ULTRA SOUND AS I SEE IT

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This article is for physiotherapists whose training did not include Ultra Sound. It will attempt to answer, in very simple terms, such questions as:—

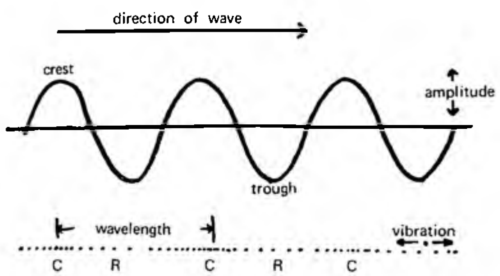
What is Ultra Sound?
How can Ultra Sound be produced?
How do Ultra Sound waves behave?
Effects of Ultra Sound on human tissue.
For what conditions should Ultra Sound be used?
What dangers are there in treatment?
Technique of application.
Latest developments.

WHAT IS ULTRA SOUND?

Sound waves are longtitudinal waves in contrast to the transverse waves of light. This means there is a to and fro movement of particles in a vertical plane and this movement is transmitted from particle to particle in a medium. The *disturbance* is transmitted the particles do not move from one end of the medium to the other. At one moment the particles are pushed together — known as *compression* and at another they are pulled apart — rarefaction.

WHY DO WE CALL THEM WAVES?

"Waves" is a term given to a periodic disturbance of particles in a medium and this disturbance can be conveniently represented graphically as a wave form.



The *compression* is represented by a *peak* of energy.
The *rarefaction* is represented by the *troughs*.
The *distance* between any two peaks is the *wavelength*.
The *rate* at which successive peaks pass a given point is the *frequency*.
The speed at which waves move is the *velocity*.
The distance each particle moves is the *amplitude*.

There is a relationship between velocity, wavelength and frequency in that:

$$\text{Velocity} = \text{Frequency} \times \text{Wavelength}$$

If the velocity is constant, i.e. if sound waves are travelling in the same medium, the waves with the highest frequency will have the smallest wavelength. This factor accounts for the differences between audible sound, with a frequency up to 16 000 cycles/sec. and a wavelength measured in cms; and the Ultra Sound we use, with a frequency of 1 megac./sec. and a wavelength of only $1\frac{1}{2}$ mm.

The velocity or rate at which the disturbance will pass through a medium varies and depends on the size and number of the atoms in the medium. In gases the velocity is slow as the atoms are far apart and the push is not easily transmitted. Audible sound, with its longer wavelength is transmitted in air but Ultra Sound as we use it is not.

Liquids, especially water transmit Ultra Sound reasonably well, but solids transmit best of all as the molecules are locked closely together and the push is easily transmitted. However transmission also depends on the elasticity of the medium as well as the density. In other words, its ability to return to its original shape after deformation, and some solids do this better than others. Tourmaline has the highest velocity of Ultra Sound transmission.

PRODUCTION OF ULTRA SOUND

Piezoelectric effect

It was found that a vibrating crystal had a difference of potential on its opposite faces. Conversely it was also found that if an alternating potential difference was applied to the crystal it would vibrate. This alternating potential difference must be at the same frequency as the natural frequency of the crystal. Quartz is used for the crystal because it is cheap; does not require a high degree of energy to keep it vibrating, only about 100 V., and its coefficient of expansion is low.

CIRCUIT

Basically a high frequency alternating current is produced by discharging a condensor through an inductance, with a valve to give the kick at the right moment, like pushing a swing.

This current is applied to the specially cut quartz on opposite faces and the quartz is bonded to a metal diaphragm. This part is known as the transducer. The bonding is difficult and expensive.

All that is now necessary is a variable resistance to increase the amplitude, i.e. the amount of push to each particle. Pulsed sound is also produced with 1:10 or 1:5. Sound: silence ratio. As the crystal dilates — compression, as it retracts, rarefaction.

HOW DO ULTRA SOUND WAVES BEHAVE?

From a point source, sound waves are concentric and spherical. Ultra Sound is usually produced by a disc therefore it is not a point source and waves are plane waves. Divergence is minimal due to the small wavelength so sonic energy can be roughly taken to beam out in almost parallel beams from the head. There is a complicated interference pattern near to the head and in some machines the clamping of the crystal results in more movement in the centre. To distribute the intensity evenly it is necessary to keep the head moving when treating with continuous sound to ensure even power distribution in the tissues, and to prevent too much energy in one area.

