The Clinical Efficacy of Ultrasound

An Honors Thesis

by

Susan Renae Naab

for

Dr. James E. Griffin

Thesis Director

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Abstract

The primary objective of this particular thesis project is to further examine the clinical efficacy of ultrasound. No investigation of clinical ultrasound would be complete without first examining the inherent properties of acoustic and ultrasonic energy. Consideration is given to the various aspects of therapeutic application of ultrasound, including the suggested dosages, coupling agents, and treatment techniques. The often neglected topic of ultrasonic induced physiological effects and their implications is expounded upon. Select clinical conditions with which ultrasound is a viable treatment choice are enumerated and their ramifications discussed. Numerous clinical conditions and situations which indicate/contraindicate the use of ultrasound as a treatment modality are listed at the conclusion of the project as a brief and useful reference for the clinician.
# The Clinical Efficacy of Ultrasound

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PROPERTIES OF ACOUSTIC ENERGY

Since ultrasound is recognized as a form of acoustic energy, a review of the inherent properties of acoustic energy will aid in ensuring a more thorough understanding of the characteristics of ultrasound. Acoustic energy is incapable of penetrating a vacuum; therefore, molecules or larger units of matter must be used as a vehicle for the acoustic energy's conduction.

Inefficient acoustic energy travel is obtained through any gas or mixture of gases. Degassed liquids, or those which are gas-free, provide a medium through which the acoustic energy is transmitted well. Optimum transmission of acoustic energy can be obtained through solids — substances which possess a high density. These properties also hold true for the energy of ultrasound.

CHARACTERISTICS OF ULTRASONIC ENERGY

In the strictest sense, ultrasound is defined as sound having a frequency greater than 20,000 Hertz — a frequency which is too high for stimulation of the sensory receptors of the human ear. Ultrasound therapy involves the conversion of electrical energy into this high frequency acoustic energy. Generally, ultrasonic waves are transverse waves of condensation and rarefaction whose beam is inversely proportional to the frequency, which is, in turn, inversely proportional to the
In other words, as the frequency of ultrasound is increased, the energy's depth of penetration is decreased.

For ultrasound to be effective, its energy must be absorbed. In the atmosphere, ultrasonic energy is almost entirely absorbed by the nitrogen, oxygen, and carbon dioxide in its midst. In the human body, protein bearing tissues are the major absorbers of ultrasonic energy. The tissue which bears the highest percentage of protein is muscle at 25%; followed closely by bone, 15-20%; and nerve, 10-15%. The fatty tissue is quite low in protein, considering that only the surrounding loose collagen tissue contains the amino-acid polymers which are inherent to proteins.

Since human soft tissue consists of 70-90% water, in addition to proteins and other solids, the velocity of sound and ultrasound in soft tissue is standardly considered to be 1500 m/s -- the same as that for water. The velocity of ultrasound in cortical bone, the most dense solid in the body, is considered to be 3500 m/s. The dramatic difference between these two velocity values is understandable, remembering that acoustic energy is transmitted most efficiently through high density solids such as cortical bone.

At tissue interfaces, the absorption of ultrasonic energy is accompanied by a considerable amount of reflection and refraction -- phenomena which account for selective heating. Reflection occurs when the acoustic impedance between two tissue layers differ, whereas refraction involves the actual bending of sound waves as they travel from one medium to the next.
Pathological and sharply localized temperature increases, within the periosteum and at or near bone-tendon junctions, can result from this reflection of ultrasonic energy. The periosteum and tendons are especially susceptible to these pathological temperature increases secondary to their poor blood supply and relatively low water content. These properties make dissemination of the reflected energy rather difficult. Nature has made a provision for this problem by supplying the periosteum with an abundance of sensory receptors, including thermal receptors, which enable the patient to become aware of the noxious stimulus and move away from the energy source prior to pathological changes taking place within the tissues — providing the patient possesses an intact sensory system. The patient may relate a feeling of a deep, dull ache of a very sudden onset (periosteal overheating), which necessitates a rapid diminution of the ultrasonic energy’s intensity.

**THERMAL EFFECTS OF ULTRASONIC ENERGY**

For an effect of ultrasonic energy to be purely thermal in origin, it must be such that it is capable of being achieved by a technique that is of a non-acoustic nature. Much of the mechanical vibratory energy of ultrasound is converted into thermal energy. An increase in the temperature of the target tissue results when energy is absorbed from the ultrasonic beam. If the local tissue temperature reaches between 40° and 45°C, hyperemia (an increased amount of blood in the area) results, assisting in the resolution of chronic inflammatory processes in the area. The combined effect of tissue temperature rise and
micromassage result in the release of histamine-like compounds which are responsible for this capillary hyperemia and spasmolysis. Tissue temperatures above 45°C are damaging to the area tissues, yet can be prevented by utilizing either a moving applicator technique or a low average intensity during ultrasound application.

