Journal of the World Federation of Orthodontists xxx (2018) 1–7

Contents lists available at ScienceDirect

Journal of the World Federation of Orthodontists

journal homepage: www.jwfo.org

Vibratory stimulus and accelerated tooth movement: A critical appraisal

Chidchanok Leethanakul [a,*], Pussadee Phusuntornsakul [b], Anute Pravitharangul [b]

[a] Associate Professor, Orthodontic Section, Department of Preventive Dentistry, Faculty of Dentistry, Prince of Songkla University, Hat Yai, Songkhla, Thailand

[b] PhD candidate, Orthodontic Section, Department of Preventive Dentistry, Faculty of Dentistry, Prince of Songkla University, Hat Yai, Songkhla, Thailand

ARTICLE INFO

Article history:
Received 6 June 2018
Accepted 23 July 2018
Available online xxx

Keywords:
accelerated tooth movement
periodontal ligament
vibration

ABSTRACT

Importance: Mechanical vibration has recently been emphasized in orthodontics as a noninvasive approach of accelerating tooth movement. This review summarizes the knowledge on the ability of mechanical vibration to accelerate tooth movement and critically analyzes the biological effects of mechanical vibration reported by in vivo and in vitro studies.

Observations: Studies on the effects of mechanical vibration in orthodontics have reported inconsistent results, which may arise from the varied vibration protocols, tooth movement mechanics, and outcomes measured. Recent animal studies reported vibration combined with orthodontic force increased the rate of tooth movement and the levels of inflammatory chemokines (CCL2) and cytokines (IL-1β, and TNF-α). Consistent with these findings, vibration combined with compressive force upregulated inflammatory mediators and RANKL in human periodontal ligament cells in vitro. Randomized controlled trials indicate the application of vibration increases the rate of tooth movement in canine distalization; however, vibration does not increase the rate of crowding correction.

Conclusion and relevance: Mechanical vibration may accelerate tooth movement by enhancing alveolar bone resorption at the compression side during orthodontic tooth movement via a mechanism related to induction of inflammatory mediators. However, the optimal vibration protocols and cellular mechanisms of action of mechanical vibration need to be well-defined before clinical application. Moreover, patient compliance and cost-effectiveness need to be considered.

1. Introduction

Orthodontic tooth movement occurs in response to a sequential process of periodontal tissue remodeling, especially alveolar bone remodeling, induced by therapeutic mechanical stress [1,2]. Usually, orthodontic treatment times range from 12 to 37 months [3]. Because prolonged treatment time is associated with increased risks of gingival inflammation, dental caries, and root resorption, orthodontic research is searching for newer methods to accelerate tooth movement. To shorten the treatment time and limit the side effects of orthodontic treatment, surgical, biological, and physical methods to accelerate tooth movement have been reported in the literature [4,5].

Surgical approaches, such as corticotomy [6,7], corticision [8], piezocision [9], periodontal ligament (PDL) distraction [10], and interseptal bone reduction [11] are based on the principle that an induced osteopenia along with the resultant inflammatory cascade promotes osteoclastogenesis [6] and accelerates tooth movement. Although the results are effective and highly predictable, surgical procedures are invasive and associated with postoperative pain and the risk of harm to periodontal tissues. Thus, patient acceptance of these procedures is considered low [12]. Biological approaches include injection of exogenous inflammatory mediators and hormones that induce bone resorption, such as prostaglandin E (PGE) [13], vitamin D [14], parathyroid hormone [15], or receptor activator of nuclear factor kappa-B ligand (RANKL) [16], into periodontal tissue. However, injected substances are rapidly flushed out through the circulation, thus daily systemic administration or local injections are deemed necessary. Moreover, the use of some of these agents can induce undesirable effects, such as root resorption and pain [5,17].

* *Corresponding author:* Orthodontic Section, Department of Preventive Dentistry, Faculty of Dentistry, Prince of Songkla University, Hat Yai, Songkhla, Thailand.
E-mail addresses: nokleethanakul@yahoo.com, chidchanok.l@psu.ac.th (C. Leethanakul).

2212-4438/$ — see front matter © 2018 World Federation of Orthodontists.
https://doi.org/10.1016/j.ejwf.2018.07.005

Several physical device–assisted approaches to accelerate tooth movement have been widely investigated, including the application of direct electric currents, electromagnetic fields [18], low-level laser therapy [19], and mechanical vibration [20,21]. Although these physical approaches have the advantage of being noninvasive, their effects on tooth movement are controversial. Mechanical vibration at a frequency of 20 to 120 Hz and magnitude below 1 g ($g = 9.8$ m/s^2) has recently been applied to increase the rate of orthodontic tooth movement as well as to reduce pain after appliance activations [20–22]; however, the effects of mechanical vibration on tooth movement in both animal and clinical studies remain controversial. Several studies [20–25] have reported mechanical vibration can accelerate tooth movement, but there exist studies [26–28] reporting contradictory findings too.

Thus, the effect of applying vibratory stimulus on the rate of tooth movement remains a controversial topic. This review is aimed to summarize the knowledge on the ability of mechanical vibration to accelerate tooth movement and critically explore the biological effects of mechanical vibration reported through in vivo and in vitro studies.

2. Mechanobiology of vibratory stimulus as an accelerating mechanics

The effects of vibration on weight-bearing bones have been investigated in many studies; vibratory signals have been shown to promote bone remodeling by stimulating bone formation and increasing bone density [29]. In medicine, whole-body vibration has been used as a nonpharmacological intervention to prevent bone loss in individuals at high risk of osteoporosis [30,31]. Recently, mechanical vibration has been applied with the aim of increasing the rate of orthodontic tooth movement and reducing pain after appliance activations [20–22].