When sonic energy strikes a medium, the energy may be:—

Reflected
Refracted
Absorbed and Transmitted.

REFLECTION

You must all have watched waves hitting a cliff and being reflected off. The cliff forms an obstacle to the waves. The rocks reflect all the water but the soil will both reflect and absorb some. We are talking here of waves travelling in one medium (water) reacting in a certain way when there is a change of medium (the cliff). Ultra Sound behaves in the same way. We have already seen that transmission of Ultra Sound depends on the elasticity of the medium. If two media have the same ability to transmit Ultra Sound — this is known as the characteristic acoustic impedance — there will be no reflection at the boundary between the two. Where one substance transmits well and the other badly, there will be a high degree of reflection. In other words, reflection occurs at the interface between two media which transmit Ultra Sound differently.

This property affects our techniques of treatment.

1. *Air does not transmit Ultra Sound.* Therefore Ultra Sound energy leaving the treatment head will be immediately reflected back into the head with a build up of energy. It has been said that this can shatter the quartz, but I think in fact it is more likely to disrupt the bonding of the quartz to the metal diaphragm. Therefore: Do not turn on sonic output with the head in air.

2. In order to transmit energy into the tissues we must have some medium to replace the air between the sound head and the skin.
   This is the coupling medium.
   To reduce reflection the medium used should have acoustic properties between the metal of the head and the tissues. Water fulfills this purpose but it is not always convenient to apply as it runs off and must also be free of air bubbles. The part can be immersed in water or a small rubber bag can be filled with water and applied between head and skin. It is still necessary in this case to introduce another couplant to reduce the air between head and bag and skin. The most commonly used couplant is an oil of some sort used between the sound head and skin which is sufficiently viscous not to run off the area being treated. Glycerol is one of the best as it transmits Ultra Sound well but it is expensive. Liquid Paraffin is often used, at some hospitals with 0.05% thymol to reduce cross-infection. The water based trade brands are good but expensive.

3. Bone reflects Ultra Sound highly *therefore avoid superficial bone.*

Ultrasound with its small wavelength is reflected more easily than audible sound. An analogy that may help in understanding this fact is a brick in a small puddle will reflect small waves we may make with our hands but in a larger pond with larger waves they will bend round the brick or simply pass over it. It depends on the size of the obstacle in relation to the wavelength.

One last point on reflection is the need to keep the sound head in contact with the skin all the time, otherwise if some part lifts off Ultra Sound is transmitted back into the head which may heat and then be uncomfortable to the patient when it again touches the skin. Of course only the part in contact will be transmitting and the efficiency of the treatment will be reduced.

Another factor governing the need to maintain constant contact with the skin when using oil, is

Refraction

You all know how light waves bend when passing through different media — look at your foot in a bath. Ultra Sound does the same and tends to bend upwards, reducing the depth of penetration. At an incident angle of more than 15 degrees the refracted beam is 90 degrees therefore there is no transmission of Ultra Sound into the tissues. When used under water there is only minimal refraction and this does not apply. Refraction depends on the velocity of the wave which depends on the density and elasticity of the medium. If the media differ markedly there will be more refraction than if the media are very alike.

Absorption and Transmission

These two factors are obviously interdependent as the more absorption in the tissue the less will be transmitted. As the sonic energy enters a tissue a certain amount of that energy is used up causing the molecules of that tissue to move. This is known as *hysteresis* and the higher the hysteresis or energy necessary to cause the movement the more that tissue will absorb Ultra Sound converting sonic energy into movement and the less it will transmit Ultra Sound. *Bone absorbs Ultra Sound* almost completely and within the first 5 mm of penetration.

Ultimately all sonic energy absorbed in the tissues is converted to heat.