A coefficient has been devised which tells the extent to which a tissue will absorb energy from a sound beam -- the intensity absorption coefficient. According to this coefficient, bone is capable of absorbing 10 times more energy than muscle, and muscle absorbs 2.5 times more energy than fat at an ultrasonic frequency of 1.0 MHz. In ideal circumstances, the comparatively low value of the absorption coefficient for fat should allow the ultrasonic beam to penetrate the fat without being considerably weakened and without overheating the fatty region. Muscle's intermediate absorption coefficient value allows a subsequent enhanced generation of heat in the muscle itself and leaves a reduced intensity ultrasonic beam with which to reach the highly absorbing bone.

NON-THERMAL EFFECTS OF ULTRASONIC ENERGY

One non-thermal effect which has been attributed to ultrasound is that of acoustic streaming. When tissue is being sonated, the vibration of the transducer generates an ultrasonic field in which unidirectional movement is superimposed upon cyclically repeated oscillatory movements of the tissue components. Acoustic streaming is this unidirectional flow which is particularly prevalent at boundaries such as the surface
of bubbles, membranes of cells, and organelles. The effects of this acoustic streaming are such that cellular responses are produced which may aid in stimulating tissue repair.\textsuperscript{10} Acoustic streaming is also known to induce changes in diffusion rates and membrane permeability, possibly altering the rates of protein synthesis and tissue repair in the process.\textsuperscript{10,11} Since the millisecond range pulses which are delivered by conventional ultrasonic machines are long enough to produce this acoustic streaming, reduction of the potentially dangerous thermal effects at the upper intensity ranges can be achieved by pulsing the energy flow while still retaining the beneficial effects of acoustic streaming.\textsuperscript{11}

A second therapeutic non-thermal effect is that of micromassage. The effect of micromassage is caused by the wave effect of the ultrasound and the mechanical reactions of the tissue which result. These reactions are pressure changes, actual compressions and expansions of the tissue itself, resulting in a micromassaging effect on the absorbing tissue.\textsuperscript{3,15} When the micromassage is combined with a tissue temperature rise, compounds are released which subsequently result in local hyperemia and spasmolysis.\textsuperscript{3}

Perhaps the most widely studied non-thermal effect of ultrasound is that of cavitation. Cavitation is defined as the process of generation of bubbles by a sound field, the various motions of such bubbles, and the physical effects brought about by the motions.\textsuperscript{3} Cavitation is classified as two separate types: stable and transient. In stable cavitation, the voids or bubbles
remain intact while oscillating for many cycles with acoustic streaming occurring around them.\textsuperscript{3,10,11} Transient cavitation occurs when the voids or bubbles grow suddenly and then collapse under the changing pressure of the ultrasonic field, the entire process taking less than the wave period.\textsuperscript{10,11} The collapse phase in transient cavitation is associated with huge but local temperature rises approaching $10^4\degree K$ within the bubble and with gross damage to cells and tissues.\textsuperscript{11} Although cavitation occurs more readily at kHz rather than MHz frequencies, there is evidence that cavitation could be produced by exposure levels at the upper end of clinical ultrasound apparatuses and therefore its effects must be considered.\textsuperscript{11}

Standing wave radiation pressure forces have been another type of non-thermal effect observed with the use of ultrasound. Blood flow inhibition has occurred in chick embryos which have been exposed to low intensities of continuous ultrasound at a frequency of 3 MHz.\textsuperscript{5} Blood cells have been observed to enter into preferred positions in the sound field, separate themselves by half a wavelength, and then remain in stationary bonds. Dyson et al. (1971) observed that if this effect took place in arteries and arterioles in humans treated with ultrasound, the tissues would be exposed to conditions of reduced oxygen availability. This effect can be minimized by moving the sound head in a manner such that the direction of the vessels relative to the direction of the propagation of the ultrasound is varied continuously.\textsuperscript{3,10}

Relaxation of polypeptide bonds has been suggested as a non-thermal mechanism by which ultrasonic energy relieves pain
caused by excess proliferation of connective tissue. Thus, ultrasound becomes an effective means of increasing range of motion where limitation is secondary to extensive hypertrophic scar tissue formation. The hypertrophic scar which comes exclusively from the epidermal margin. Significant increases in tendon extensibility and relaxation of skeletal muscle upon absorption of ultrasound may also be attributed to the relaxation of polypeptide bonds within the tissues.

