properties
- Fluid Element,
- Frequency
- Degree of Tissue Vascularization

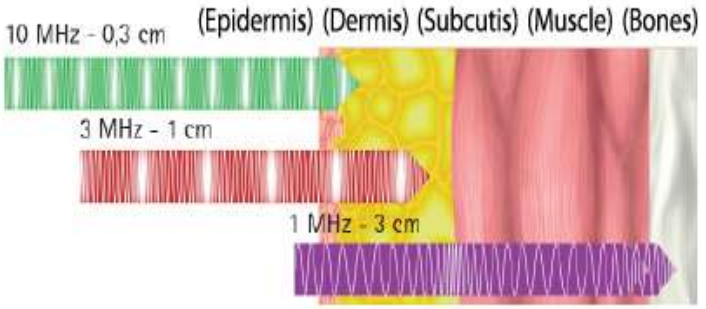
- **Tissues with higher water content**
  low absorption rate & high penetration rate.
- **Tissues with higher protein content**
  high absorption rate & low penetration rate.

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



Frequency (1MHz)
Decrease Absorption
Increase Penetration

Frequency (3MHz)
Increase Absorption
Decrease Penetration



Attenuation of US

Attenuation is a gradual decrease in the intensity of US 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.

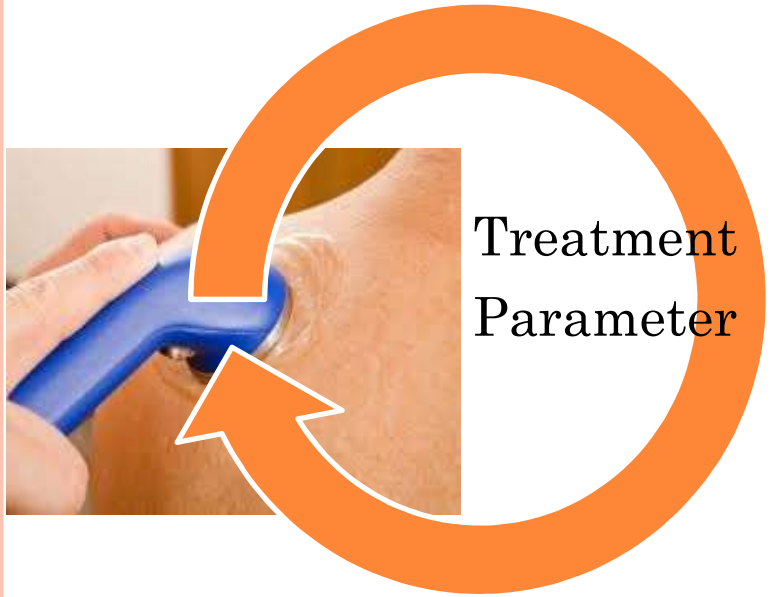
The higher the tissue with protein content, the more the attenuation.

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

	skin	Fat	Muscles	Tendon	Cartilage	Bone
I MHz	11.1	50	24.6	6.2	6	21
3 MHz	4	16.5	8	2	2	0

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

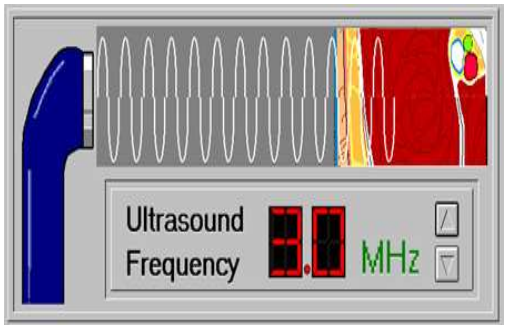


- Frequency
- Intensity
- Mode and Duty cycle
- Treatment duration
- Number/frequency of treatment
- Conducting media
- **Technique of applications**

1-Frequency of US

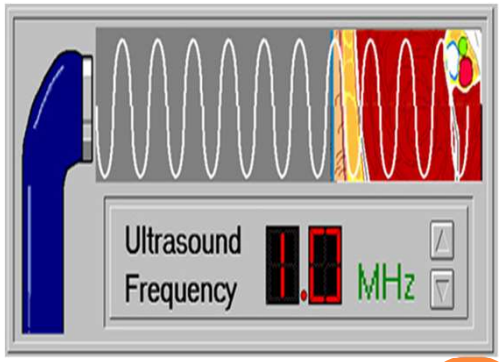
3MHz US

- Less depth of penetration
- more absorption in superficial tissues.
- appropriate for superficial lesions (2-3cm) such as planter fasciitis, Achilles tendinitis , tennis elbow.