What in fact do we mean by heat? To discuss this we must first consider energy. You all know that energy is never lost, it is simply converted from one form to another. There are two types of energy, *potential and kinetic.* Kinetic energy is the energy of movement, and there are two types of kinetic energy, *directional and random.* When current passes along a wire this is directional kinetic energy but in its passage molecules on the fringe are knocked and their normal degree of movement is increased. This is random kinetic energy. In a radiator bar this increase in random kinetic energy is sufficient to produce heat. Which brings us back to the point what do we mean by heat? A table may feel cool to you, but the table would feel hot to an ice block; therefore heat is relative, and one body is hotter than another if when in contact heat flows from the one to the other. The chair you are sitting on will be warm when you stand up. In fact what is being transmitted when heat is transmitted is the movement of molecules. The hotter body has a higher degree of random kinetic energy and when in contact with a cooler body whose molecules are moving more slowly the energy from the one passes to the other until the average kinetic energy of the two are the same and they are then at the same temperature. So if we increase the average kinetic energy of the molecules of a substance we are producing heat and this is what ultra sound does. Increase of the movement of molecules in the tissues.

In human tissue those substances with a high water content will have a low hysteresis, i.e. low energy consumption to cause movement, and will not absorb as much Ultra Sound and therefore not be heated as much as tissues with a high hysteresis which will absorb a high degree of Ultra Sound and therefore produce more heat, and transmit little or no Ultra Sound. *Skin, fat and muscle have a low hysteresis, fibrous tissue, bone and cartilage high.*

When considering transmission in the tissues we must also remember reflection and refraction at the interfaces between the different tissues and we find that sonic energy is reduced to half its surface intensity at 5 cm depth using a 1megacycle output due to both absorption and refraction and reflection. This is known as the half value thickness and one must therefore consider the depth of the tissue we wish to heat when setting out output.

Let us consider now the energy passing through the usual arrangement of tissue we insonate.

There is not a great deal of reflection between skin, subcutaneous tissue and fat, but there is obviously some absorption. The fibrous sheath of the muscle will reflect to some extent, then the energy passes through the individual muscle fibres being absorbed on its way and again more energy is reflected from the sheath on the far side. When the waves reach the periosteum some is reflected but the main effect on this tissue is due to it's close proximity to bone. As we have already seen, bone reflects Ultra Sound highly and absorbs the remaining energy very rapidly. This means there is a build up of energy in the periosteum both due to the reflection from the bone, AND, as the high degree of absorption in the bone means a rapid heating of bone and bone conducts heat badly, dissipation of this heat is not more deeply into the bone but immediately out to the periosteum. This tissue contains many sensory nerve endings and we all know that sensory receptors of all kinds will register pain when stimulated beyond their tolerance. *This aching, burning pain is the danger signal in Ultra Sound* that your intensity is too high.

When the intensity is below this danger level, heat will be conducted from these deeper structures and will only register as warmth if it is sufficient to filter through to the temperature receptors in the dermis. Often a patient feels warmth only some time after treatment. The thing to remember though, is that heat is being produced at a deeper level, in fact this is the advantage of Ultra Sound over diathermy in that fat is not heated with Ultra Sound and one can cause deeper tissue heating.

Effects of Ultra Sound on Human Tissue

Here one enters the controversy of thermal versus non-thermal. It amounts partly to a question of deciding at what point is movement mechanical energy and at what point is it heat? Our physics department suggest it depends which molecule you are sitting on! There is no doubt that the physiological effects of Ultra Sound are those of heat. Whether there are any grounds for saying that some of these are greater than could be produced by heat and are therefore due to the pressure of the movement of the molecules — they have a very high acceleration — is a matter for keen debate and not yet successfully proven. The effects on human tissue appear to be:—

Increase in blood flow.
Increase in cell membrane permeability.
Increase in metabolism — denaturing of protein if too hot.
Pain threshold raised.
Inflammatory cellular response.
Fibrous tissue more extensible.
Muscle spasm reduced.

Of these *increase in cell membrane permeability* is often termed a mechanical effect due to water molecules being knocked off the membrane which then dries, shrinks and the pores enlarge. If you were on the membrane you would class the movement of the water as mechanical but if you were on the water molecule you would get hot moving out of the way. It comes back to which molecule you are sitting on.

Improving the *extensibility of fibrous tissue* may be due to the pressure involved which disrupts the collagen fibers in the matrix or merely due to softening of the matrix itself. *Muscle Spasm* is said to be relieved by heating reducing the susceptibility of the muscle spindles and the gamma efferents, but there appear to be no grounds for the belief that it acts in this way.

