

Acceleration of Tooth Movement in Orthodontics: A Review of Literature

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ABSTRACT

Objectives: The demand for orthodontic treatment is nowadays increasing significantly for aesthetic improvement and to correct various kinds of malocclusion, yet the prolonged treatment time remains the main obstacle. This review aimed to demonstrate various orthodontic techniques and highlight the evidence-based successful approaches used for acceleration of orthodontic tooth movement.

Materials and Methods: Data and sources of information pertaining to accelerated orthodontic tooth movement premised on English-written articles were searched using electronic databases including Google Scholar, Scopus, PubMed and MEDLINE.

Results: This review demonstrated the availability of different surgical and non-surgical methods to enhance tooth movement, with a wide range of advantages and disadvantages.

Conclusions: Although literature is replete with accelerating techniques, there are still uncertainties and unanswered questions towards most of these techniques and, hence, further research is needed to support the evidence for the enhancement of orthodontic tooth movement.

KEY WORDS

tooth acceleration, orthodontic treatment, enhanced orthodontic movement

INTRODUCTION

Orthodontic treatment is often described as a lengthy procedure since the average time for a successful orthodontic treatment ranges between 18 to 24 months¹⁾. Prolonged orthodontic treatment involves many disadvantages such as psychosocial effects on the patients, white spot lesions, permanent enamel damage, gingival recession, and root resorption^{2,3)}. Therefore, methods of accelerating orthodontic tooth movement (OTM) aim at shortening the treatment duration and minimizing these adverse effects.

Researchers have examined whether it is feasible to move a tooth faster than rates achieved by using conventional methods. Most attempts to accelerate tooth movement can broadly be categorized into surgical and non-surgical approaches⁴⁾. An increase in knowledge and development of the alveolar topography has been the main aid in acceleration of orthodontic tooth movement. Corticotomies and multiple tooth osteotomies have been the main surgical ways to assist rapid tooth movement⁵⁾. Other surgical methods include micro-osteoperforations, piezocision, and periodontal ligament (PDL) distraction. Although many surgical techniques have shown to yield promising outcomes, the limited application was due to their invasiveness^{6,7)}.

Non-surgical methods include the use of self-ligating brackets, medications, microvibrations, low-intensity laser, photobiomodulation, electromagnetic fields, and direct electrical currents⁷⁾. Debate is ongoing whether surgical or non-surgical methods are clinically effective in producing faster rates of OTM as compared with the conventional techniques. Therefore, this paper aims to review and highlight the evi-

dence-based successful techniques used for acceleration of orthodontic tooth movement, and evaluate the hard and soft tissue responses to the various methods advocated in the literature.

PERIODONTAL AND BONE RESPONSE TO OTM

During OTM, many changes occur in the tooth supporting tissues depending on amount, direction, and duration of the force applied, as well as the age and growth status of the patient. The orthodontic treatment is based on the principle that if prolonged light pressure is applied to a tooth, tooth movement occurs as the bone around the tooth remodels. The bone is selectively removed in some area (compression site) and added to other areas (tension site) resulting in tooth movement. Because bone response is mediated by periodontal ligament, tooth movement is primarily a periodontal ligament (PDL) phenomenon expressed by alterations in blood flow through PDL as the flow decreases on the compression side and increases on the tension side (Figure 1)⁸⁾. The use of a light force is valuable as the application of excessive forces causes pressure on the PDL and investing bone leading to diminished blood supply and bone necrosis⁹⁾. This is followed by delayed tooth movement for few weeks until osteoclastic differentiation within adjacent bone marrow space induces "undermining resorption" that removes the lamina dura next to the compressed PDL¹⁰⁾.