ULTRASOUND VERSUS CONVENTIONAL THERMOTHERAPY

There are a considerable number of advantages that ultrasonic therapy possesses over the various forms of conventional thermotherapy, the electromagnetic energies. These advantages often provide the clinician with the confidence and rationale necessary to decide upon the most efficient modality for patient care.

Perhaps the property inherent to ultrasonic energy that is most often considered when choosing to utilize ultrasound over other forms of electromagnetic energy is ultrasound's superior depth of penetration. With an ultrasonic frequency of 1 Mc, approximately 50% of the ultrasonic energy will penetrate to a depth of 5 cm within the soft tissues. When an even deeper penetration is desired, the clinician may decide upon using a lower ultrasonic frequency when considering that 50% of the energy of 90 kc ultrasound will, within the soft tissues, reach a depth of 10 cm. These energy penetration values become rather significant when one recalls that the various forms of electromagnetic energy only penetrate to a depth of 1-2 cm,
causing a more superficial tissue temperature rise than is achieved with ultrasound.\textsuperscript{15} When the clinician desires to affect the deeper lying tissues of the body, ultrasound often becomes the physical agent of choice.

Another characteristic inherent to ultrasonic energy is that the least amount of ultrasonic energy is absorbed in those tissues which are the most homogenous.\textsuperscript{15} The most nearly homogenous tissue in the human body is subcutaneous fat; thus, an insignificant amount of ultrasonic energy is absorbed by this tissue. This property of ultrasound allows the energy to be transmitted through the subcutaneous fat and efficiently reach the underlying target tissues. When the various forms of electromagnetic energy are utilized, a significant amount of the energy is absorbed by the subcutaneous fat, causing excessive fat temperature rise and preventing the energy to be efficiently transmitted to the underlying tissues. Thus, when a deeper tissue temperature rise is achieved by electromagnetic energy, it is primarily caused by the reaction of cutaneous nerves and/or secondary conduction, making the heating of deeper lying tissues fairly inefficient with electromagnetic energy.

An often cited disadvantage of electromagnetic energy in the form of short wave or microwave energy is that of "hot-spot" formation and subsequent risk of tissue damage to adjacent tissue in the presence of metal implants.\textsuperscript{15} Since metal implants are more homogenous than the surrounding tissues, the metal actually reflects the ultrasonic energy instead of absorbing or
concentrating the energy. In this manner, abnormal heat buildup is avoided with the use of ultrasonic energy.

Another significant advantage of ultrasound over the various forms of electromagnetic energy is that of providing pain relief via mechanisms other than through a tissue temperature rise or thermal effect of ultrasonic energy. The non-thermal effects of ultrasound provide the clinician with a tool to combat a variety of pathologies not significantly affected by the traditional forms of electromagnetic energy.

In the past, a variety of means have been employed to heat localized tissue volumes to uniform levels in the hyperthermic treatment of cancer -- usually, microwave or radio-frequency inductive heating. With these forms of heating, inhomogeneities (fat distribution, bone, or tissue types which differ) can disrupt the electrical field substantially with subsequent nonuniform heat patterns and compromised clinical efficacy. Alternatively, acoustic energy provides reasonably uniform heating. Ultrasonic energy focusing into spot or distributed foci has enabled the production of highly homogenous, non-toxic thermal patterns in regularly shaped tumors. Since overall tumor response (size reduction, growth delay) has been found to depend on thermal homogeneity, shaped focus ultrasound provides a simple, inexpensive means of configuring a thermal field to distribute heat optimally.

A study has been conducted to evaluate the effects of ultrasonic energy versus various types of thermotherapy and subsequently establish the most effective and the least time-
consuming mode of treatment for recent soft tissue injuries. This study revealed therapeutic superiority of ultrasound on soft tissue injuries over the conventional forms of thermotherapy including short-wave diathermy, infrared, and paraffin baths. Ultrasound also possesses the added advantage of being well tolerated by a majority of patients. In an investigation in which 156 individual ultrasonic treatment sessions were performed, there were no cutaneous burns, reports of substantial discomfort, or indications of systemic symptoms.

**CLINICAL ULTRASONIC FREQUENCIES**

When considering the significance of the variety of ultrasonic frequencies, it is imperative that one is aware of the inverse frequency-energy penetration ratio which predominates. The governing of this ratio is such that the lower the ultrasonic frequency, the less energy that is absorbed per volume of tissue; thus, the depth of penetration is greater. As the clinician's objective becomes that of directly affecting those tissues which lie progressively deeper to the superficial layer of tissues, the lower the frequency of ultrasound is chosen.