The relief of pain by heat is another thorny problem. Ischeamic pain is easily relieved by the increase in blood supply. Pain from muscle spasm would be relieved if the spasm were relieved. The effects on nerve itself appear to cause destruction at low energies of Ultra Sound or only very transient interruption of function.

One must always remember that expression of pain is governed by emotion and that the handling of a patient will go a long way to relieving pain regardless of what modality is used.

5. **For what conditions should ultra sound be used?**

Here there are so many conflicting opinions that it is impossible to state anything definitely. One can read of benefits to one condition using several different dosages in the same publication that states Ultra Sound was of no value at all. Too often there are several modalities used and it is not possible to state with any degree of confidence that Ultra Sound was the main factor involved.

In one article on shoulder hand syndrome, hot packs and whirl-pool and Ultra Sound and active and passive movements were used. One must also never overlook "the tender loving care" part of treatment and the power of suggestion. For myself I would suggest use Ultra Sound as a convenient method of applying heat to structures such as tendon and capsules and muscle attachments to bone where the area is small and localised and always follow up with the main part of treatment which is movement.

I see no point in giving a patient both Ultra Sound and Short Wave. It is difficult to feel that heat could be used to relieve pain at spinal nerve roots as the bone of the laminae would prevent energy penetrating that far. Conversely it would be unwise to insonate a laminectomy scar for fear of damaging the cord which is not then so protected.

Healed scars would be benefitted and there appears to be evidence of benefit to Dupytron's contracture. New wounds would I feel be a contraindication, as the very effects of Ultra Sound are destructive in the initial healing process of fibrous tissue and have been shown to produce acute inflammation and worse scarring. I would suggest three weeks as the very earliest to use Ultra Sound in this field.

Regeneration of tissue has been accelerated in a rabbit's ear, if using only 0,5 w/cm^2 for 5 mins. More than this caused destruction and less, no effect. To translate this to a human gravitational ulcer is difficult as the conditions are very different. So far evidence of benefit is not encouraging with the skin often breaking down, though others feel ultra sound is of some use.

In mild inflammatory conditions a low intensity may just accelerate blood flow sufficiently to help resolution without increasing congestion. However membrane permeability is also increased and hyperaemia in any form will increase oedema. The best method of reducing oedema remains movement.

In *recent trauma* the effects of Ultra Sound are again widely debated. A great deal depends on what one means by recent? If immediate, i.e. the next day, Ultra Sound is obviously contraindicated to the initial healing process. This has been shown clinically. One must ask oneself if in fact any effects are possible at the low doses some people use which are said to be beneficial. In recent literature, footballers with injuries have been treated by high intensities for long periods several times a day. The effect of this appears to have been the destruction of the nerve cells which removed pain, therefore active movement was possible. As these nerves are superficial and not damaged for any great length they appear to regenerate quite quickly but it seems rather a drastic method of pain relief.

DANGERS

In considering dangers, the contraindications must first be listed. Again controversy. However it would appear wiser not to treat:

Brain tissue.
Eyes — damage to the lens.
Tumours — dispersal of malignant emboli.
Pregnant uterus — haemorrhage due to tearing of placenta.
Reproductive organs.
Tuberculosis, sepsis of bone or soft tissue.
Recent haemorrhage and haemophilia.
After deep X-ray therapy — devitalises the skin.
Peripheral Vascular Disease as there is a danger of tissue necrosis due to heat not being dissipated.

BURNS are the obvious danger with the periosteal pain being the danger signal.

OVERDOSE the condition exacerbated usually by increasing congestion.

CAVITATION does not occur at therapeutically used levels.

ELECTRIC SHOCK as applies to the use of any faulty apparatus.

TECHNIQUE OF APPLICATION AND DOSAGES

1. Test machine — in small bowl of water, not with water on sound head.
2. Test skin for hot and cold sensation — although periosteal pain is the first to be stimulated, the same nerve supplies the skin so a defect there might presuppose a defect in the periosteal nerves as well.
3. Use a suitable coupling medium. It is not necessary to increase dose in water as attenuation is slight over the distance we use which is about 2 cms. Wipe off bubbles or use degassed water to prevent reflection.
4. Cover an area about three times the size of the treatment head.
5. Avoid superficial bone and nerve or use very low dose.
6. Keep head moving if using continuous Ultra Sound.
7. Keep head in contact with direct coupling.

