Applications Of Therapeutic Ultrasound In Dentistry And In The Craniofacial Area: Present And Future

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ABSTRACT

The aim of this article is to outline the applications of therapeutic ultrasound on tooth and bone formation in the craniofacial area. The scientific background and clinical applications will be highlighted. Many problems in dentistry and in the craniofacial area exist without a definitive treatment. This review will point out the current state of the art and potential uses of therapeutic ultrasound to solve most of these problems.

SOMMAIRE

Le but de cet article est de décrire les applications des ultrasons thérapeutiques sur la formation des dents et des os dans la région craniofaciale. Les fondations scientifiques et les applications cliniques seront accentués. Plusieurs problèmes dentaires et craniofaciales existent sans traitements définis. Cet article de revue fera le point des connaissances les plus récentes et des des applications potentielles des ultrasons thérapeutiques pour résoudre la plupart de ces problèmes.

1. INTRODUCTION

Ultrasound, a form of mechanical energy that is transmitted through biological tissues as an acoustic pressure wave at frequencies above the limit of human hearing, is used widely in medicine as a operative (That is used to crush renal and liver stones and usually of frequency range between 2 - 8 K Hz), therapeutic (that is used in physiotherapy and usually of frequency range between 20 K Hz 3M Hz and either in the continuous or pulsed modes), and diagnostic tool (usually of a frequency range between 1.6-12 M Hz).1-3 Both therapeutic US, and some operative US, use intensities as high as one to three W/cm2 and can cause considerable heating in living tissues. To take full advantage of this energy absorption, physical therapists often use such levels of US acutely to decrease joint stiffness, reduce pain and muscle spasms, and improve muscle mobility.4 The exact mechanisms by which ultrasound produces these effects are not fully understood. However, there is ample evidence in the literature that therapeutic ultrasound can produce stimulatory effects at the gene, cellular and tissue levels. The purpose of this review article is to present the effect of therapeutic ultrasound on cellular and subcellular levels and its potential use in other medical therapeutic applications.

2. TISSUE REPAIR AND STIMULATORY EFFECTS OF ULTRASOUND

Mechanical energy in the form of ultrasound or other types of mechanical loading is now accepted to have a stimulatory effect on bone and other tissues. Historically, Wolff demonstrated a relationship between the architecture of cancellous bone and the forces acting upon the skeleton.5 A recent report supports Wolff's conclusion that the form and architecture of bone adapt to the mechanical environment by remodeling to accommodate the magnitude and direction of the applied stress.6 Because ultrasound is a type of pressure wave, it was hypothesized that ultrasound can enhance healing of bone fractures, and it was proven to do so in 1952 in rabbits. 7 These findings were followed by the first clinical use of ultrasound to stimulate fracture-healing in 1953, when it was demonstrated that the ultrasound treatment was safe and produced an increase in periosteal callus (bone fracture healing tissue). 8 The use of therapeutic ultrasound to facilitate bone fracture healing re-emerged in the seventies and became more popular in the late 1990s with the FDA approval for clinical use of long bone fracture healing.9,10 Distraction osteogenesis, also known as Ilizarove technique or bone lengthening was first reported by Codvilla in 1905.11 This technique was popularized in Russia during World War II.12 This technique was introduced into the craniofacial region13 to lengthen short bones, such as the upper and lower jaws, and also to correct facial asymmetry in cases of congenital syndromes, Hemifacial microsomia, and craniosynostosis.14,15 One of the problems encountered in craniofacial or long bone distraction osteogenesis, especially with external appliances was the risk for potential trauma and patient incapacitation.16,17 Another problem when intraoral tooth-borne distraction devices were used was that the final result of bone lengthening was modified by the masticatory muscle forces. This led to bending of the newly formed bony callus.18 Moreover, with regular distraction osteogenesis technique, it is mandatory for the patient to have the distraction device for an extended period of time, usually 6-8 months, to ensure complete bone formation and maturation at the distraction site. In most scenarios, the patient can be incapacitated from work and other life activities. Based on that, several researchers studied different methodologies to enhance bone healing during distraction osteogenesis. These techniques included the use of insulin-like growth factor, electrical stimulation and therapeutic ultrasound. 19-22

Therapeutic ultrasound produced growth modification of the endplate in the tibia of growing rats. 23 It has also been reported to produce growth modification of the mandibular condyle and stimulate mandibular growth in growing rabbits and monkeys.24,25 These results led to trying to use therapeutic ultrasound to stimulate mandibular growth in underdeveloped mandibles of patients with hemifacial microsomia. These therapeutic ultrasound results, however, were complemented by the use of lower jaw stretching appliances, known as functional appliances.26 These results however are limited to growing animals and or human patients. The long-term stability of these results as well as the potential stimulation in adults is a real scientific challenge. A historical discovery was reported in 2002, when the lower incisor of adult rabbits were sectioned during the course of mandibular osteotomy intended for osteodistraction. 27 That was the first time in history that new dental tissue (osteodentine and cementum) was formed in a few days using ultrasound. This discovery brought with it a questionable application to human teeth, since it is known that the teeth of rodents, including rabbits, are continually erupting throughout their life. This led us to move to an exploratory human trial. In orthodontics, many patients seeking treatment for crowded teeth usually require removal of their first or second premolars to provide the required spaces. These potentially extracted teeth are often candidates for human experimental studies, since the patients are going to lose them anyway. For this preliminary study, twelve orthodontic patients requiring removal of their first premolars were chosen and consented to participate in this study. Premolars on both sides in each patient were moved orthodontically to induce resorption of their roots. For each patient, one premolar was treated with ultrasound for twenty minutes per day for four weeks and the premolar on the other side was used as a self control. After four weeks, all premolars were extracted and examined with either a scanning electron microscope or histologically. Both examinations revealed that the ultrasound treated premolars showed healing of the root resorption with newly formed cementum and dentine, while the nontreated premolars showed increased areas of root resorption. 28 This is the first time in history that human teeth roots showed new dental tissue formation in the roots in four weeks, especially treating external tooth root resorption. The potential application of this treatment method is that other forms of tooth root resorption, like those after trauma or after root canal treatment, or root fracture may be treated with this type of ultrasound. However, more research is needed to test this methodology in such cases.