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RATE OF ORTHODONTIC TOOTH MOVEMENT

Research has shown that the rate of biological tooth movement following an optimal mechanical force application is about 1.0 - 1.5 mm in 4 - 5 weeks¹². Tooth movement can occur at different rates and individuals show different responses to treatment depending on many factors including magnitude and duration of force, quality of bone trabeculae, patient age, number and shape of roots and type of tooth movement. The response to orthodontic force is expected to be delayed in elderly patients compared to growing children due to the less dense alveolar bone and more cellular PDL in the children¹³. In addition, teeth in the maxillary arch are more responsive to orthodontics than those of the mandible because the maxilla is primarily composed of trabecular bone, which exhibits faster resorption than dense cortical bone. The rate of tooth movement is also affected by the type of movement as teeth move faster by tipping than by translation¹⁴.

METHODS OF ACCELERATION OF OTM

Non-surgical methods for the acceleration of OTM

These techniques have always been preferred by both the clinicians and the patients. All these approaches have shown acceptable outcomes with varying degrees of success.

I. Biological approach

This includes chemical substances, neurotransmitters, and medications. Many of these factors have been involved in OTM acceleration research and the effect of their local and/or systemic administration has been tested, mainly in animal models, with variable results.

I) Systemic/Local Administration of Biological Substances and Hormones

These factors work by stimulating the activity of osteoclasts either indirectly, by stimulating the expression of RANKL on osteoblasts, or directly by affecting osteoclast and osteoblast functions. However, these factors are rapidly flushed by blood circulation so daily systemic administration or daily injection is needed, necessitating several doses per day¹⁵. These factors include:-

A) Epidermal Growth Factor (EGF) is a small polypeptide growth factor found in a variety of tissues (kidney, submandibular glands) and body fluids (saliva, amniotic fluid) that primarily stimulate proliferation and differentiation of epithelial and mesenchymal cells¹⁵. It has been demonstrated that EGF has catabolic effects on bone. An organ culture study found that administering a high dose of EGF to rats caused an elevation of osteoclast cell density on the trabecular bone surface and stimulated bone resorption¹⁶. Local injection of EGF (encapsulated in liposomes) into the root furcation region of the maxillary left first molar after elastic band insertion induced greater osteoclast recruitment¹⁵.

B) Cytokines are soluble, small proteins that are produced by immune system cells, which modulate the cellular activity and play an important role in the bone remodeling processes *in vivo*¹⁷. The inflammatory cells that produce cytokines are osteoblast, fibroblast, endothelial cells and macrophages¹⁸. Cytokines, particularly Interleukin-1 alpha and 1 beta, Tumor Necrosis Factor, Gamma Interferon have been implicated in the mediation of bone remodeling process *in vitro*¹⁹. The first experimental evidence was that after the application of a tipping force, Interleukin - 1 was found in the periodontal tissues of cat canine teeth. RANKL, which is a membrane-bound protein on the osteoblasts, is a cytokine involved also in the acceleration of OTM that binds to the RANK on the osteoclasts and causes osteoclastogenesis²⁰.

C) Prostaglandins are lipid autacoids synthesized by arachidonic acid by the action of cyclooxygenase (COX)²¹.

Prostaglandin E is one of the most widely studied agents in animal and clinical models, which reported that prostaglandin E1 (PGE1) and prostaglandin E2 (PGE2) stimulated bone resorption, directly acting on osteoclasts²². Previous studies have shown that injections of exogenous PGE2 over an extended period of time accelerated OTM. However, it was found that the local injection of different concentrations and num-

bers of PGE2 alone caused root resorption, while the administration of PGE2 with calcium stabilized root resorption with acceleration of OTM^{22,23}.

D) Parathyroid Hormone (PTH) is secreted by parathyroid gland and plays a significant role in influencing bone remodeling and serum calcium level; by increasing the concentration of calcium in the blood, it stimulates bone resorption¹⁶. It has been shown that it is more advantageous to administer PTH locally than systemically as local injection causes local bone resorption, and the slow-release application is efficient as this keeps the local concentration of PTH for a long time. Chronic elevation of PTH leads to pathological effects on the kidneys and bones; consequently, the safety and efficiency of this factor in accelerating orthodontic movement need to be further investigated¹⁶.