1MHz US

- Greater depth of penetration into deeper tissue
- Effective for deeper lesion (3-5cm).



2-ULTRASOUND INTENSITY (1-3W/CM²)

Intensity (0.1-3W/cm²): is the power per unit area of the ultrasound head (watts/cm²) $\text{Intensity (SAI)} = \frac{power\ (watts)}{effective\ radiating\ area\ (cm^2)}$

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

- Too high intensity causes tissue damage (>2.5-3W.Cm²)
- Lowest intensity achieves a desired therapeutic effect (≤1.5W.Cm²)

Injury stage	intensity (W/cm²)	Temperature increases	Indication
Acute	**0.1 - 0.3**	Non-thermal	Acute injury /tissue healing
Subacute	**0.2 - 0.50**	Mild thermal (1⁰C)	Sub-acute injury/tissue healing
Chronic	**>0.3-0.8**	Moderate thermal (2-3⁰C)	Chronic inflammation, pain, trigger points
		Vigorous heating (<4⁰C)	Stretch collagen

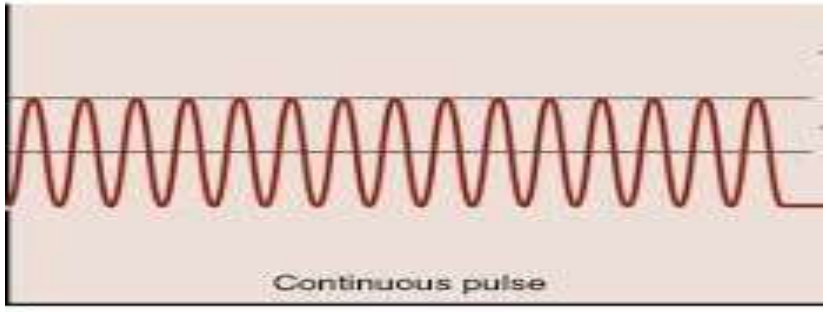
higher frequency (3MHz).

Patient perception should consider when controlling intensity

3-Mode of US Delivery and Duty cycle

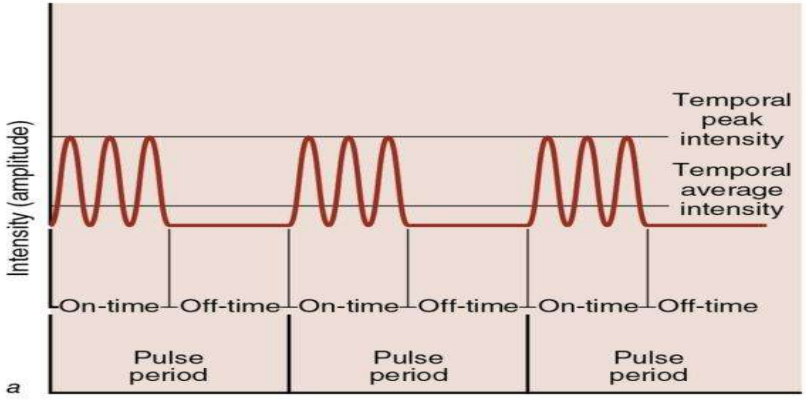
Continuous mode US

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?)