In an investigation involving 107 patients with the clinical diagnosis of osteoarthritis of the knee, hip, shoulder, or vertebrae treated with either 89 kc or 1 Mc ultrasound; a significantly greater number of patients receiving the low frequency had longer-lasting relief from pain than those patients receiving the 1 Mc ultrasound treatments. This significant result has been attributed to the aforementioned superior depth
of penetration of ultrasonic energy inherent to the lower frequency ultrasound, making the absorption of ultrasonic energy by sensory and motor nerves in greater quantities possible.\textsuperscript{14,15,20}

Of all the ultrasonic generators in clinical use, approximately 90\% are 1 Mc in frequency. Theoretically, the reason for the great majority of clinical ultrasonic generators possessing this frequency is that a 1 Mc generator is a compromise between those which produce thermal effects (thought to be generators that are 2 Mc and higher in frequency) and those which produce non-thermal effects (thought to be generators that are 500 kc or lower in frequency).\textsuperscript{15} The clinician, therefore, must not only take into consideration the depth of the target tissue, but also whether predominately the thermal or non-thermal properties will significantly affect the pathology being treated.

CONTINUOUS VERSUS PULSED ULTRASOUND

Ultrasonic generators are capable of delivering either a continuous or pulsed form of ultrasonic energy. The continuous form of ultrasound is capable of achieving a greater depth of penetration and is utilized more for its heating/thermal effects.\textsuperscript{1,12} Conversely, the pulsed form of ultrasound is often beneficial for producing the physiological effects other than those achieved by heating the target tissues with the added ability of using higher peak intensities with less risk of tissue damage, especially between the periosteum/bone interface.\textsuperscript{1,12,17} The pulsed variety of ultrasound is effective in reducing adhesions, increasing the healing rate in tissue which is
positioned directly over superficial bones, and in treating especially specific, small treatment areas, or those conditions in which pathologically overheating the target tissues may become a reality.17

SUGGESTED ULTRASOUND INTENSITY AND DOSAGE LEVELS

When selecting ultrasound dosage and intensity levels, the clinician must contemplate both the desired physiologic and therapeutic responses rather than merely arbitrarily setting the generator's intensity dial. According to the Arnt-Schultz principle, a subthreshold quantity of energy will not cause a demonstrable physiological change; application of threshold and above energy will stimulate the absorbing tissue to normal function; and finally, the application of a supramaximal quantity of energy will destroy the absorbing tissue or prevent it from functioning normally.8 Although this principle is quite valid, there is presently disagreement as to the level of subthreshold, threshold, and supramaximal quantities of energy for any one cell or tissue; yet careless treatment into the supramaximal range can obviously be dangerous.

In 1982, the Burdick Corporation of Milton, Wisconsin recommended the following guide for selecting intensities of ultrasound: 0.5–1.0 w/cm² for direct application of ultrasound to an acute injury near the skin’s surface and add 0.5 w/cm² for each deviation from that method and/or injury type, realizing that whatever method is used the patient’s comfort level ultimately determines the ultrasound’s intensity level.17 The Burdick Corporation attempted to clarify their recommendations
with these treatment examples: 1.0-1.5 w/cm² would be required to treat an acute injury near the skin's surface with an indirect application technique and 2.0-2.5 w/cm² would be necessary to treat a chronic injury deep within the tissue using an indirect application technique. Obviously, vital importance has to be placed upon the proportion of the sound head's energy output actually reaching the patient and the amount of energy which is lost in transmission across the coupling agent -- values which are not widely agreed upon. Investigations have shown, however, that different dosage levels of ultrasonic energy may have different effects on tissue healing, nerve conduction, and cell permeability even within the narrow clinical intensity range of 0.2-3.0 w/cm². When determining the most effective ultrasound treatment, the clinician should consider the following: depth of target tissue, type of tissue interposed between the sound head and target tissue, frequency of the apparatus, brand and age of apparatus, size of treatment area, continuous versus pulsed type of ultrasonic energy, type of coupling agent, thermal and/or non-thermal effects desired, and most importantly, patient sensation. Instead of applying ultrasound at a fixed intensity for any given patient and/or pathology, the clinician should select an intensity of ultrasound which gives the patient a gentle sensation of warmth/tingling with each ultrasound treatment, regardless of the reading on the apparatus's output intensity scale.
IMPORTANCE OF CALIBRATION OF ULTRASONIC GENERATORS

There has been found to be wide disparity of actual acoustic output among clinical ultrasound apparatuses secondary to the length of time since the apparatus's most recent calibration and the amount of use/abuse the apparatus has undergone. This information becomes rather significant when considering that some clinicians may gauge a patient's treatment intensity by the intensity output scale instead of using the patient's sensation as a guide when treating a patient with diminished sensory input. Generally, the intensity output indicated on an ultrasound apparatus is considered to be unreliable when it has failed to be calibrated within the last six months. Until such time that there is standardized and enforced acoustic (rather than electric) power output measurement of ultrasound generators, a gentle sensation of warmth is perhaps the clinician's best guide of intensity. This procedure, of course, brings up the question concerning the patient with a deficit in the sensory nervous system and/or an emotional disturbance. Significant damage is unlikely to occur if the intensity used on the trunk or proximal extremity does not exceed 1.5 w/cm² and distal extremity does not exceed 0.5 w/cm², assuming an area of 150 cm² is being treated for a period of 5 minutes with a steadily moving sound head and the apparatus has been calibrated within the last six months.

