Review Article

Prospective utility of therapeutic ultrasound in dentistry—Review with recent comprehensive update

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Abstract

Background: The utility of ultrasound (US) for therapeutic purposes is still in its infancy. Therapeutic US (TUS) has been used widely in medical field for urological application, surgical intervention, bone healing, and osteointegration in cancer and healing of full thickness excised skin lesions, and within dentistry as a prediagnostic, diagnostic and therapeutic purpose. The purpose of the paper is to review and determine the efficacy of US as one of the treatment modalities for its role in maxillofacial region to reduce pain and promote soft tissue healing.

Materials and Methods: A Medline search included of the international literature published between 1976 and 2011 and was restricted to English language articles, published work of past researchers including *in vitro* and *in vivo* studies, recent additions of textbooks on surgical and therapeutic applications of US and, current articles in conference papers and reports accessed from the internet using Google search engine on therapeutic ultrasound.

Results: Very few article regarding effect of therapeutic of US for its use of insonation for treatment of patient with pain and soft tissue injury are available. This review article mainly emphasizes the therapeutic utility of US in dentistry for its effectiveness to decrease joint stiffness, reduce pain and muscle spasms and improve muscle mobility. *In vivo* studies have shown very little clinical effects.

Conclusions: Further research is warranted in this clinically important area to make the development of noninvasive, multifunctional ultrasound devices for repair, regeneration and other therapeutic utility a success.

Key Words: Dentistry, mechanism, therapeutic ultrasound

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INTRODUCTION

Utility of ultrasound (US) as a diagnostic purpose is well documented in literatures. The therapeutic US in dentistry ranges its involvement for treatment in myofacial pain dysfunction syndrome, temperomandibular joint disorder, silolitotripsy of salivary calculi, craniofacial deformaties, descaling of teeth, root canal procedure, amalgam packing,

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extraction of teeth, cleaning of instrument prior to sterilization and dentures. The diagnostic application of US uses intensities typically between 5 and 500 W/cm^2.[1] The surgical application of US uses intensity levels of 5 to more than 300W/cm^2.[2] Whereas the therapeutic application of US uses intensities between 1 and 3 W/cm^2.[3] The use of low intensity US (3 MHz, 0.1 W/cm^2, 2 ms pulses with 8 ms spaces, 5 min duration has been shown to have a major anti-inflammatory effect and could be related to an inhibition in release of inflammatory mediators from cells. The objectives of ultrasound treatment are to accelerate healing, increase the extendibility of collagen fibers, decrease joint stiffness, provide pain relief, improve mobility, and reduce muscle spasm.[4] US is also being used in conjunction with hyperthermia, photoradio, and chemotherapy (sonodynamic therapy). It has been postulated that the combined effect of two or more methods in treatment might give a synergistic effect imparting a better therapy to the patient.[5]

MATERIALS AND METHODS

A thorough search was made using Pubmed and Google in English language using the keywords; dentistry, mechanism, therapeutic ultrasound. The current concept of mechanism of action of therapeutic US along with its application in myofascial pain, temporomandibular dysfunction, salivary calculi, wound healing in osteointegration, in oral cancers, full thickness excised skin lesions and ultrasonic descaling to achieve the therapeutic utility in dentistry either alone or in conjunction with other available treatment modalities have been reviewed thoroughly using published work of past researchers, current articles in conference papers and reports accessed from the internet using google search engine on therapeutic ultrasound in dentistry.

Various therapeutic US equipment used by the different authors in their studies were Amrex Synchrosonic U200 for myofascial pain, electromagnetic lithotriptor (Minilith SL1, Storz Medical, Kreuzelingen, Switzerland) for Lithotripsy, Rank Sonacel Multiphon MkII for full thickness excised lesions, Sonicated Accelerated Fracture Healing System, Exogen, Piscataway, NJ for fracture treatment and Sonic-accelerated fracture-healing system device (SAFHS) model 2000, Smith and Nephew, Memphis, TN, USA in cases of osteogenesis in vertically distracted edentulous mandible.

Mechanism of action of therapeutic US (TU)

The biophysical effects of Therapeutic US have been examined mainly *in vitro* studies.[6] Therapeutic results obtained by ultrasonic energy are thought to be due to[7]

1. Increased vascular and fluid circulation
2. Increase in cell permeability
3. Increase in pain threshold and a break in pain cycle

The Physiological effect of ultrasound may induce thermal and non-thermal physical effects in tissues.