Several hypotheses have been proposed to explain how vibration enhances the rate of orthodontic tooth movement. It is reported that vibration may stimulate differentiation of osteoclasts from hematopoietic cells by increasing blood flow. These signals may be mediated in response to direct effects on the cell membrane, changes in ion transport, activation of stretch-activated channels, activatory changes in the attachments between skeletal bones and extracellular matrix, or modification of intracellular signals that regulate gene expression to promote bone remodeling [24]. Recently, clinical and animal studies and investigations at the cellular level have found that vibration may enhance orthodontic tooth movement via a mechanism related to induction of inflammatory mediators [20, 23, 25, 32, 33]. Leethanakul et al. [20] reported increase in levels of secreted interleukin (IL)-1β in gingival crevicular fluid on the pressure side of the canine that received vibration than the canine receiving orthodontic force alone. IL-1β could stimulate osteoblasts to produce macrophage colony-stimulating factor and RANKL, which bind to their respective receptors, colony stimulating factor 1 receptor and RANK, on osteoclast precursors to promote osteoclastogenesis [1]. However, one animal study suggested that vibration inhibits tooth movement by inducing disorganization of the PDL [27].

Harmful levels of vibration are defined as a function of magnitude (g-force, where g = earth's gravitational field, acceleration of 9.81 m/s^2, or 0.0098 N), frequency (Hz, or cycles per second), and duration (time of exposure) [34]. Vibration protocols using a magnitude below 1 g, frequency of 20 to 120 Hz, and duration of less than 30 minutes per day have been used in several studies of vibration-assisted tooth movement and whole-body vibration [21, 29]. Use of vibration at a g-force greater than 1 g in medicine should be approached with extreme caution due to the risk of pathogenic effects to the musculoskeletal system [32].

3. Clinical interventional studies

The use of vibratory devices in conjunction with orthodontic tooth movement has been examined in eight clinical studies [20–22,26,28,35–37], of which one is a quasi-experimental study [22] and the other seven are randomized controlled trials (RCTs). In terms of tooth movement, the rate of canine distalization was evaluated in two studies [20,21], retraction of the anterior teeth was examined in one study [26], and tooth alignment based on an irregularity index was assessed in the remaining studies [22,28,35–37]. The characteristics of these clinical studies are summarized in Table 1.

In 2010, Kau et al. [22] was the first to report that application of a vibratory device (30 Hz, 0.2 N, 20 min/d) led to a rapid reduction in Little's irregularity index score of 2.1 mm per month for the mandibular arch and 3.0 mm per week for the maxillary arch. This suggested that vibration accelerated the rate of tooth movement compared with the normal rate of orthodontic tooth movement (1 mm/mo). However, that study was a quasi-experimental study without a control group. RCTs related to the effects of vibration on canine distalization reported consistent results that vibration increases the rate of tooth movement. Pavlin et al. [21] reported that application of vibration significantly increased the rate of maxillary canine distalization to 1.16 mm per month (30 Hz, 0.25 N, 20 min/d) during orthodontic treatment compared with 0.79 mm per month for a 180-g NiTi coil spring applied to a nonfunctional device. Similarly, we previously reported the combination of vibratory stimulation from an electric tooth brush (125 Hz, 5 minutes per time, three times per day) with 60-g force increased the distance of canine distalization to 2.85 mm in the experimental group compared with 1.77 mm in the control group at the end of the second month. The level of IL-1β in gingival fluid on the pressure side of the distalizing canine was also significantly higher in the vibratory group than the control group [20]. In contrast, DiBiase et al. [26] examined the effect of supplemental vibration on the rate of anterior teeth retraction in a multicenter study and found that the rate of mandibular arch space closure was not significantly different among the orthodontic group, vibration (30 Hz, 0.2 N, 20 min/d) combined with orthodontic group, and sham group. In that study, the force was generated from a NiTi coil spring attached to the first molar from a hook between the lateral incisors and canines; the spring was stretched no more than twice its length, although the magnitude of force was not quantified.

In addition, four RCTs reported that vibration did not significantly affect the rate of anterior teeth aligning [28, 35–37]. Miles and colleagues [28,36] could not observe any significant change in the irregularity index or pain level during initial alignment in patients treated using a 0.014-inch NiTi archwire after application of vibration at 111 Hz and 0.06 N for 20 minutes per day [28] or 30 Hz and 0.25 N for 20 minutes per day [36]. Similarly, Woodhouse et al. [35] found no significant differences in the initial or overall rates of alignment among the orthodontic group, vibration combined with orthodontic group (30 Hz, 0.25 N, 20 min/d), or sham group during the orthodontic alignment phase. A recent study examined the use of vibration (30 Hz, 0.25 N, 20 min/d) in conjunction with aligner treatment [37]. The reductions in the irregularity index and pain were not significantly different among the vibration, control, or sham groups.

The conflicting effects of vibration reported by these clinical studies may arise from the variations in the vibration protocols, tooth movement mechanics, and outcomes measured. From a clinical perspective, these RCTs assessed three types of tooth movement mechanics and measured two outcomes: (1) the rate of anterior teeth aligning using irregularity index outcome [22,28,35–37], and (2) canine distalization [20,21] or anterior teeth retraction [26] based on the distance of tooth movement outcome.

Please cite this article in press as: Leethanakul C, et al., Vibratory stimulus and accelerated tooth movement: A critical appraisal, Journal of the World Federation of Orthodontists (2018), https://doi.org/10.1016/j.ejwf.2018.07.005