An investigation surveying the use and performance of ultrasonic therapy equipment in Pinellas County, Florida revealed that, in general, the ultrasonic therapy units in use were out of calibration, with a majority of the units appearing to be
incapable of delivering a prescribed amount of ultrasonic energy to the patient. The lack of calibration of equipment capable of measuring acoustic output was listed as one of twenty-four of the more significant medical equipment problems in the "Study of the Dimensions and Problems Associated with Equipment Malfunction and Accidents in Hospitals" conducted for the California Hospital Association — a complaint which was also the most common voiced by the users of the apparatus. These findings once again illustrate the necessity for both frequent calibration and an accurate means with which to measure the acoustic output of the ultrasound apparatus.

COUPLING AGENTS AND THEIR SIGNIFICANCE

When ultrasound is given to a patient, some type of coupling medium in the form of a liquid or semi-solid lotion, ointment, or cream must be applied to the patient's skin overlying the designated treatment area. This procedure minimizes the amount of air trapped in the pores of the skin when the sound head is applied, allowing for a much more efficient transmission of the ultrasonic energy. An additional benefit of using a coupling agent is the reduction of friction between the surface of the sound head and the patient's skin.

There is disparity as to which ultrasound coupling agent is the most efficient in transmitting energy from the transducer to the patient. In an investigation conducted by Reid and Cummings dealing with the transmissivity of various coupling agents as measured by near field measurement technics, aquasonic gel (commercial thixotropic agent), transmitting a mean of 72.60%,
was discovered to be the most efficient energy transmitting agent when using an 870 kc/s ultrasound generator with continuous wave transmission.\(^7\cdot^8\) Glycerol was found to be an acceptable substitute for the aquasonic gel; whereas water, ECG couplant, and liquid paraffin were next in order of decreasing transmission efficiency.\(^7\cdot^9\) Interestingly enough, the liquid paraffin, a commonly used coupling medium, transmitted as little as 19.06% of the ultrasonic energy.\(^9\cdot^9\) Therefore, this investigation revealed that the choice of coupling agent may significantly influence the effective therapeutic dosage of ultrasonic energy available to the patient.

Transmissivity through various coupling agents was measured in an investigation designed by Warren and his colleagues using far field measurement techniques through a thin film of couplant and then a large volume of degassed water. Glycerol was found to be 75-100% as efficient as the degassed water, and mineral oil was as efficient as, or more so, than the degassed water.\(^1^3\) Thus, Warren's investigation leads the clinician to the reasonable conclusion that when choosing a coupling agent for use with the direct contact technique, the minor differences in the coupling agents' transmissivity is not a major concern.

When using the direct contact technique, and especially when using the stationary technique, the clinician should keep in mind that the ultrasound transducer becomes warm, liquifying coupling gels and emulsions in the process. Also, the skin temperatures of body segments which are located more proximal are relatively high in comparison to distal segments; and liquification of gels
and emulsions is more probable. When a coupling agent liquifies, it may drain off the treatment area, providing for a relatively non-uniform transmission of ultrasonic energy. Therefore, a more viscous coupling medium must be used in those instances when liquification may adversely affect the uniformity of ultrasound transmission.

The most effective couplant for use with the immersion technique seems to be ordinary tap water, a couplant which is capable of transmitting ultrasound efficiently even in the presence of massive bubble formation. Water's acoustic impedance is fairly close to that of the soft tissue in the body, and when preheated can aid the clinician in achieving both maximal thermal and non-thermal effects with the ultrasonic energy.