E) Thyroxin and Calcitonin are hormones released by thyroid gland, which play an important role in regulation and reabsorption of calcium. It has been demonstrated that locally injected Thyroxin increased the rate of tooth movement by activating osteoclasts¹⁸.

F) Relaxin is a naturally occurring hormone with a primary function of widening the pubic ligaments during childbirth and has many other functions such as collagen turnover, angiogenesis and anti-fibrosis effects. It is thought that relaxin might accelerate orthodontic tooth movement through inducing alterations in the PDL²⁴. Local administration of human relaxin in rats accelerated OTM rate, but at the expense of inducing changes in the level of PDL organization and reducing its mechanical strength with a marked increase in tooth mobility¹⁶.

G) 1,25 dihydroxycholecalciferol (Vitamin D3 or Calcitriol) is a biologically active form of vitamin D and plays an important role in calcium homeostasis²⁵. The first *in vivo* study to examine the effect of locally injected calcitriol in accelerating OTM was conducted on humans by accelerating canine distalization. On clinical efficacy basis, the dose of 25 pg calcitriol produced about 51% faster rate compared to control side, while each of the 15 pg and 40 pg doses resulted in about 10% accelerated OTM. In addition, the periapical radiographs did not show any damaging effect of calcitriol to the surrounding tissues²². A comparison between local injection of vitamin D and PGE2 in two different groups of rats showed no significant difference in acceleration between the two agents. However, the number of osteoblasts on the pressure side in the group injected with vitamin D was greater than in the PGE2 group. This indicates that vitamin D may be more effective in bone turnover²⁶.

II) Neurotransmitters

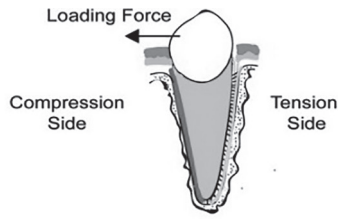
The neurons originating from trigeminal ganglion supply dental and periodontal tissues. These neurons contain many neuropeptides such as substance P, Calcitonin gene-related peptide (CGRP) and vasoactive intestinal polypeptide (VIP); all these neurons are passive under neutral conditions. Mechanical force application during orthodontic treatment induces the release of active proteins, which in turn cause local inflammation and release of these neuropeptides¹⁸. These neuropeptides can increase the vascular permeability and affect the bone remodeling directly²⁰.

III) Medications

The medications that influence OTM are divided into four main categories:-

A) Non-steroidal anti-inflammatory drugs (NSAIDs) are used to overcome the pain and discomfort following application of mechanical force to the teeth during orthodontic treatment. The mechanism of action of these drugs is inhibition of the prostaglandins (PGs) synthesis since the latter are responsible for hyperalgesia. Although chemically disparate, they produce therapeutic effects by ability to inhibit the activity of Cyclooxygenase enzymes (COX-1, COX-2)²⁷. Many studies were conducted to investigate the effects of NSAIDs on OTM, with the consistent findings of reducing the rate of OTM. However, these effects were premised on short-term administrations; moreover, the results varied depending on the dose and frequency of administration of these drugs¹⁸. It has been reported that the NSAIDs slow the tooth movement because they inhibit the inflammatory reaction produced by PGs. The whole process is controlled by inhibition of cyclooxygenase (COX) activity, leading to altered vascular and extravascular matrix remodeling, causing a reduction in the rate of tooth movement²⁸.

B) Acetaminophen (Paracetamol) is not involved under NSAIDs and lacks anti-inflammatory effects, though it has almost a similar



	Compression	Tension
Increase	Cox2 → PGE ₂ → RANKL TNF α MMPs eNOS → NO IL-1 β	IL-10 → OPG TGF β TIMPs iNOS → NO
Decrease	OPG	RANKL
Outcome	↑ Osteoclasts ↑ Resorption ↓ Apposition	↓ Osteoclasts ↓ Resorption ↑ Apposition

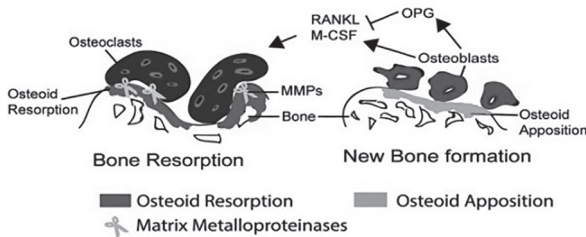


Figure 1: Biological response to orthodontic force¹¹.