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DOSAGES

Expressed in Watts /cm² of treatment head X time.
Treatment head usually 5cm² and total output of machine 15 watts, therefore maximum available is 3 W/cm².
For chonic conditions start at 0,5 mins and work up to 1,5 W/cm² or 2 W/cm² depending on patient's tolerance and machine.

Acute conditions, low dosage and short time to start, 0,25 W/cm² for 3 mins.

Try in chronic conditions to reach optimum dosage for Watts in three treatments then increase the time by 1 or 2 mins per treatment. Limit to 12 — 15 treatments.

Latest reading — disappointing, nothing new.

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PREMIXED NITROUS OXIDE AND OXYGEN — A REVIEW

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A physiotherapist is often confronted with the problem of having to treat a patient who is in pain. If adequate pain relief is not obtained, then not only is the treatment less effective, but it is always disagreeable for the patient. The use of potent narcotic analgesics does not solve this problem. If given in adequate dosage to provide effective pain relief, the patient often has respiratory depression and is drowsy and unco-operative. The ideal analgesic adjuvant for use during physiotherapy should have the following properties:

1. It should provide profound analgesia with minimal hypnosis — i.e. a conscious, co-operative patient free of pain.
2. Administration should involve a simple technique.
3. It should be sufficiently free of dangerous side effects, to enable administration to be performed by trained physiotherapists while not under direct medical supervision.
4. It should not be habit forming.
5. It should not interfere with or worsen diseases that the patient may have.

Such an agent may prove to be nitrous oxide.

History, Physical and Pharmacological Properties of Nitrous Oxide

Nitrous Oxide (Syn., Nitrogen monoxide; Formula, N_2O) is a colourless gas with a faint sweetish odour. It is supplied in blue cylinders into which it has been compressed to a pressure of 650 lb/sq. in. At this pressure, N_2O is in a liquid form. As it is released from the cylinder it returns to the gaseous state. It is non flammable.

N_2O is the oldest of the gaseous anaesthetic agents. It was first prepared by Priestley in 1776. In 1779 Humphrey Davy after experiments on himself, announced that it had anaesthetic properties, and suggested that it be used to relieve pain. His suggestion went unheeded until 1844 when Colton administered N_2O to Wells while a dentist extracted one of Wells' teeth. Wells' later attempt to introduce N_2O as an anaesthetic agent met with ridicule when during the demonstration the patient cried out. In 1868 Andrews introduced oxygen administration with nitrous oxide in the manner of its present-day use.

The early techniques of administering nitrous oxide were by giving the pure gas. Many of the effects and accidents which were ascribed to N_2O were the results of hypoxia. Provided sufficient oxygen (21% or above) is given, the effects on body systems are slight.

On the central nervous system, the effect depends on the concentration inhaled. Nitrous oxide has good analgesic properties while it is a weak anaesthetic agent. G. D. Parbrook[1,2] showed that a mixture of 25% nitrous oxide with 75% oxygen provides better analgesia than 15 mg of morphine. He showed that after ceasing to inhale 25% nitrous oxide, significant analgesia persisted for five minutes, and disappeared after 15 minutes. If concentrations of 50% and above are inhaled, consciousness is usually lost.

With subanaesthetic concentrations, a feeling of euphoria is often experienced — hence the name "laughing gas". Sensory effects include tingling, numbness, dizziness as well as auditory and visual disturbances. At the higher concentrations nausea and confusion may appear. Nausea is particularly likely if hypoxia is present. Depression of the respiratory centre does not occur. Habituation is a possible hazard with repeated use, especially in persons who tend to become euphoric.

There is no effect on bronchial secretions. Pulse and blood pressure remain unchanged, there being no direct action on the heart. Some improvement of peripheral blood flow does occur. Kidney and liver functions are unaffected. Depression of skeletal muscular tone is minimal. Smooth muscle is unaffected. Depression of bone marrow function in leukopaenia only occurs if nitrous oxide is inhaled continuously for more than 24-48 hours.[3, 4]

Nitrous oxide is reasonably insoluble in the blood. Uptake and excretion via the lungs is rapid. Its effects are therefore rapidly acting and quickly wear off after terminating administration.[5] Today nitrous oxide is used in the majority