PULSED MODES US: DUTY CYCLE

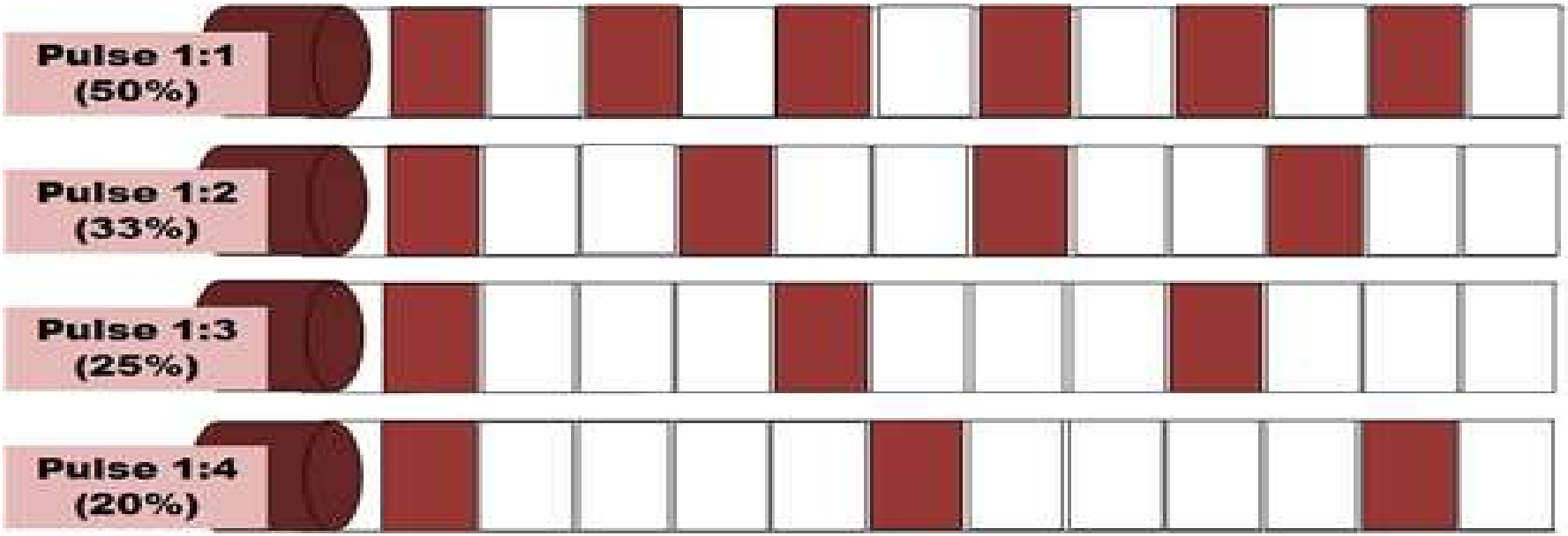
$$\text{Mark; space ratio} = \frac{pulse\ duration\ (on\ time)}{interpulsr\ intervak\ (off\ time)}$$

$$\text{Duty cycle} = \frac{pulse\ duration\ (on\ time)}{Pulse\ peroid\ (on\ time + off\ time)}$$

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%

PULSED MODES US: DUTY CYCLE



- 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

Frequency	Vigrous heating > 4^0C
1MHz	1.5w/cm^2 for 12-14 minutes@ 100% duty cycle
3MHz	1.5w/cm^2 for 4-7mins@100%duty cycle
1MHz	2W/cm^2 for 8-10 mins@100% duty cycle
3MHz	0.8-1.0W/cm^2 for 4-5mins@100%duty cycle

