A – Ultrasound

With the exception of thermal agents, ultrasound is the most commonly used modality in the management of soft tissue complaints [1].

B - Characteristics of therapeutic ultrasound

Ultrasound is a form of acoustic energy, consisting of inaudible high frequency mechanical vibrations that may produce thermal or non-thermal effects upon the tissue. Ultrasound waves are created when a generator produces electrical energy that is converted to acoustic energy through mechanical deformation of a piezoelectric crystal located within the transducer. Ultrasound causes molecular collision in a medium, which allows its transmission by propagation of the wave through vibration of molecules and a progressive loss of the intensity of the energy occurs with passage through the tissue (*attenuation*), due to absorption and/or dispersion.

Therapeutic ultrasound has a frequency range of 0.75 to 3 MHz, with most ultrasound units set at a frequency of 1 or 3 MHz. Ultrasound at a frequency of 1MHz is absorbed primarily by tissues at 3 to 5 cm depth. The lower the frequency of the waves the greater the depth of penetration and the lower the absorption. 1 MHz ultrasound is thus recommended for deeper injuries, particularly those patients with considerable subcutaneous fat, whereas a frequency of 3MHz is suggested for more superficial lesions at depths of 1-2 cm.

The greater the density of the medium (tissue), the faster is the velocity of the ultrasound wave travelling through it. Low absorption (and therefore high penetration) of ultrasound waves is seen in tissues that are high in water content (e.g. fat), whereas absorption is higher in those tissue rich in protein (e.g. skeletal muscle). Tissues are characterised by their *acoustic impedance*, the product of their density and the speed that ultrasound will travel through it. When travelling through more than one tissue, some of the ultrasound will be transmitted to the next tissue and some will scatter at the boundaries that separate them: the larger the difference in acoustic impedance, the greater the scattering. The percentage of energy reflected at the soft tissue / fat interface is 1% as compared to

40% at the soft tissue / bone interface [2]. When ultrasound energy reflected at tissue interfaces meets further waves being transmitted, a standing wave (hot spot) may be created, which has potential adverse effects upon tissue. This can be minimised by ensuring that the apparatus delivers a uniform wave, using pulsed waves (see below), and moving the transducer during treatment.

Since almost all energy is reflected away at the soft tissue / air interface, coupling media, in the form of water, oils and most commonly gels, prevent reflection of the waves by excluding air from between the transducer and patient. Different media have different impedances. The criteria for any coupling medium are that its acoustic impedance should be similar to the impedance of the transducer, that it absorbs little of the ultrasound passing through it, that it remains free of air bubbles and that it allows easy movement of the transducer over the skin surface.

The larger the diameter of the effective radiating area of the face of the transducer, the more focused the beam of ultrasound produced. Within this beam, energy is not evenly distributed, the greatest non-uniformity occurring close to the transducer surface (near zone). The variability of the beam intensity is termed the Beam Nonuniformity Ratio (BNR); this should optimally be 1:1 but, failing this, should be less than 8.

Therapeutic ultrasound can be pulsed or continuous. The former has on/off cycles and the amount of energy being delivered can be varied by adjusting the duration of either part of the cycle. Continuous ultrasound has a greater heating effect but either form at low intensity will produce non-thermal effects.

Ultrasound ‘dosage’ can also be varied by alteration of its amplitude and intensity. Various definitions of ultrasound intensity exist and machines differ with respect to the definition chosen for their intensity setting.

B - Modified forms of ultrasound

Modified forms of ultrasound include *phonophoresis* and *Extracorporeal Shock Wave Therapy (ESWT).* Phonophoresis involves the use of ultrasound energy and its effects upon cell permeability for the transdermal delivery of low molecular weight drugs. ESWT involves high energy, focussed ultrasound energy delivered using a modified lithotripter and is described further below.

B - The Physiological Effects of Ultrasound

Ultrasound may induce thermal and non-thermal physical effects in tissues. When it is applied for thermal effects, non-thermal effects will also occur, but through alteration of the dose parameters, non-thermal effects can be achieved in the absence of thermal effects. Reported thermal effects of ultrasound upon tissue include increased blood flow, reduction in muscle spasm, increased extensibility of collagen fibres, and a pro-inflammatory response. It is estimated that thermal effects occur with elevation of tissue temperature to 40 - 45 degrees C for at least 5 minutes [3]. Excessive thermal effects, seen in particular with higher ultrasound intensities, may damage the tissue. The use of ultrasound in subacute or chronic conditions aims to relieve pain and spasm, and to increase tissue extensibility in the ten minutes after heating, before the tissue cools. This may be of use in combination with stretching exercises to achieve optimal tissue length. Lengthening with thermal doses of ultrasound has been demonstrated in the ligament of normal knees [4] and in scar tissue [5].

