Therapeutic Ultra-Sound

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The results of research, the use of sophisticated equipment and the contribution of electronics to the field of medicine have contributed in a big way towards a change in the management of various medical/surgical conditions, and especially so in Orthopaedic practice. In a general population whose pace of life is getting fast and whose degree of daily activity is increasing, the need of an efficient treatment that aims to return the patient back to his/her activities in as short a time as possible is felt. This is not possible in all instances but there is a great number of conditions such as sprains, bursitis, tendonitis, capsulitis, etc, that can be treated in such a way as to keep the patient mobile rather than restrict him to bed, chair or immobilise him in plaster! Obviously some other form of treatment in lieu of rest must be applied and this can take the form of ultra-sonic waves, heat energy, electric therapy etc. Of these, ultrasound plays a special role, and proof of this is the number of patients successfully referred to the physiotherapy department for ultrasound treatment. It was with this view in mind that I became attracted to this well documented account of the discovery of ultrasound, its physical properties, and its effects on the tissues, its indications and contra-indications. Every doctor who refers a patient for ultrasonic therapy and every physiotherapist that applies the treatment must be conversant with its properties, indications and contra-indications. Those who are not, are well advised to read this article carefully.

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Ultra-sound is defined as sound with a frequency above the audible limit of 20KHz. The frequency used for therapeutic ultra-sound ranges from 500KHz to 3MHz (500,000 cycles per second to 3 million cycles per second).

Way back in 1883 Galton used a whistle to measure the upper limit of the audible acoustic spectrum. Quartz transducers used to transmit and receive ultrasonic waves first came into use just after the first world war. Langerin used low frequency ultra-sound propagation in water as a means of detecting submarines, and for communication. Early experiments using high intensity ultra-sound observed effects including the death of fish which swam through the beam, and painful sensations in the hand if placed in the beam. The fact that effects were obtained in tissues led to the use of ultra-sound in the modification of tissues, both in surgical and therapeutic applications.

Generation of Ultra-sound

A device which converts energy from one form to another is known as a transducer. For medical purposes, ultra-sound is usually produced by a piezo-electric material. Crystals of some materials have the property that, when a voltage is applied across them, they change shape, and conversely, when they are compressed, a voltage develops across them. This is the piezo-electric effect. The most commonly occurring piezo-electric material is quartz, but artificially made ceramics such as lead zirconate titanate or barium titanate are now being used in therapeutic ultra-sound.

A rapidly varying sinusoidal voltage is applied across the flat surface of the ceramic. Thus the ceramic expands and contracts with simple harmonic motion. As the transducer face moves forward, the medium in which it is immersed, is compressed and as it moves back, a rarefaction is created.

Transmission of Ultra-sound

This depends on the case and speed with which the media can be deformed and is indicated by the acoustic impedance of the material. Sound waves travel more easily through a medium with a high rather than a low characteristic impedance, for example more easily through steel than through water.

Ultra-sound energy is propagated in soft tissue as longitudinal mechanical waves in a directional beam whose shape depends upon the diameter of the transducer relative to the wavelength of the ultra-sound in the tissue. These longitudinal waves will be converted to a transverse wave when something solid, like bone, lies in the path of the sound beam. For therapeutic purposes it is important to note that a transverse wave will not travel through fluids. When a sound wave encounters a different medium from the one in which it is travelling it may be reflected, refracted and/or absorbed or scattered.

Reflection:

When an ultrasonic wave is incident on an interface between two different types of tissues some reflection will occur. The amount of reflection will depend on the characteristic acoustic impedance (z) of the tissues involved. (z is the product of the density of the medium and the sound velocity in that medium). The reflected beam interacts with the incident beam and this may lead to the formation of standing waves. This is important when irradiating over bone which has a considerably higher acoustic impedance than soft tissue. Standing waves may affect the flow of blood[3].

Refraction:

Waves may continue to travel through the new medium; if it strikes the new medium at a right angle it will continue to travel in a straight line, otherwise refraction occurs and this depends on the relative velocities of the two media. The greater the difference in velocities the greater the angle through which the wave bends.

Absorption:

As the waves travel through any medium some are absorbed, resulting in a reduction in intensity and heat being produced.