Thermal effects (Continuous wave exposure)[8,9]

Thermal effects are those that are due to heating and may include

- Increased blood flow
- Reduction in muscle spasm
- Increased extensibility of collagen fibers
- Pro-inflammatory response

It is estimated that thermal effects can occur with elevation of tissue temperature to 40-45ºC for at least 5 min.

Excessive thermal effects, seen in particular with higher ultrasound intensities, may damage the tissue.

Non Thermal Effects (Pulsed Exposure)[9,10]

It can be achieved with or without thermal effects. The reality is that the two effects are inseparable. It includes cavitation and acoustic microstreaming

Cavitation

- Occurs when gas filled bubbles expand and compress because of ultrasonically induced pressure changes in tissue fluids, with a resulting increase in 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 and can be suppressed by the use of very short pulses.

Acoustic microstreaming

- The unidirectional movement of fluids along cell membranes, within the ultrasound field as a result of mechanical pressure.
- It may alter cell membrane structure, function and permeability which have been suggested to stimulate tissue repair.

Cavitation and Microstreaming effect that have been demonstrated *in vitro* include

- Stimulation of fibroblast activity
- Increased in protein synthesis
- Increased blood flow
- Tissue regeneration
- Bone healing

The Arndt-Schulz law states that weak stimuli increase physiologic activity and very strong stimuli inhibit or abolish activity. In treating the head and neck, one should always use weak intensity for ultrasonic therapy. The weak intensity used for therapy is 0.1-0.6 W/cm^2 and in no case should the treatment exceed 0.6 W/cm^2 or a total output of 3 W.[7] The more chronic the tissue state, the less sensitive, and hence the greater the intensity required at the lesion in order to instigate a physiological response. The intensity required at the lesion for acute tissue state is 0.1-0.3 W/cm^2 and for chronic is 0.3-0.8 W/cm^2.[11]

Characteristics[6]–

- It has a frequency range of 0.75-3 MHz, with most machines set at a frequency of 1 or 3 MHz.
- Low frequency ultrasound waves have greater depth of penetration but are less focused.
- Ultrasound at a frequency of 1 MHz is absorbed primarily by tissues at a depth of 3-5 cm and is therefore recommended for deeper injuries and in patients with more subcutaneous fat.
- A frequency of 3 MHz is recommended for more superficial lesions at depths of 1-2 cm.
- Low absorption of ultrasound waves is seen in tissues that are high in water content (e.g., fat), whereas absorption is higher in tissues rich in protein (e.g., skeletal muscle)
- Larger the difference in acoustic impedance between different tissues, the less the transmission from one to the other.

The long term action of therapeutic ultrasound on humans is uncertain; however it is believed that short-term *in vivo* findings will depend on maximum temperature achieved and the length of time the temperature is maintained. Exposure for therapy is restricted to 3-15 minutes and is discontinued on discomfort.[4]

The choice of US therapy head size depends on the extent of the area under treatment. The intensity, time of insonation and US treatment head can be varied to suit the particular clinical situation, but still with the goal of achieving at least 2250 J of US energy per treatment session.[12]

DISCUSSION AND RESULTS

Ultrasonic therapy in myofascial pain

Esposito and colleague in their study used ultrasound sequentially to treat 28 patients with MPDS who did not respond significantly to 6-8 weeks of occlusal splints therapy and used pulsed ultrasound at a frequency of 1 MHz, a pulse repetition rate of 120 Hz, and intensity of 0.75 to 2 W/cm^2 for 3 to 5 min. Treatment was discontinued when the patient became asymptomatic or when no further improvement was noted and concluded that ultrasound is most successful in alleviating muscle symptoms and less effective in reducing symptoms associated with the disk. Ultrasound decreases inflammation, increases vasodilatation and waste removal, accelerates lymph flow, and stimulates metabolism. Pain relief is theorized to be related to washout of pain mediators by increased blood flow, changes in nerve conduction, or alterations in cell membrane permeability that decreases inflammation.[4]