It has been suggested that the non-thermal effects of ultrasound are more important in the treatment of soft tissue lesions than are thermal effects [6]. These non-thermal properties of ultrasound include *cavitation* and *acoustic microstreaming*. Cavitation is the form of gas filled bubbles that expand and compress due to ultrasonically induced pressure changes in tissue fluids [7]. As a result there is increased flow in the surrounding fluid. Stable (regular) cavitation is considered to be beneficial to injured tissue, whereas unstable (transient) cavitation is considered to cause tissue

damage [7]. Acoustic microstreaming, the unidirectional movement of fluids along cell membranes, occurs due to the mechanical pressure changes within the ultrasound field. Microstreaming may alter cell membrane structure, function and permeability [8], which has been suggested to stimulate tissue repair [6]. Effects of cavitation and microstreaming that have been demonstrated in vitro include stimulation of fibroblast repair and collagen synthesis, tissue regeneration and bone healing [9,10]. Adverse effects of ultrasound have also been reported.

Most of our knowledge of the effects of ultrasound on living tissue is gained through in in-vitro studies or in animal models and many have focused in particular upon skin wounds and ulcers. It has been suggested that ultrasound interacts with one or more components of inflammation, and earlier resolution of inflammation [11], accelerated fibrinolysis [12], stimulation of macrophage-derived fibroblast mitogenic factors [13], heightened fibroblast recruitment [14], accelerated angiogenesis [15], increased matrix synthesis, more dense collagen fibrils [16] and increased tissue tensile strength [9], have all been demonstrated in vitro. Such findings form the basis of the rationale for the use of ultrasound to promote and accelerate tissue healing and repair. However, as has been detailed in earlier chapters, the pathophysiology of many soft tissue lesions, in particular tendinopathies, and the mechanisms of healing of such lesions, are poorly understood in comparison to those of the skin. The effects of ultrasound upon these processes are not yet known.

Research on the use of ultrasound specifically in tendon healing is minimal and relates only to animals. Using a range of regimes, variable increases in the tensile strength, the energy absorption, increased mobility, improved alignment of collagen fibrils, reduced inflammatory infiltrate and scar tissue of tenotomised rabbit and cockerels tendons [17], of but not in others. [18-20]. These findings not only demonstrate the variety of therapeutic regimes (and definitions of treatment intensities), but also the conflicting evidence that exists on the issue of the use of therapeutic ultrasound in tendon lesions, even in animal studies. Caution must be exercised in extrapolating

these results to human tendon lesions, as differences exist between species in the types of collagen in tendon.

B - The evidence for clinical effect

Gam and Johanssen reviewed 293 papers published between 1953 and 1993 to evaluate the evidence of effect of ultrasound in the treatment of musculoskeletal pain [21]. Twenty-two trials of a variety of soft tissue disorders comparing ultrasound treatment with sham-ultrasound treated, non-ultrasound treatment and untreated groups were found. The studies were generally found to be methodologically lacking. Data from 13 studies were presented in a way that made pooling possible; no evidence was found for pain relief with ultrasound treatment. Further papers have been published on the subject of ultrasound treatment upon soft tissue lesions, but few have added any support to the use of ultrasound [22,23].

There has been some suggestion that ultrasound may be of particular use in the early stages after injury, whereas many studies have evaluated more chronic lesions (or are unspecified in duration). This has been addressed in part by the use of Delayed Onset Muscle Soreness (DOMS) as a clinical model of acute inflammation. A reduction in pain and tenderness and increased muscle strength with pulsed ultrasound in DOMS in the quadriceps has been reported [24] but other studies have refuted this [25,26].

It is apparent that, although ultrasound is used extensively in soft tissue injuries and there are rational theories for its use, sound evidence for its effectiveness in such conditions is lacking. While in vitro studies have demonstrated many of the effects described earlier to occur, these have failed to translate into in vivo success. The absence of evidence for benefit for ultrasound in soft tissue lesions may be due to a true lack of effect, but poor study design or technical factors may play a role. Inadequate calibration of machines has also been noted [27].

Definitions used in ultrasound therapy [1].

Term	Definition
Power	Total amount of energy in an ultrasound beam (Watts)
Acoustic impedance of a tissue	The product of the density of the tissue and the speed tl ultrasound will travel through it.
Attenuation	Progressive loss of energy during passage through tissu
Beam Nonuniformity Ratio (BNR)	The variability of the beam intensity: the ratio of the m intensity of the transducer to the average intensity acro transducer face.
Coupling medium	Substance that prevents the reflection of ultrasound at t tissue / air interface
Duty cycle	The percentage of time that ultrasound that is delivered on/off cycle.
Standing wave (hot spot)	Created when reflected ultrasound meets further waves transmitted, with potential adverse effects on tissue.
Intensity (common examples):	
1. Spatial averaged intensity (SAI)	Intensity averaged over the area of the transducer. Calc dividing the power output by the effective radiating are transducer head.
2. Spatial peak intensity (SPI)	The maximum intensity over time.
3. Temporal peak intensity (or pulsed averaged intensity)	The peak intensity during the on period of pulsed ultras
4. Temporal-averaged intensity (TAI)	The average power during the on off periods of pulsed
5. Spatial averaged temporal peak intensity (SATP)	The maximum intensity occurring during a single pulse

Some variables that may affect the dosage of ultrasound delivered to target tissue.