Another stimulatory effect of therapeutic ultrasound is on the healing of artificially cut, repaired and immobilized tendo-calcaneus in rabbits. It was found that ultrasound induced a significant increase in the tensile strength, tensile stress and energy absorption capacity of the tendons when applied for 5 minutes every day for 9 days. These findings suggested that sonication at similarly low intensities may enhance the healing process of surgically repaired human tendo-calcaneus.29 Also, ultrasound was found to promote the healing of medial collateral ligaments in rats when treated for 5-10 days.30

3. MECHANISM BY WHICH THERAPEUTIC ULTRASOUND ENHANCES TISSUE FORMATION

Long before its use in clinical situations, therapeutic ultrasound was tested on cellular levels and in animal experiments. In addition, the clinically achieved results of using ultrasound have been studied in-vitro and provided many explanations for those results. It was found that low intensity (0.75 MHz) ultrasound is effective in liberating preformed fibroblast growth factors from a macrophage-like cell line, possibly by producing permeability changes, whereas higher intensity (3.0 MHz) ultrasound appeared to stimulate the cell's ability to synthesize and secrete fibroblast mitogenic factors.31 Also, it has been recently reported that ultrasound stimulates type I and III collagen expression of tendon cells as well as upregulates the transforming growth factor beta in-vitro.32,33 It has also been shown that therapeutic ultrasound stimulates the expression of the proliferating cell nuclear antigen in cultured tendon cells as evaluated by immunocytochemistry and by reverse transcription-polymerase chain reaction. A dose-dependent increase in the cellularity of tendons was reported as ten minutes of treatment achieved maximum cellularity compared to 5 minutes of treatment time. 34 These facts provide an explanation of the clinical effect of therapeutic ultrasound in stimulating tissue repair.

Moreover, therapeutic ultrasound was reported to stimulate the proliferation of the cartilage cells without influencing cell differentiation. 35 Also, therapeutic ultrasound was reported to stimulate aggrecan mRNA expression and proteoglycan synthesis by chondrocytes.36 This may explain a means by which ultrasound enhances endochondral ossification (bone growth within the cartilage that is known to be the type of bone growth involved in bone fracture healing and long bone growth), increases the mechanical strength of fractures, and facilitates fracture repair.

Moreover, ultrasound can also affect vascular tone directly, and hence enhance tissue perfusion as well as increase vasodilation. It was reported that the application of 40 kHz ultrasound at intensities from 0.25 to 0.75 W/cm2 progressively improved perfusion over 60 minutes and reversed acidosis, but these effects were both completely blocked by pre-treatment with the nitric oxide synthase inhibitor. Histological examination showed greater capillary circumference in ultrasound exposed muscle compared to unexposed tissue with no other histological changes. 37 Moreover, it has been reported that therapeutic ultrasound stimulates matrix production by cementoblasts in vitro.38 This result supports previous research which reported that ultrasound stimulates teeth eruption and formation, and repairs tooth root resorption after orthodontic treatment.27,28

4. SAFETY OF DAILY USE OF THERAPEUTIC ULTRASOUND FOR EXTENDED PERIODS OF TIME.

With the recent and more advanced applications of therapeutic ultrasound, there is an increasing concern about the safety of repeatedly using it for extended periods of time in humans for as long as months or years on a daily basis. In addition to reports that ultrasound is being used to diagnose early stages of cancer,39 it has been reported that when human patients used low-intensity pulsed ultrasound (LIPUS) to enhance bone fracture healing for 114 + 10 days, there were no reported complications related to its use.9 It has been reported that the current safety limit for diagnostic ultrasound is 0.72 W/cm2,40 which is almost three times that of the LIPUS power that has been approved by FDA and Health Canada (0.30 W/cm2). It is generally accepted that there is no real evidence of adverse human health effects of diagnostic ultrasound and its use is not contraindicated for medical purposes at the recommended levels.41 Moreover, ultrasound with an intensity of 7 W/cm2 with a frequency of 340 kHz for 30 minutes is being used for thrombolysis of cerebral infarction using continuous ultrasound insonation with no harmful effect on the brain.42 Previously, when LIPUS was used to repair orthodontically-induced tooth root resorption, an acoustic absorber was used to prevent any unwanted potential exposure of the neighboring tissues to unwanted LIPUS.28 In reviewing the available literature, no major concerns with repeated use of therapeutic ultrasound for extended periods of time were found. However, more in-vitro studies may be conducted to test if there is a potential for cellular damage due to ultrasound application for extended periods of time.

5. FUTURE DIRECTIONS

Future studies might be aimed at testing the effect of therapeutic ultrasound on tissue engineering of teeth, bone, and other body tissues/organs. The promises on gene as well as cellular stimulation by ultrasound can open a new era of investigations and applications for different clinical problems that have never been tested before. Moreover, its use to stimulate nerve and muscle function and growth is still a new area to be explored.

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