Another study conducted on 102 patients with myofascial trigger points in one side of the upper trapezius muscles by Esenyel M and investigated the effectiveness of ultrasound treatment and trigger point injections in combination with neck stretching exercises concluded that the effectiveness of ultrasound therapy is comparable to trigger point injections and should be offered as non invasive treatment of choice, especially to the patients who wants to avoid injections. The heating effect of ultrasound impairs conductivity of an insonated nerve and thus decreases the sensation of pain.[13]

Majlesi and Ulalan in their study on 72 patients with pain at one side of the upper trapezius muscles who received a high-power, pain threshold, static ultrasound technique in continuous modes, and patients with control group received the conventional ultrasound with the stroke technique and the intensity used was 1.5 W/cm^2 and concluded that high-power, pain-threshold, static ultrasound technique resolves acute active trigger points more rapidly than does treatment with conventional ultrasound technique. Thus concluded that therapeutic ultrasound may be considered for palliative treatment of patient with acute myofascial pain syndrome, but demands more communication and concentration between patient and therapist.[14]

Ariji *et al.* in another study on fifteen patients with temporomandibular disorder who underwent massage treatment alternately on the bilateral masseter and temporal muscles with an oral rehabilitation robot and sonography was performed before and after treatment. The existence of anechoic areas was relevant to visual analog scale (VAS) scores regarding muscle pain and concluded that after massage treatment, the masseter thickness of the symptomatic side in the unilateral group decreased, and anechoic areas disappeared in 85% of the muscles. Masseter thickness and existence of anechoic areas might be related to the therapeutic efficacy regarding muscle pain.[15]

Ultrasonic therapy for temporomandibular joint Dysfunction

A study on 100 patients treated for symptoms believed to be caused by temporomandibular joint dysfunctions and associated symptoms of muscle spasm and concluded that the ultrasonic therapy was not alone effective in relieving symptoms but more effective when used as an adjunct to the accepted modalities of therapy, such as occlusal splint therapy, heat applications, acupuncture, and muscle conditioning exercises.[7]

Kropmans Th. J.B and colleagues analyzed 24 scientific papers concerning the therapeutic outcome of various surgeries and physical therapy, which included ultrasound therapy and found that no significant difference occurred in various therapies instituted for temporomandibular dysfunction.[16]

Another study evaluated the effectiveness of a treatment based on short-wave diathermy, a pulsed short-wave diathermy, ultrasound therapy and laser therapy and found that there was no statistically significant difference in success rate between any of the four tested treatment, although each individually was significantly better than placebo treatment. The time of improvement appeared to vary between the four methods, and found a shorter period of improvement after short-wave diathermy and mega pulse than following ultrasound and laser.[17]

Ultrasound guided lithotripsy of salivary calculi using an electromagnetic lithotripter

Extracorporeal shock wave (ESWL) lithotripsy was introduced for the therapy of salivary calculi. Fifty-four consecutive patients underwent lithotripsy with a specially designed lithotripter between 1997 and 2002 for the sialolithiasis of the parotid and submandibular gland.

Sialolithotripsy was performed with an electromagnetic lithotriptor with an integrated B-Mode ultrasound targeting device (In-Line Transducer) and concluded that the device used in this study, proved to be useful and the success rate was far better for parotid gland calculi than for submandibular calculi. Handling was easy and straightforward and the integrated B-mode sonography allowed reliable targeting of the calculus. Shock waves crush the calculus *in situ* and the fragments are rinsed through the duct by salivary flow. The shock wave is generated outside the patient body and is focused through the skin onto the calculus.[18]

Ultrasound therapy in bone healing and osteointegration

"Therapeutic" low intensity pulsed ultrasound has been shown to accelerate bone fracture healing indicating that ultrasound may be used as a tool to facilitate hard tissue regeneration.[19]

Certain studies on animals were carried out on bilateral midshaft femur fractures in rats and midshaft ulna fracture in dogs[19-20] and showed an 16.9% greater bone mineral content, 81.3% greater mechanical strength, 25.8% increase in bone size at active ultrasound-treated fracture site and increased vascularity around the fracture sites, respectively.