Frequency
Wavelength
Intensity
Amplitude
Effective radiating area of transducer head
BNR
Continuous / pulsed therapy
Coupling medium
Tissue composition
Movement of transducer

References

1. Speed CA. Therapeutic ultrasound in soft tissue lesions. *Rheumatology*. 2001 Dec;40(12):1331-6.
2. McDiarmid T, Burns PN. Clinical applications of therapeutic ultrasound. Physiotherapy 1987; 73; 155.
3. Prentice WE. Therapeutic modalities in Sports Medicine. 3rd edition. Mosby. St Louis 1994.
4. Ellis DG. Cross-sectional area measurement for tendon specimens: a comparison of several methods. J Biomech 1969; 2: 175-186.
5. Noyes FR, Torvik PJ, Hyde WB, DeLucas JL. Biomechanics of ligamnt failure II. An analysis of immobilisation exercise and reconditioning effects in primates. J Bone Joint Surg (Am) 1974; 56: 1406-1418.
6. Dyson-M, Suckling-J. Stimulation of tissue repair by ultrasound: a survey of the mechanisms involved. Physiotherapy, .1978; 64(4): 105-8.
7. Wells PNT. Biomedical Ultrasonics. Academic Press, London 1977.
8. Dyson M. Mechanisms involved in therapeutic ultrasound. Physiotherapy 1987; 73(3): 116-120.
9. Dyson M, Luke DA. Induction of mast cell degranulation in skin by ultrasound. IEEE Transactions and Ultrasonics, Ferroelectrics and Frequency control 1986;UFFC-33: 194.
10. Pilla AA, Figueiredo M, Nasser P et al. Non-invasive low intensity pulsed ultrasound: a potent accelaerator of bone repair. Proc 36th Annual Meeting, Orthopaedics Research Society, New Orleans 1990.
11. Young-SR; Dyson-M. Effect of therapeutic ultrasound on the healing of full-thickness excised skin lesions. Ultrasonics. 1990 May; 28(3): 175-80.
12. Harpaz D, Chen X, Francis CW et al. Ultrasound enhancement of thrombolysis and reperfusion in vitro. J Am Coll Cardiol 1993; 2: 1507-1511.
13. Young-SR; Dyson-M. Macrophage responsiveness to therapeutic ultrasound. Ultrasound-Med-

Biol. 1990; 16(8): 809-16.

14. Young S, Dyson M. The effects of therapeutic ultrasound on the healing of full thickness excised skin lesions. Ultrasonics 1990; 28: 175-180.
15. Young-SR; Dyson-M The effect of therapeutic ultrasound on angiogenesis. Ultrasound-Med-Biol. 1990; 16(3): 261-9.
16. Friedar S: Apilot study: The therapeutic effect of ultrasound following partial rupture of achilles tendons in male rats. J Orthop Sports Phys Ther 1988; 10: 39.
17. Enwemeka CS. The effects of therapeutic ultrasound on tendon healing. A Biomechanical Study. Am J Phys Med Rehabil 1989; 68: 283-287.
18. Gan-BS; Huys-S; Sherebrin-MH; Scilley-CG The effects of ultrasound treatment on flexor tendon healing in the chicken limb.J-Hand-Surg-Br.1995 Dec; 20(6): 809-14.
19. Turner-SM; Powell-ES; Ng-CS The effect of ultrasound on the healing of repaired cockerel tendon: is collagen cross-linkage a factor? J-Hand-Surg-Br.1989 Nov; 14(4): 428-33.
20. Roberts M, Rutherford JH, Harris D. The effect of ultrasound on flexor tendon repairs in the rabbit. Hand 1982; 14: 17-20.
21. Gam AN, Johannsen F. Ultrasound therapy in musculoskeletal disorders: a meta-analysis. Pain 1995; 63: 85-91.
22. Green S, Buchbinder R, Glazier R, Forbes A. Systematic review of randomised controlled trials of interventions for painful shoulder: selection criteria, outcome assessment and efficacy. Br Med J 1998; 316: 354 –360.
23. Van der Heijden GJMG, van der Windt DAWM, de Winter AF. Physiotherapy for patients with shoulder disorders: a systematic review of randomised controlled clinical trials. Br Med J 1997; 315: 25-30.
24. Hasson-S; Mundorf-R; Barnes-W; Williams-J; Fujii-M Effect of pulsed ultrasound versus placebo on muscle soreness perception and muscular performance. Scand-J-Rehabil-Med.1990;

22(4): 199-205.

25. Craig-JA, Bradley-J, Walsh-DM, Baxter-GD, Allen-JM Delayed onset muscle soreness: lack of effect of therapeutic ultrasound in humans. Arch-Phys-Med-Rehabil1999; 80(3): 318-23.
26. Ciccone C, Leggin B, Callamaro J. Effects of ultrasound and trolamine salicylate on delayed-onset muscle soreness. Phys Ther 1991; 71: 666.
27. Pye SD, Milford C. The performance of ultrasound physiotherapy machines in Lothian Region, Scotland, 1992. Ultrasound Med Biol 1994; 20 (4): 347-359.