**PHONOPHORESIS AND ITS INDICATIONS**

Phonophoresis is a process by which whole molecules of a medication are driven away from the transducer, through a patient's skin, and into the target tissue structures by virtue of exposure to ultrasonic energy. This movement or driving force is secondary to radiation pressure changes caused by the transmission of high frequency sound waves through the couplant containing a specific medication and into the target tissue. Phonophoresis is capable of driving medications to the depth of ultrasonic energy penetration (up to 5 cm for 1 Mc and 10 cm for 90 kc ultrasonic frequencies). A five minute phonophoretic treatment appears adequate to drive enough medication to provide substantial pain relief if the treatment area is not greater than 150 cm².
Most commonly, 0.5-10% hydrocortisone cream is the medication used in phonophoretic treatment for its anti-inflammatory effects. Other medications used with phonophoresis include: 10% hydrocortisone with xylocaine ointment (for anesthetic), Myoflex Cream (aspirin), or a combination of dexamethosone and 2% lidocaine gel. The ability of ultrasonic energy to transiently increase membrane permeability may be the reason for the pain relief exhibited by the patient, since diffusion of an anti-inflammatory, analgesic, or anesthetic agent is enhanced by the external application of ultrasound.

Some indications for the application of phonophoretic treatment include the following: postacute soft tissue trauma, tendonitis, muscle strains, contusions, and as an alternative to injective therapy. The clinician should also consider any contraindications to the medications used for the phonophoresis and to ultrasound itself prior to applying the treatment.

GENERAL PHYSIOLOGICAL EFFECTS OF ULTRASOUND

When exposing an osteoarthritic joint or a periarticular lesion to clinical ultrasonic energy, the physiological effects may act to block pain transmission by vibration or by rise in tissue temperature or by a combination of the two. Generally, the physiological effects observed when tissue is exposed to therapeutic levels of ultrasonic energy are considered to include the following: increased blood and lymph flow rates, hyperemia, enhanced tissue metabolism, greater connective tissue extensibility, relaxation of skeletal muscle, elevated enzymatic activity, increased cellular transmembrane permeability, and
diminution of peripheral nerve conduction velocity (with ultrasound intensity between 0.5-1.5 w/cm²) which may produce an analgesic effect. Additionally, ultrasound may stimulate inhibition of nonbacterial inflammation, reabsorption of adhesions and calcific deposits, and breaking up of hematomas. Ultrasound is also the logical modality choice when the clinician desires to increase the perfusion of a calcific bursa, with the mechanical action of the ultrasonic waves affecting the bursal sac.

EFFECTS OF ULTRASOUND ON MUSCLE BLOOD FLOW

Most of the measurements to determine the effects of ultrasound on muscle blood flow have be done via plethysmography techniques. This technique gives rise to two major errors: (1) plethysmography fails to differentiate between the blood flow in the various tissue compartments of skin, adipose tissue, muscle, and bone; and (2) plethysmography measures blood flow over a large volume instead of the well defined region to which the ultrasound is applied -- in the process allowing the small degree of change in total limb blood flow to mask the large change in the small volume of tissue which is actually being sonated.

In an investigation conducted by Wyper and his colleagues, the technique of xenon-133 washout was used to measure the local blood flow in the vastus lateralis muscle of 7 adult volunteers between the ages of 21 and 45 during the application of therapeutic ultrasound. The implication of their investigation was that most of the ultrasonic energy had been dissipated in the tissue other than muscle, perhaps at the muscle-bone interface.
Thus, the investigators determined ultrasound as a rather inefficient means of enhancing muscle blood flow, with exercise and microwave energy being more efficient alternatives.  

**DIRECT EFFECTS OF ULTRASOUND ON MUSCLE TORQUE**

Although there have been numerous investigations conducted illuminating the physiological effects of ultrasound, few have focused on the direct effects on the muscle itself. Black and colleagues performed research to determine the effect of continuous ultrasound to the anterior tibialis muscle compartment on ankle dorsiflexion torque assessed immediately, 30 minutes, and 60 minutes after treatment. The conclusion of this study was that despite the known physiologic effects of clinical ultrasound, merely one treatment of ultrasound, when used before exercise, does not alter peak maximal isometric or isotonic torque during a volitional activity. Further investigation is essential in this particular area to determine whether or not the peak isotonic or isometric torques are affected significantly by a series of therapeutic ultrasound treatments rather than merely one.

**TISSUE REPAIR VIA ULTRASOUND**

In the continuing attempt to discover which aspects of the tissue repair process are affected by ultrasound, investigators have been examining the cells which are essential for the production of healthy granulation/scar tissue -- the fibroblasts. The following changes occurring during the tissue repair process have been observed: (1) stimulation of protein synthesis;
(2) ultrastructural changes -- including plasma membrane alteration, vacuolation, and dilation of the granular endoplasmic reticulum; (3) decrease in electrophoretic mobility; (4) modification of locomotor behavior; and (5) temporary elevation of intracellular calcium ion concentration. Evidence illustrates that the stimulation of protein synthesis induced by ultrasound is associated with an increase in lysosomal permeability. The significance of this finding is that the lysosomes contain hydrolytic enzymes whose activity is enhanced secondary to the increased permeability of their membranes. This, in turn, may stimulate protein synthesis, an integral part of the tissue repair process, by increasing the availability of precursor substances within the cells.