A literature review was conducted by Erdogan and his colleague on the effects of ultrasound therapy on bone healing and the studies regarding clinical applications in long bones and maxillofacial bones and concluded that therapeutic ultrasound in clinical settings is a noninvasive application and has no serious complications or side effects. It may be an acceptable treatment of choice in many types of clinical procedures involving maxillofacial bones.[21]

Distraction osteogenesis is considered a successful technique to gain bone and soft-tissue mass in persons with a variety of craniofacial deformities. A study by El-Bialy on 36 New Zealand rabbits which were divided into three groups and osteodistraction was performed at 3 mm/day for 5 days. Group 1 received pulsed, group 2 received continuous ultrasound, and group 3 was the control group (distraction only). Bone formation was assessed by quantitative bone density (QBD), mechanical testing, and histological examination and concludes that bone formation by rapid distraction osteogenesis (3 mm/day) of the mandibular bone can be improved with both pulsed and continuous ultrasound. Earlier stages of bone healing were enhanced more by continuous, whereas late stages were enhanced by pulsed, ultrasound.[22]

Law in his study on low intensity pulsed ultrasound (LIPUS) on dentoalveolar tooth root fracture in rat mandible slices, concluded that daily application of LIPUS enhances healing of the dentin, cementum and alveolar bone and this stimulation seems to be dose (treatment time) dependent.[23]

In the case of osteodistraction, ultrasound therapy may accelerate the mineralization of the tissue within the distraction gap. The primary effect of ultrasound in osteodistraction seems to occur early in the treatment process and the overall bone healing process occurs relatively early.[24]

Schortinghuis *et al.* conducted a vertical mandibular distraction over a distance of 5.1 ± 1.2 mm. Ultrasound or placebo therapy was started daily from the first day of distraction. The active sonic-accelerated fracture-healing system devices were used for ultrasound treatment. The placebo devices did not emit an ultrasound pulse and ultrasonographs were taken regularly and concluded that ultrasound treatment does not appear to stimulate bone formation in the severely resorbed vertical distracted mandible but it is a useful way to detect calcified tissue inside the distraction gap, much earlier than by using serial radiographs.[24]

Ultrasound therapy in cancer

A method which selectively affects malignant cells without causing any damage to the surrounding normal tissue is safe; ultrasound could certainly be considered a treatment of choice for at least certain malignant diseases.[25]

Activated Cancer Therapy (ACT), also known as sonodynamic photodynamic therapy (SPDT) is a novel therapeutic modality that utilise a nontoxic photosensitive agent with reported ultrasound-activated properties.[26-28]

Potentiated cytotoxicity by ultrasound was first demonstrated by Kremkau *et al.*, when mouse leukemia L1210 cells were exposed to continuous wave ultrasound, suspended in nitrogen mustard solution *in vitro*. Mice subsequently inoculated with these cells had longer survival times than control animals that received cells exposed to the drug but not ultrasound.[27]

Kenyon in a case series of 115 patients with a variety of cancer diagnoses (out of which are 4 head and neck cancer) reports on experiences of treatment over a 4-year period using sublingual administration of a new dual activation agent, Sonnelux-1, followed by a protocol of LED light and low-intensity ultrasound exposure. Initial clinical observation suggests SPDT is worthy of further investigation as an effective and well tolerated treatment for a wide variety of primary and metastatic tumors, including those refractory to chemotherapy.[26]

This ground can also be utilized in treatment of patient with oral squamous cell carcinoma.

Ultrasound on the healing of full thickness excised lesions

Ultrasound is widely used as a therapeutic agent in medicine and dentistry to accelerate repair, modify scar tissue production, and to reduce pain.

Young in his study suggested that US therapy can be useful in accelerating the inflammatory and early proliferative stages of repair.[5]

Other applications

Ultrasonic descaling

The main application of ultrasound in dentistry is to remove both dental plaque and calculus deposits from the surfaces of teeth using an ultrasonic descaler. These instruments operate at frequencies of 25-42 kHz and are useful in that they reduce the mechanical effort required by the clinician. Furthermore they are easy to operate and there is a reduction in both the treatment time and the level of discomfort to the patient.[29]

A magnetostrictive or a piezoelectric transducer within the handpiece is used to produce the ultrasonic vibrations. Both designs utilize a flow of cooling water which is passed through the handpiece and onto the oscillating tip. The cooling water serves to reduce frictional heating at the tooth/tip interface.[29]

Clinical studies on the quality of the descaling process show that both manual and ultrasonic instrumentation remove the attached calculus from the tooth surface efficiently with no apparent differences between either technique and are followed by scanning electron microscope studies of the enamel and dentinal surfaces following routine descaling procedures. This suggested that ultrasonic devices tended to remove the calculus in small fragments with burnishing of the remaining deposits, while hand instruments remove the calculus in much larger fragments. However, calculus removal by the ultrasonic descaler was superior from those teeth where there was good access.[29]

The removal of the surface layer of necrotic cementum from periodontal diseases is an established part of the descaling process. Both the hand and ultrasonic instrumentation produced similar rates of resolution of inflamed periodontal tissue.