Treatment duration

Average 7 minutes

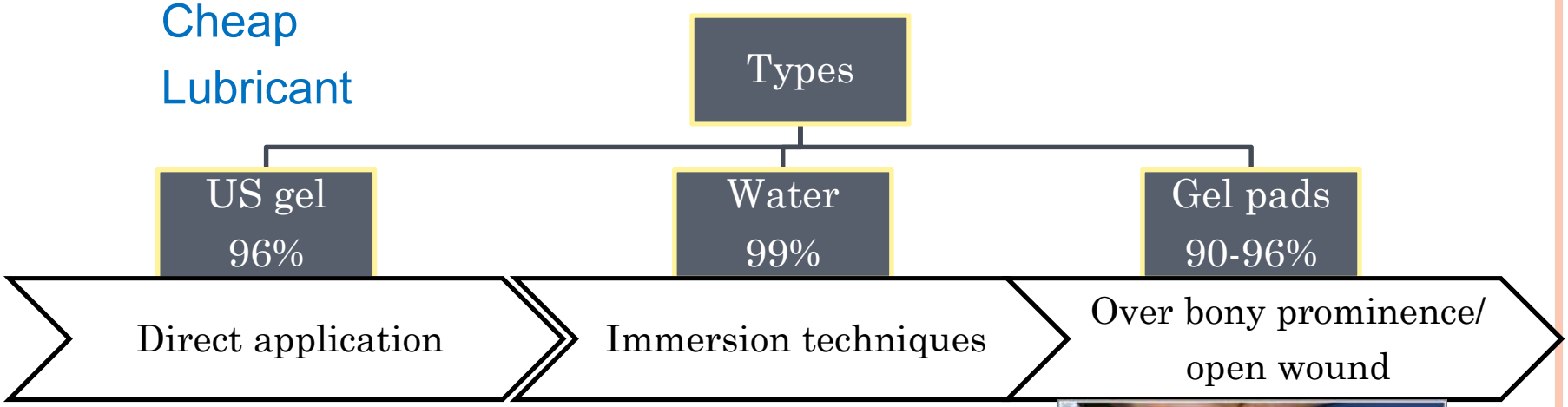
Range 5-10 minutes/area

6-Conducting Media

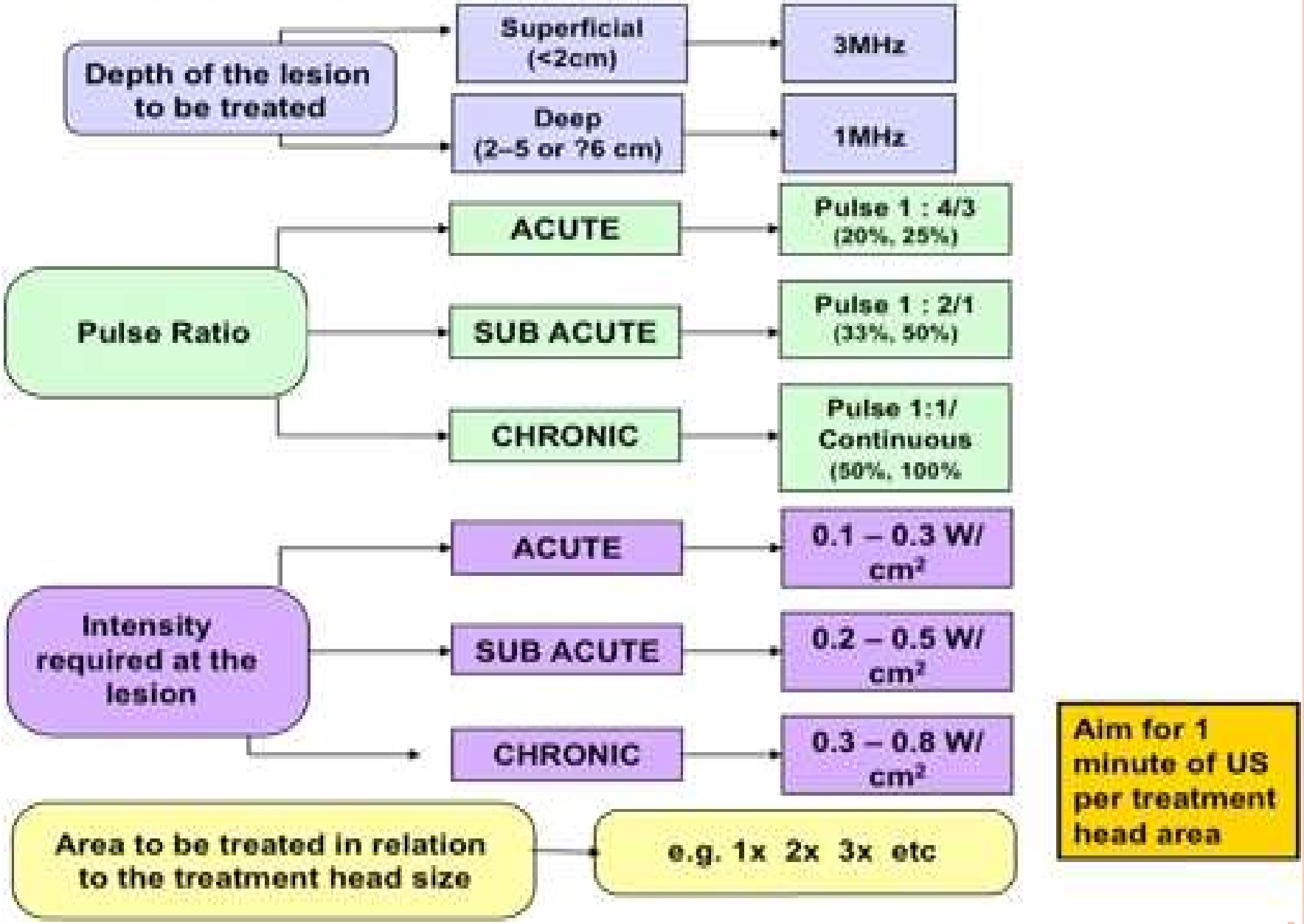
A substance that facilitates the transmission of ultrasound energy by decreasing impedance at the air-skin interface