The amount of absorption that is likely to take place in a tissue is characterised by this absorption coefficient. Tissues with a high collagen content absorb most strongly. Most soft tissues have similar absorption coefficients (0.5 dB cm^{-1} MHz^{-1}) but muscle has a slightly higher coefficient (1.5 dB cm^{-1} MHz^{-1}) and lung and skull bone have high absorption coefficients (20 dB cm^{-1} MHz^{-1}).[8]

The beam is reduced to half its intensity in a certain distance i.e. the *half value distance* and this depends on the nature of the medium and the frequency of the waves. In general, attenuation increases with rising frequency, thus, a 3 MHz beam will travel less than a 1 MHz beam. For example the half value distance for 1 MHz in air is 2.5mm, in water 1.5 m and in skin 40 mm.

Ultra-sound is rapidly attenuated in air, and only 0.1% of the incident energy is transmitted across the air/tissue interface. Thus ultra-sound is always applied via a coupling medium. This coupling agent must not absorb much ultra-sound and must provide a good acoustic match with the tissues so that reflection at the skin surface is minimised[6].

Scatter:

Most tissues contain numerous acoustic inhomogeneities. The incident ultrasonic beam thus suffers multiple reflections while being transmitted through the tissue. Some of these reflections carry energy out of the main beam. Thus the effect of scatter would be to diffuse the heating effect of the main beam.

Intensity:

This is the energy crossing a unit area in a unit time (watts per centimetre squared W cm^2)

Ultrasonic Field

This can be thought of as being composed of two distinct regions. The *near field* and the *far field*. Close to the transducer, in the near field or Freznel zone, the beam is mainly confined to a cylinder having the diameter as the transducer. The intensity within this zone varies considerably both along and across the beam and it is not until the far field or Fraunhofer zone that the intensity becomes regular without marked changes in intensity. The near field extends a distance $r^2/$ from the transducer face, where r is the transducer radius and is the ultrasonic wavelength in that medium. In the far field the ultra-sound beam diverges, consequently the use of a smaller transducer or ultra-sound with a longer wavelength will lead to a less directional beam and inaccurate treatment. In therapeutic use the transducer is typically 15mm in radius, therefore the extent of the near field in water with a 1 Mhz transducer will be 150mm.

As has been discussed above the intensity in the near field can be very *peaky*, and although the spatial average of intensity may be low, the peak intensity can be considerably higher. This is one reason why the treatment head must be kept moving during treatment (Hill, 1970). (*See graph at the end of the article*).

Mode

The ultrasonic beam can be continuous or pulsed. For example 1:1; this exemplifies that the time ratio the ultra-sound is on is for 2 milliseconds and off for 2 milliseconds, with a resulting decrease in thermal effect[7].

Physiological and Therapeutic Effects of Ultra-sound.

Physiological effects at a chemical, histological level

1. There is a metabolic increase in the tissues[2].
2. DNA synthesis is increased in cells, particularly fibroblasts.
3. Fibroblasts can increase their collagen production and the endoplasmic reticulum becomes swollen with newly formed collagen.
4. Polymerisation of collagen is held up, and the excess laying down of collagen is prevented in the isonated tissues.
5. Softening of a cement type substance which attaches fibres to the basement membrane in connective tissue.
6. Tissue regeneration/repair is speeded up.[4]
7. Decreased nerve conduction in C fibres giving an analgesic effect.[1]
8. Endothelial damage in the small blood vessels with little blister-like formations which are usually reversible.
9. Parathrombosis/Stasis; a therapeutic dose with a static transducer for 15 minutes will cause clumping together of the red blood cells at every half wavelength. The clumps are always surrounded by plasma but may cause blockage in small vessels and ischaemia. Occasionally the clumping and stasis is not reversible on cessation of ultra-sound. It occurs more readily in larger bore veins. This is another reason why the treatment head must be kept moving.
10. Increases fibroblast movement in the isonated tissues.
11. Myofibroblast activity is increased.
12. Fibroblast membrane permeability is increased. Substances synthesized can pass out more readily.
13. Lysosomal membrane fragility is increased withconsequent release of proteolytic enzymes, thus the acute symptoms in an acute inflammation may be exacerbated by ultrasound.
14. Increases tensile strength and elasticity of the scar tissue.[1]