A study which reported that in root planning, hand instruments were superior to ultrasonic descalers and concluded that either root planning or areas of the mouth where access is difficult, ultrasonic descalers are relatively ineffective.

In clinical studies, most investigators agree that tissues surrounding teeth that are subjected to ultrasonic descaling show more rapid resolution to health, as demonstrated by a larger reduction in tissues inflammation than where a hand instruments was used. This may be due to an increase rate of collagen production stimulated by the ultrasonic descaler.[29]

Advantages[29]

- The use of an ultrasonic descaler is that calculus removal is accomplished more rapidly than with conventional hand instruments
- Reduction in discomfort
- It is related to a reduction in both physical effort and complex manipulation

Disadvantages[29]

- The possible loss of tactile sensation when using the device makes it difficult to be sure that all calculus has been removed completely, a problem that does not appear to exist when using hand instruments.

Modification of the ultrasonic desaclers[29]

Endodontics

Ultrasonic vibrations may be used to prepare and clean the root canal of nonvital teeth before filling is commenced. These instruments are essentially a direct adaptation of the ultrasonic descaler where rigid metal rod is driven to oscillate in its longitudinal mode and a small file is attached near the end of the main driver and is set at a angle of 60º-90º to the main longitudinal axis. Accordingly, during operation a transverse wave is set up along the length of the file and this oscillating file is placed within the root canal of the tooth and abrades the walls removing contaminated organic and inorganic material.

An antiseptic solution is often passed over the oscillating tip to aid in the cleaning process and the occurrence of acoustic micro streaming fields developed around small irregularities protruding from the file surface increases the effectiveness of the disinfectant.

Surgical applications

The ultrasonic descaler has also been adapted for use in dental surgical procedure such as removal of the apical portion of the root of teeth and surgical extraction of teeth.

Advantage

- Good hemorrhage control and visibility
- No adverse effects reported so far
- Healing appears uneventful with minimal patient discomfort.

Other dental uses

1. In conservative dentistry[29] - the adapted ultrasonic descaler has been used for the condensation of amalgam restoration together with restoration contouring and elimination of interproximal ledges.
2. In orthodontic treatment[29] – to remove interdental contacts between teeth, cemented orthodontic brackets, and superficial decalcification of enamel.
3. The ultrasonic descaler may also be used to remove fractured metal posts from teeth by breaking the cement seal.[29]
4. Ultrasound therapy promoting dentin formation and repair may also have the potential benefit of alleviating dentin hypersensitivity by inducing occlusion of dentinal tubules.[30]

Ultrasonic cleaning bath[29]

The ultrasound is often used commercially in the cleaning of solid objects by the immersion in liquid and subsequent exposure to the mechanical effects of cavitational activity and acoustic microstreaming.

Ultrasonic cleaning baths operating at frequencies of 18-100 kHz are used in dentistry for removing debris from instruments prior to sterilization, calculus and staining from dentures, and disinfecting rubber base impressions to casting.

CONCLUSION

Ultrasound at power levels are capable of causing heating, and biologic effects is extensive and considered to be the prevalent source of ultrasonic irradiation to humans. Thus a reasonable amount of palliation can be achieved by utilizing the US for therapeutic effect in dentistry either alone or in conjunction with other available treatment guide.

It would be premature to abandon the use of US for therapeutic utility only because of current lack of clinical evidence. Studies must emphasis of the regular calibration of US units, coupling media and transducer surface area. Reliable method which can be reproducible for better performance of US Physiotherapy equipment should be developed to ensure the delivery of standard dosage of US therapy.

Various authors have commented that most treatments involving the use of therapeutic ultrasound are based upon personal opinion and experience, and that there is a need for more controlled experiments to be done to investigate the clinical claims that ultrasound does indeed accelerate healing. The continuing advances in this field may promise exciting developments in the coming years.

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