TISSUE DAMAGE VIA ULTRASOUND

Pain has been described as the total set of responses an individual makes to a stimulus which causes, or is about to cause, tissue damage. Tissue damage is the response prompted by that noxious stimulus. When pieces of skin which were exposed to ultrasound for a total time duration of 14 hours over a period of 7.5 months were examined, the investigators found that excised skin samples exhibited a minor chronic-inflammatory irritation which included: increased keratosis, augmented pigmentation, and minor loosening of the cutaneous and subcutaneous connective tissue. Twenty-five years after this investigation that exceeded all therapeutic and diagnostic ultrasound limits was completed, a follow-up study was performed. Interestingly enough, no significant histological traits or anomalies were
discovered. Therefore, residual effects of conscientiously applied ultrasound treatments are most likely to be negligible.

**CLINICAL CONDITIONS IN WHICH ULTRASOUND IS USED**

*Periarticular Pathologies:*

Clinical ultrasonic energy has been used for the treatment of periarticular pathologies such as tendonitis, bursitis, arthritis, sprains, and strains for approximately 30 years. Clinicians base the use of this modality for these musculo-skeletal pathologies on the various physiological effects attributed to ultrasonic energy: augmentation of blood flow, increased capillary permeability and tissue metabolism, enhancement of fibrous tissue extensibility, elevation of pain threshold, and the alteration of neuromuscular activity leading to muscle relaxation.\(^9\)\(^,\)\(^13\) The results of these physiological effects may be the promotion of healing, diminution of muscle spasm and pain, and range of motion facilitation.\(^9\)

In a controlled, randomized double-blind trial performed by Downing and Weinstein, patients suffering from supraspinatus tendonitis, subacromial bursitis, or adhesive capsulitis were studied to determine whether or not the application of ultrasound diminishes pain and increases range of motion further than the usual program of range of motion exercises or the combination of range of motion exercises and non-steroidal anti-inflammatory drugs.\(^9\) This pilot study determined that ultrasound adds no significant further benefit over treatment with range of motion exercises or the treatment combination of non-steroidal anti-inflammatory drugs and range of motion exercises.\(^9\) The
clinician should be aware that this investigation was a pilot study and additional clinical trials to determine the efficacy of ultrasound is warranted prior to disposing ultrasound as a treatment modality with these pathologies.

There continues to be a small percentage of patients suffering from some form of periarticular pathology who have an apparent calcium salt deposition upon or within the irritated tissue. Ultrasound has been found to be an effective means of relieving the patient's pain, yet the exact mechanism through which the pain is relieved has not been determined. Pain relief from the periarticular pathologies could be secondary to relaxation of the area skeletal muscle and/or the apparent net result of resorption of the abnormal calcium deposition from the affected tissue. 15

Burns:

The formation of scar contractures in extensive, deep burns is unavoidable, so much so that the transplanted tissue forms scars and contracts from 30-40% in dimension. 21 Ultrasound, when applied to connective tissue, has a stimulating effect: the number of new cellular forms and nuclei increases, the fibrous structures change morphologically with a predominance of elastic fibers, traumatized nerve is reinnervated, and the proper placement of the newly formed collagenous fibers (the precursor of the coarse scar) is facilitated. 21 Tissue transplants, therefore, become elastic and mobile by ultrasound's ability to improve nutrition, increase metabolism, accelerate reinnervation, and strengthen the regenerative processes in general. In
addition to the aforementioned effects on the tissue transplant, the use of ultrasonic energy in the treatment of burns may result in: (1) loosening and removing the necrotic tissue crust, (2) stimulating growth of granulation tissue and obtaining a supple scar, and (3) permitting the early use of therapeutic exercise. These effects allow the burn patient to return to a more normal lifestyle as early as possible.

When choosing an agent with which to treat burn wounds, the clinician must strive toward a relatively painless, rapid, and safe debridement of eschar without interfering with epithelial proliferation, altering the patient's body metabolism, or staining the tissue. Ultrasound just may be the treatment modality to use. The apparent cleaning effects of ultrasound result from the cavitation phenomena at the interface between the liquid coupling agent and the tissue to be cleaned. The cavitation action actually draws particles of contamination away from the relatively stiff tissue surface. Thus, the ultrasound acts to debride the burn wound, removing sepsis-causing microorganisms from the wound area in the process. Addition of electrolyte or a chemical agent in the liquid coupling medium may further enhance the effect of the ultrasonic action.