Mechanical physiological effects

1. *Micro-massage:* the membranes and particles within the cell vibrate but not the whole cell.
2. *Micro-shaking* by means of the alternate compression and rarefaction the particles and membranes vibrate.
3. *Acoustic streaming* which causes increased membrane permeability. The microstreaming next to a membrane in damaged tissues causes increased absorption and diffusion of the exudate.
4. *Acoustic radiation pressure:* (the pushing force caused by the alternating compression and rarefaction). The positive pressure is followed by a negative pressure which never quite returns to the pre-pressure situation, and hence the idea that one can drive medication through the skin. A process known as *Phonophoresis.*
5. *Cavitation:* The alternating waves of high and reduced pressure causes the formation, growth and pulsation of gas or vapour filled voids. It can occur in body fluids, cell suspensions or in tissues. Cavitations can occur in two ways: (a) Stable cavitations which are formed but remain intact for many cycles. (b) Transient cavitation, the bubbles grow suddenly and collapse under the changing pressure of the ultrasonic field, with a resulting huge, local rise in temperature. This will cause gross damage to cells and tissues. This will not occur if the transducer is kept moving.
6. *Heat:* The backwards and forwards movement of particles causes friction and this is converted into heat probably sub-threshold heat. Using pulsed beam, the heat generated is so minute that this is not sufficient for a therapeutic effect.

Summary of physiological effects

— Thermal
— Mechanical
— Chemical

Summary of therapeutic effects

— Absorption of extravasated tissue fluids
— Heating
— Tissue Repair
— Thinning/Softening of fibrotic tissue
— Analgesic
— Spasmolysis
— Phonophoresis
— Diagnostically. (Ultra-sound with a frequency of 1MHz can be used to diagnose certain early fractures. For example the metacarpals; which do not show up on X-Ray. The suspected site is isonated with continuous ultra-sound and should an ache be felt, then a fracture has to be kept in mind).

Contra-indications to the use of ultra-sound

a) eye, ear, ovaries, testes, abdominal organs and CNS
b) pregnant uterus
c) tumours
d) thrombosis or phlebitis
e) haemorrhage
f) infection
g) devitalised tissue following radiotherapy
h) diminished peripheral circulation
i) implants/arthroplasties
j) intra-uterine device
k) cervical ganglion and vagus nerve if patient suffers from cardiac diseases.

Precautions one should take prior to treatment

a) Diminished skin sensation - is not a contraindication so long as the operator has sound anatomical knowledge and is familiar with the apparatus. Extra care should always be taken with these kinds of patients and a skin sensation test should always be carried out.
b) Should a patient complain of a burning sensation which is compatible with raising of the periosteum then stop treatment and amend.
c) An ache or a strong, uncomfortable vibratory feeling is compatible with heating of the bone. STOP and amend treatment.
d) Damage to transducer due to inadequate coupling will result in shattering of the quartz or ceramic with no out-put of the apparatus. This is the easiest way that ultrasonic apparatus is damaged. The average cost of an ultrasonic transducer is Lm60.
e) Hearing-Aids should be removed.
f) Ultra-sound may interfer with a demand type of pacemaker.
g) The apparatus should be given time to rest as output intensities vary if the apparatus is used for long periods of time.

Common conditions in which Ultra-sound is used:

— sprains and strains
— tenosynovitis
— tendonitis and paratendonitis
— haematoma
— bursitis and epicondylitis
— capsulitis
— fascitis
— Dupuytren's contracture
— adhesions of scar tissue
— venous ulcers
— minor fractures (disregard the fracture and treat the surrounding soft tissues).
— episiotomy scars
— surgical wounds