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



Ultrasound Dose Calculation

TISSUE TYPE	SUPERFICIAL TISSUE (<2.5 CM)	DEEP TISSUE (2.5–5 CM)
MUSCLE	3 MHz 1 W/cm² 100% duty 7 min	1 MHz 1.5 W/cm² 100% duty 14 min
TENDON	3 MHz 0.8–1.0 W/ cm² 100% duty 4–5 min	1 MHz 1.5 W/cm² 100% duty 10 min
AREA = 2x sound head size **RATE** = 4 cm/second		

Place tissue on stretch near end of US treatment, before manual therapy is initiated

Stretching 'window' after US:
3 min. for muscle
5 min. for tendon/ligament

Recommendations based on Gallo & Silva, 2018 and may vary by manufacturer

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

- Increase pain threshold due to decrease nerve conduction velocity
- Decrease muscle spasm
- Increase blood flow.
- Increase extensibility of soft tissue /decreased viscosity of tissue fluid
- Increase deposition of collagen tissue
- Increased enzyme activity
- Increased tissue perfusion (oxygenation)

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

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

1-Stable cavitation Gas bubbles oscillate "**to and fro**" within the US pressure waves, creating faster transmigrations of ions at cellular level, due to increase permeability of cell membrane and associated with acoustic microstreaming.

Unstable cavitation is minimized by:

Using space-averaged intensities < $2.5 W/cm^2$

Using a pulsed source of ultrasound

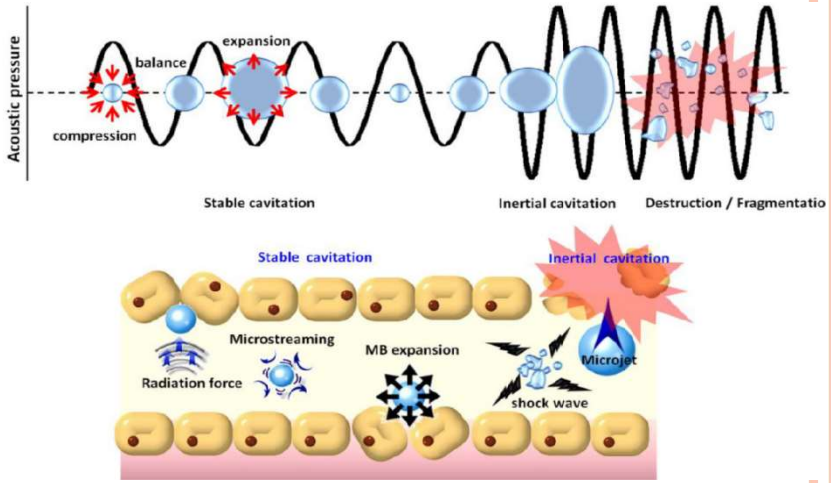
Moving the treatment head

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

1-Stable cavitation Gas bubbles oscillate "**to and fro**" within the US pressure waves, creating faster transmigrations of ions at cellular level, due to increase permeability of cell membrane and associated with acoustic microstreaming.