Dermis Disorders:

Psoriasis, a benign hyperproliferative disease, has been effectively regressed by ultrasonic induced hyperthermia in the 42-45°C range. An investigation performed by Orenberg and colleagues, while illustrating that the psoriatic lesions were regressed via ultrasound, failed to make a definitive statement
about the length of remission induced. The response of the psoriatic lesions seems to be temporary, with the clearing of the lesion being limited to the field of treatment. Orenberg noted that the earliest and most consistent change histologically in the psoriatic lesions was one of tissue repair, the reappearance or enhancement of the granular layer.

Ultrasound has also been successfully used in the treatment of hypodermitis sclerodermiformis (HS), a skin disease characterized by well-circumscribed, chronic, painful, tender, single or multiple, board-like, indurated, sharply bordered lesions, occurring in the legs of patients with venous insufficiency. HS is often either undiagnosed, or misdiagnosed as phlebitis, cellulitis, or stasis dermatitis. Unlike these other clinical entities, HS responds favorably to ultrasound treatments.

Dupuytren's Contracture:

Dupuytren's contracture is characterized by the dimpling of skin on the medial border of the hand as it becomes adherent to the underlying fascia, causing alteration in the local circulation with atrophy and cicatrization of the underlying skin. An investigation performed by Markham and Wood showed that the appearance of the contractured hand improved, nodules and dimples tended to become less noticeable, and the general improvement in circulation of the hand brought about a more natural color distribution in the skin of the palm. Clinical ultrasound acts to soften the skin overlying the contracted bands of fascia and subsequently diminishes the severity of the
deformity — thus, the surgery following becomes easier and the improvement in local circulation leads to enhanced wound healing. After the surgical wounds have healed, the application of clinical ultrasound reduces hypertrophic scarring and, when combined with gentle active and passive movement, accelerates the post-surgical recovery.

**Plantar Warts:**

The plantar wart, verruca plantaris, is a dermal lesion characterized by a thickening of the outer cornifying layers of epithelium with a probable viral etiology. Vaughn's research determined the direct method to be superior to the underwater method in the treatment of plantar warts. All of the plantar warts were destroyed in 25 of the 30 patients (83%) treated by the direct method, whereas only 21 of the 41 patients (51%) treated by the underwater method experienced total resolution of the dermal lesion. Nevertheless, ultrasound in either form remains a viable treatment modality, with pain and tenderness of the affected area being diminished in addition to the lesion being abolished in a majority of the cases.

**Fracture Healing:**

Fibular fracture repair has been shown to be accelerated and modified through the treatment of ultrasound. Brookes and Dyson found ultrasound treatment to be most effective when given during the first two weeks after injury. During this time, the inflammatory and early proliferative phases occur. Therefore, the fracture sites are being cleared of debris, factors
stimulating repair are being released, and cell migration and division are most active, leading to the formation of a blastema and soft callus which unite the bone fragments.\textsuperscript{2} The bone repair stimulated by the ultrasound tends to be of the juvenile type, involving direct ossification with little production of cartilage when the ultrasound treatment is confined to the first two weeks after injury. When the ultrasound treatment is confined to the third and fourth weeks, cartilage growth may be accelerated and bony union delayed.\textsuperscript{2} Brookes and Dyson also determined ultrasound treatment at 1.5 MHz to be more effective than at 3.0 MHz, postulating that since thermal effects tend to be greater at higher frequencies and all other factors are kept constant, the decrease in effectiveness at higher frequencies suggests a non-thermal involvement in the stimulation of fracture repair.\textsuperscript{2}
INDICATIONS AND CONTRAINDICATIONS FOR ULTRASONIC THERAPY

Indications for the Clinical Use of Ultrasound:

- Strained and Torn Ligaments
- Inflamed Tendons and Tendon Sheaths
- Lacerations and Other Soft Tissue Damage
- Hypertrophic Scar Tissue Sensitivity and Tension
- Varicose Ulcers
- Amputation Neuromata
- Strained and Torn Muscles
- Inflamed and Damaged Joint Capsules
- Fasciitis
- Treatment Soreness (Applicable after Mobilization Techniques)
- Chronic Arthritis
- Plantar Warts
- Pressure Sores
- Chronic Systemic Peripheral Arterial Diseases
- Organized Hematoma
- Fracture Healing (within the first two weeks after injury)
- Dermis Disorders

Contraindications for the Clinical Use of Ultrasound:

- Whenever Tissue Temperature Rise Hinders Normal Function
- Thoracic Area of Pacemaker Patient
- Area of Malignancy
- Area Overlying Epiphyseal Centers
- Healing Fractures (after the first two weeks after injury)
- Local Sonation Over Thrombophlebitis or Plebothrombosis
The Clinical Efficacy of Ultrasound

Bibliography