Unusual conditions for ultra-sound treatment

— soreness after manipulations or mobilisations

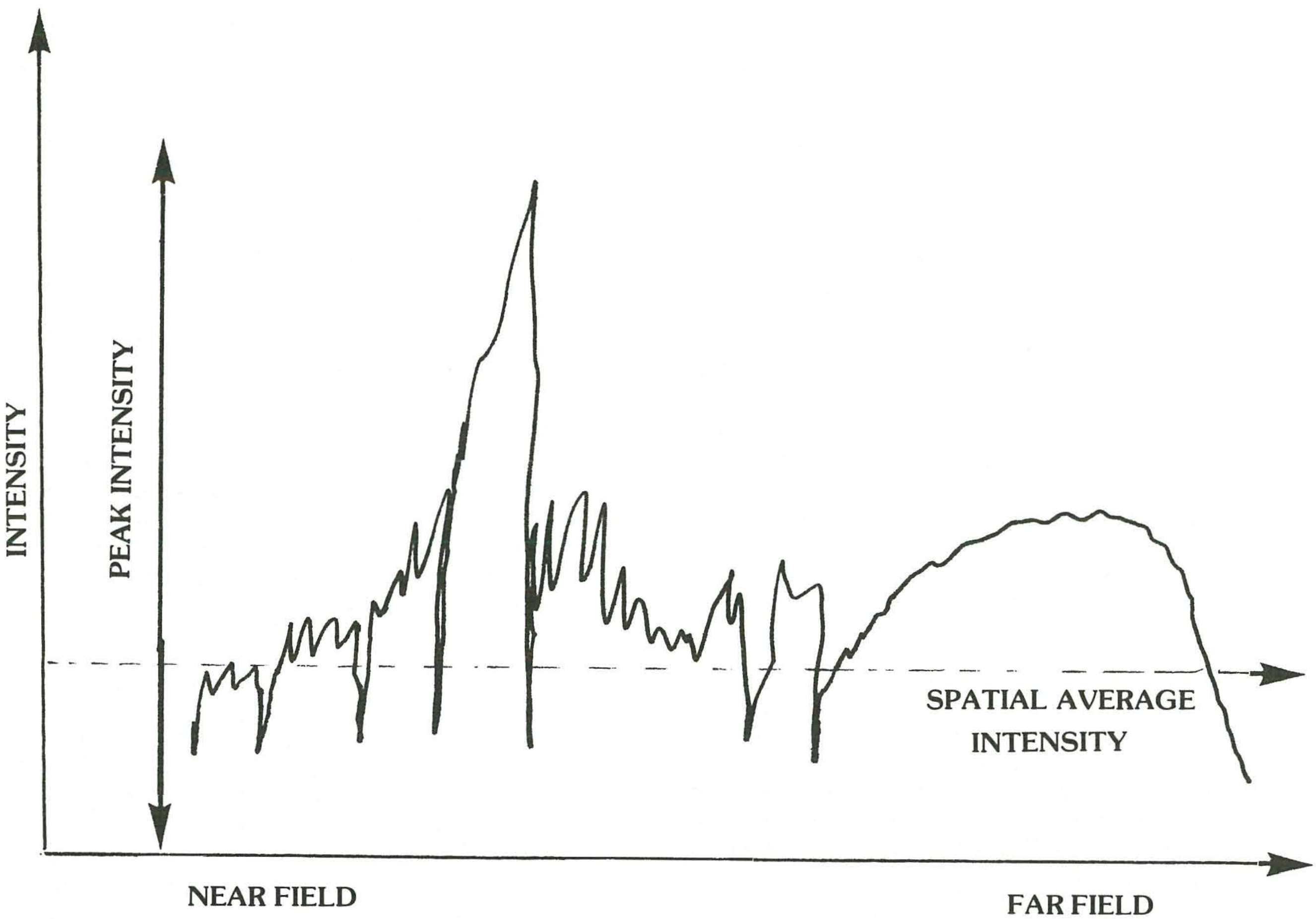

Fig. 1 Beam Profiles, illustrating significance of peak intensity and space average intensity in near and far fields.

— neuroma
— post herpatic pain
— breast engorgement

Case Report

History:

G.F., a 33 year old female from Mqabba was referred to the physiotherapy department on the 26.12.85 with right Longhead of Biceps Tendonitis.

On examination, the patient presented with generalised pain on flexion of the shoulder joint, a localised tender spot under the right acromion process and limitation of medial rotation. The patient's major complaint was the pain in the right shoulder as she came to clean windows. The patient was treated solely by means of ultra-sound. On her first appointment 27-12-85 she was given ultra-sound at an intensity of 0.5 W/cm^2 for 1$^1/_2$ minutes, with a pulsed mode for pain relief using a rank sonacel ultrasound unit with a frequency of 3 MHz. Following this she was treated daily for twelve other consecutive treatments using the same apparatus but an increased dose of 0.8 W/cm^2. It is also interesting to note that the patient did not rest the shoulder but continued to carry out her daily chores. She was discharged on the 14-1-86 with no pain in the shoulder region, full range of movement at this joint and functionally able to carry out her occupation without any hindrance.

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