The effects of low-intensity pulsed ultrasound on the rate of orthodontic tooth movement

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Accelerating alveolar bone remodeling and thus accelerating the velocity of orthodontic tooth movement is highly desirable by orthodontists and patients. Low-intensity pulsed ultrasound (LIPUS) stimulation has been reported to promote fracture healing to treat bone nonunion, and to accelerate bone maturation and remodeling during the consolidation stage of distraction osteogenesis. Low-intensity pulsed ultrasound (LIPUS) is a safe, non-invasive approach, which has demonstrated the potential to increase the rate of tooth movement. The purpose of this review article is to help readers understand the science behind this technology and to discuss the different potential applications of LIPUS in orthodontics. (Semin Orthod 2015; 21:219–223.) © ***2015 Elsevier Inc. All rights reserved.***

Introduction

Orthodontic treatment is a process to achieve appropriate esthetics and masticatory function through movement of teeth by applying an external physical force. In this regard, stimulating proper physiological reactions in the surrounding tissue is the main focus of orthodontic treatment.[1,2] Optimizing proper biological responses may not only accelerate tooth movement, but also decrease side effects. In order to improve the velocity of orthodontic treatment, previous studies have utilized different biochemical agents, such as osteocalcin and prostaglandin E2 (PGE2),[3] parathyroid hormone,[4] and dihydroxyvitamin D3 [1,25-(OH)2D3].[5] However, due to systemic effects, their application in orthodontics has not been justified.[1] Therefore, recent studies have focused on exploring the potential use of non-invasive physical methods to achieve faster orthodontic tooth movement.[2,6,7] One of the potential physical approaches suggested in these studies is low-intensity pulsed ultrasound (LIPUS). To validate the use of LIPUS in orthodontics, a search of the current literature was conducted using ISI Web of Knowledge, Science Direct, and PubMed search engines.

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Funding: This study was supported by grants from The Scientific and Technological Project of Shaanxi Province of China, PR China (2008K14-03 to Dr. Duan), who had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

1073-8746/12/1801-$30.00/0

http://dx.doi.org/10.1053/j.sodo.2015.06.009

Biological effects of LIPUS

LIPUS (30–100 mW/cm^2) is a form of mechanical energy that is transmitted through living tissues as acoustic pressure waves, resulting in biochemical changes at the cellular and molecular levels.[8] These biochemical changes may have several therapeutic benefits, one of which includes an increase in rate of soft and hard tissue healing.[9,10] Therefore, LIPUS is widely used in the field of physical therapy, and has been approved by the U.S. Food and Drug Administration (FDA) as a modality of treatment.

Since LIPUS can improve the rate of bone healing after trauma, a number of studies have tried to understand its biostimulatory effects, especially in regard to the osteoblastic and osteoclastic responses. It has been reported that

in response to LIPUS, there is up-regulation of osteogenic markers, such as IL-8, bFGF, VEGF, TGF-β, alkaline phosphatase, and non-collagenous bone proteins, as well as concomitant down-regulation of the osteoclastic markers.[4,11–14] It has also been reported that the biostimulatory effects of LIPUS are derived from the induction of micro-stream signals and mechanical stresses. These signals directly stimulate cell membranes, cytoskeletal structures, and focal adhesion molecules, which result in signal transduction and subsequent gene transcription.[15]

Previous studies[16,17] have shown that the periodontal ligament contains precursor cells of cementoblasts and osteoblasts in the perivascular area. Cyclic mechanical stimulation of the PDL, via the regulation of EGF/EGFR system, would induce the differentiation of these precursor cells toward either the osteoblastic or cementoblastic pathway.[16,18] This biological effect of LIPUS may help with repair of root resorption.[19,20]

Similarly, LIPUS has been reported to upregulate fibroblast growth factors (from a macrophage-like cell line) and angiogenic factor (CD31).[21,22] It also has been demonstrated that applying LIPUS on human gingival fibroblasts (5 min per day for 3 weeks) upregulates ALP and OPN expressions in these cells, which indicates the possibility of osteogenic differentiation.[23]

LIPUS is distinguished by being non-invasive and easy to use, and the signal is considered neither thermal nor destructive.[24] Compared with other types of ultrasound, LIPUS has a better biological effect in promoting tissue healing.[25–27] Therefore, LIPUS has been used to promote the healing of various types of hard and soft tissues, such as fractured bone, intervertebral disc, and cartilage.[28] It has also been used to enhance mandibular growth in children with hemifacial microsomia.[29] In addition, LIPUS induces a significant increase in the amount of predentin, cementum, and the number of cells in the PDL and the sub-odontoblast layer[29–33]; which indicates that LIPUS is a potential method to prevent root resorption during orthodontic tooth movement.[30] LIPUS is generally utilized in 1.5 MHz frequency pulses with a pulse width of 200 μs, repeated at 1 kHz at an intensity of 30 mW/cm^2 for 20 min per day as recommended by the FDA.[34–36]

While the clinical applications of LIPUS in the medical field are well-studied, there are very few studies on LIPUS stimulation for orthodontic tooth movement.[34,37]

LIPUS treatment and orthodontic tooth movement

There is a narrowing of the PDL in the pressure side of the tooth immediately upon orthodontic forces on the periodontium. Shortly after, osteoclasts differentiate along the wall of alveolar bone, initiating bone resorption, which is considered the initial stage of the tooth movement. Regions of bone resorption are seen as an increase in the width of the PDL.

In the later stage of tooth movement, there is an increase in the proliferation and differentiation of local cells into fibroblasts and osteoclasts, followed by the deposition of osteoid tissue on the tension side of the tooth. The original periodontal fibers are gradually embedded in the new layers of osteoid until the PDL has returned to its original width.[38]

There is no difference observed between the tissue reactions in orthodontic tooth movement with or without LIPUS stimulation.[37,39] However, the changes observed in tissue upon LIPUS stimulation are more extensive, resulting in the rapid movement of teeth during the orthodontic treatment.[37,40]

A list of previous studies on the application of LIPUS during orthodontic treatment is shown in the Table. These studies illustrated that LIPUS can be used in orthodontics to reduce the risk of root resorption, increase the rate of tooth movement, or modify mandibular growth. In addition, LIPUS promotes the proliferation of cells in PDL and alveolar bone, which improves the quality of the periodontium and reduces the possiblity of relapse after orthodontic treatment.[41,42]

Discussion

The ultimate aim of orthodontic tooth movement is to move teeth in the most effective way with minimal side effects such as root resorption. Recent studies have provided evidence of the beneficial effects of LIPUS on the rate of orthodontic tooth movement[37]; however, the