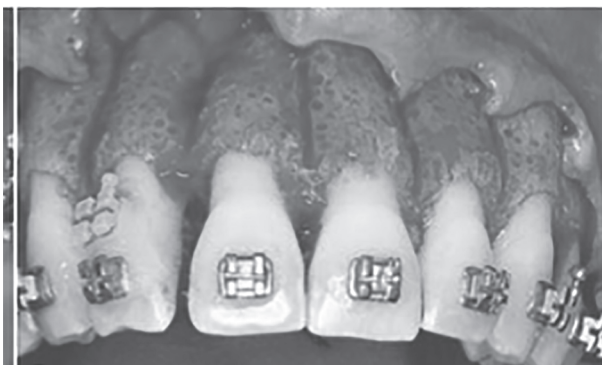


Figure 2: Corticotomy cuts¹⁰.



Figure 3: Micro-osteoperforations through alveolar bone⁷

chemical structure. Studies have shown that there is no significant adverse effect of paracetamol on rate of OTM, hence, it can be considered as the most commonly used and safe drug for pain management during orthodontic treatment¹⁸.

C) **Corticosteroids** have been shown to have an inhibitory effect on bone formation. They may increase tooth movement rate, and because

the formation of new bone is slowed in a treated patient, they decrease the stability of both tooth movement and orthodontic treatment outcome²⁸.

D) Bisphosphonates (BPNs) have a direct effect on calcium homeostasis and bone metabolism. Studies have shown that BPNs have an inhibitory effect on orthodontic tooth movement, thus delay the tooth movement. On the other hand, topical application of BPNs could be helpful in anchoring and retaining teeth under orthodontic treatment²⁸.

2. Device-assisted treatment

This depends on the idea that applying orthodontic forces causes bone bending and a bioelectrical potential develops. This approach includes:-

A) **Direct light electric current.** It has been demonstrated that electric current application (about 20 μ A for 5 h daily) was capable of accelerating orthodontic tooth movement. It was reported that external electricity enhances osteogenesis around the negative electrode when the current level is between 5 and 20 μ A, while resorption of bone may occur around the positive electrode (anode)¹⁶. However, the use of this method is less popular than other methods as the existing evidence is insufficient to support whether electrical current could be effective in accelerating OTM with safety in humans.

B) **Low level laser therapy (LLLT).** The advantages of this method are non-invasiveness, ease of use, and localized action. Studies have shown that LLLT increases osteoblastic activity, vascularization, and organization of collagen fibers²⁹. It enhances the proliferation of osteoclasts, osteoblasts and fibroblasts, thus affects bone remodeling and accelerates tooth movement by the production of ATP and activation of cytochrome C. Aluminum-gallium-arsenide (Al-Ga-As) diode lasers are most currently used for these interventions and have a deep tissue penetration in comparison to other modalities, hence providing the clinicians with a suitable penetrative instrument with great efficiency and minimal side effects¹⁶.

A recent clinical study showed that the laser wavelength in a continuous wave mode at 800 nm with an output of 0.25 mW and exposure of 10 s accelerated tooth movement at 1.3 fold³⁰. However, more research is needed to establish the most efficient protocol that would enhance the effect and reduce the frequency of irradiation sessions.

C) **Resonance vibration.** The application of resonance vibration (60 Hz) to the first molars in rats for 8 minutes per a week during orthodontic movement increased tooth movement by 15% compared with the controls by stimulating expression of RANKL and osteoclastic differentiation in the PDL. There was no collateral damage to the periodontal tissues or root resorption of the treated teeth due to the natural frequency of the vibration applied³¹. In another study, the combination of light orthodontic force with vibratory stimuli using an electric toothbrush enhanced secretion of IL-1 β in gingival crevicular fluid, bone resorption activity, and accelerated tooth movement³². However, the use of ultrasonic vibration was associated with certain hazards as it may cause thermal damage to the dental pulp¹⁶.