2-Unstable cavitation 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.

(High frequency/high intensity US)



Unstable cavitation is minimized by:

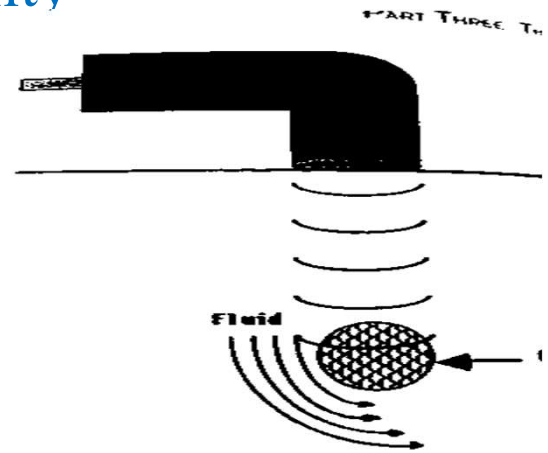
- Using space-averaged intensities < 2.5W/cm^2
- Using a pulsed source of ultrasound
- Moving the treatment head

2-Acoustic Microstreaming:

is localized, unidirectional fluid movement around the vibrating bubble.

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

https://www.youtube.com/watch?v=CTcfwD_vhd0



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
- Enhanced angiogenesis
- Enhanced wound contraction

Clinical applications (Indications/therapeutic of US

- Acute and sub-acute traumatic and inflammatory conditions
  - 1-Soft tissue injuries (tendinitis, ligament sprain, muscle strain)
  - 2-Painful shoulder e.g. frozen shoulder
  - 3- Bursitis
- Chronic rheumatoid and arthritic conditions
  - 1-Rheumatic conditions
  - 2-Osteoarthitis
  - 3-Rheumatic nodules
- Dermal Ulcer and surgical skin incision
  - 1-Venous ulcer
  - 2-Pressure sores
  - 3-Surgical wound
- Soft tissue shortening and scar contracture
  - 1-Scar tissue (surgical and post burn)
  - 3-Plantar fasciitis
- Pain relief
  - 1-Low back pain
  - 2-Neck pain
  - 3-Rheumatic pain
  - 4-Phantom pain

Clinical applications (Indications/therapeutic of US

Acute and chronic traumatic and inflammatory conditions such as tendinitis, ligament sprain, muscle strain) frozen shoulder Bursitis

Chronic rheumatoid and arthritic conditions such as osteoarthritis and Rheumatic nodules

Wound healing such as Dermal Ulcer, surgical skin incision and venous ulcer diabetic foot ulcer

Soft tissue shortening and contracture such as Scar tissue (surgical and post burn) and Plantar fasciitis

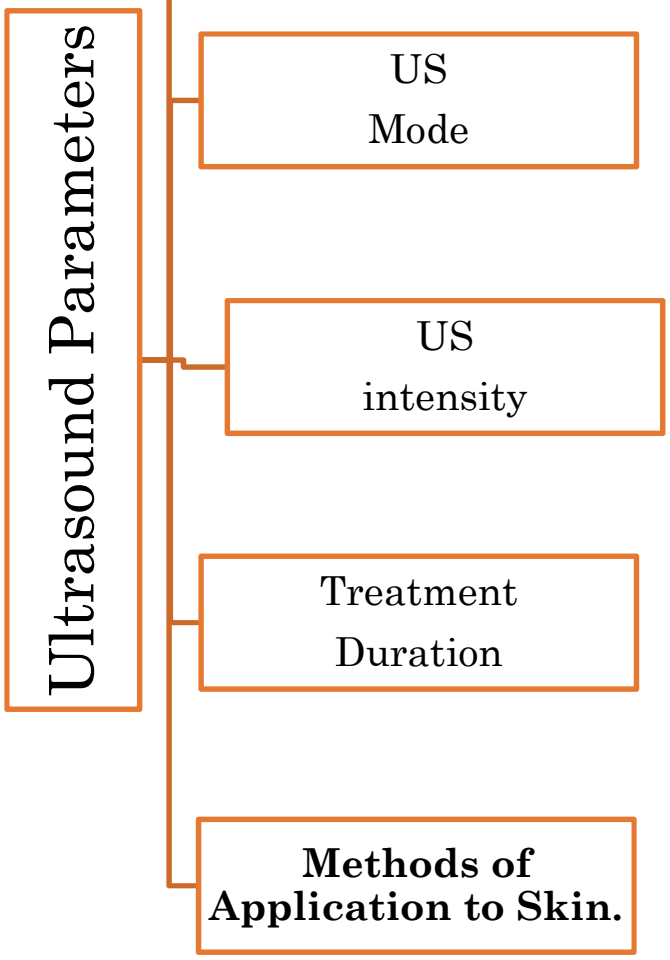
E-PHONOPHORESIS

Phonophoresis : Transdermal (movement of the drugs through skin into subcutaneous tissues) Drug Delivery using ultrasound

Phonophoresis depends on

1. Frequency
2. Intensity
3. Duty cycle
4. Treatment Duration
5. Nature of the drug molecule

E-PHONOPHORESIS



low-frequency 20 - 100 kHz
high frequency 700 KHz - 16 MHz
Most common 1-3 MHz.

DC 1:1 and 1:4

0.1W/cm^2 to 2 W/cm^2.

8-10 minutes

Before US application
Simultaneous with US
Before US application

DRUGS USED IN PHONOPHORESIS

Anti-inflammatory

- Cortisol
- Dexamethasone
- Salicylates

Analgesics

- Lidocaine

Phonophoresis is most often used to treat:

- Tendonitis
- Bursitis
- Adhesive capsulitis (frozen shoulder)
- Arthritis

Contraindications for therapeutic US

Malignant tumors	Increase rate of tumors growth and size. So avoid US over, or around area of tumors
Pregnant Uterus	Do Not apply US over the pregnant uterus.
Spread of Infection	Don't apply US over ,area with bacterial or viral infection could be spread by US ,
Tuberculosis	**Risk of** reactivating encapsulated TB.
Nervous System:	Where nerve tissue is exposed, e.g. over a spina bifida or after a laminectomy.
Specialized Tissue	Fluid-filled eye -retinal damage could occur. Treatment over the male/female reproductive organs
Vascular Problems	Don't apply US over area of thrombophlebitis, atherosclerosis, Uncontrollable hemophilia
Pacemaker	May heat the pacemaker,
Radiotherapy:	Do not treat because of the risk of encouraging pre-cancerous changes

Precautions for therapeutic US

Acute inflammation	Avoid use US to produce thermal effect
Epiphyseal Plates	Do Not apply US on cartilaginous epiphyseal plates because growth of the bone is impeded, If necessary pulsed US of low intensity
Cement and implant	Don't apply US in case of Plastic cement e.g. Breast implant, low intensity, pulsed US is recommended Metal implant e.g. screws, plates joint replacement low intensity pulsed US, short intensity

Case studies

Complete the following case studies on your own. It is important to remember that there is no single way to treat any condition.

Case Study #1

A 52-year-old patient is referred by her physician with diagnosis of frozen shoulder. She states that her pain began three months ago but she did not seek treatment because she hoped it would get better on its own. She presents with moderate protective muscle spasm of her upper right trapezius and her shoulder is limited in ROM of extension and external rotation.

Case Study #2

A 24-year-old patient referred with diagnosis of patellar ligament strain. The injury was sustained three days ago while playing soccer. Patient presents with moderate edema and pain to palpation. Prior treatment has consisted of rest and ice.

Case Study #3

A 58-year-old female patient presents with knee pain, stiffness and swelling associated with Osteoarthritis. Patient is starting to have difficulty performing daily tasks; specifically walking, getting in and out of her car, and standing for longer periods of time (i.e. showering, washing dishes, etc.)

Target tissue will be treated:----------

Stage of conditions: ----------

Goals of treatment: ----------

Ultrasound treatment parameters: ----------

Position of patients during treatment: ----------

Justification (rational): ----------