D) **Static or pulsed magnetic field.** Histological analyses have shown that magnetic fields influence and activate the alveolar bone remodeling. Hyalinization in the PDL was decreased in the presence of static magnetic field, which also contributed to accelerated tooth movement¹⁶. In a study conducted on 10 orthodontic patients who needed canine retraction, the canines were exposed to a pulsed electromagnetic field (1 Hz) after extraction of first premolars, canine retraction was accelerated 1.57 \pm 0.83 mm more than the control group³³. However, another study showed that the magnetic Field increased root resorption of the treated teeth and increased width of the PDL, raising concerns about the effectiveness and safety of this method³⁴.

SURGICAL METHODS FOR THE ACCELERATION OF OTM

These techniques are clinically effective and have been used for adult patients, as the bone turnover increased after bone grafting, fracture, and osteotomy. These techniques include:-

Inter-septal alveolar surgery. This surgical approach is called distraction osteogenesis, which involves distraction of PDL or distraction of the dentoalveolar bone. For rapid canine retraction (after the extraction of the first premolar), the interseptal bone distal to the canine

is undermined 1 to 1.5 mm in thickness and the socket is deepened to the length of the canine. The retraction of the canine is carried out by the activation of an intraoral device directly after the surgery. In this concept, the compact bone is replaced by the woven bone and tooth movement is easier and quicker due to the reduced resistance of the bone³⁵. It has been reported that this technique accelerates tooth movement without causing significant root resorption, ankylosis or root fracture. However, some results showed concerns regarding the vitality of the retracted canines after six months of retraction³⁵.

Osteotomy and corticotomy. Osteotomy is defined as a surgical cut involving both the cortical and trabecular bones. Corticotomy, on the other hand, is a surgical cut (Figure 2) through the cortical bone only, perforated or mechanically altered in a controlled surgical manner³⁶. The surgical cuts are conducted by using micromotor under irrigation, or piezosurgical instruments³⁰.

In a study that involved surgical holes technique for canine distalization, it was shown that the corticotomy-assisted canine distalization demonstrated 42.6% greater net canine distalization than the non-surgical side⁵. It has been reported that traditional vertical and horizontal osteotomies impose an increased risk of postoperative tooth devitalization or even bone necrosis, depending on the severity of injury to the trabecular bone. There is also an increased risk of periodontal damage, mainly in cases in which the interradicular space is less than 2 mm³⁶. Corticotomy is one of the most common surgical procedures that is used to reduce orthodontic treatment time as the surgical cut through the cortical bone rather than medullary bone reduces the resistance of the cortical bone and accelerates tooth movement.

Piezocision. Piezocision-assisted orthodontics is an innovative, minimally invasive surgical procedure designed to accelerate OTM while correcting/preventing mucogingival defects by adding bone and/or soft tissues³⁶. Advantages are minimum invasiveness and better patient compliance. Disadvantages are risks of damaging roots, as incisions and corticotomies are conducted blindly³⁰.

Micro-osteoperforations (MOP) (Figure 3). In a single center, single-blinded study to investigate this procedure on humans, it was found that MOPs significantly increased the rate of canine retraction 2.3 fold compared to the control group by increasing the expression of cytokines and chemokines, which are known to recruit osteoclast precursors and stimulate osteoclastic differentiation³⁷.

DISCUSSION

Nowadays, the majority of orthodontic patients are demanding for a safer and shorter orthodontic treatment duration, especially when considering adult orthodontics³⁸. Success achieved from foremost trials encouraged the development of various surgical and non-surgical techniques, with emphasis to minimize the adverse effects.

The rate of OTM is determined by bone remodeling, which is a result of inflammatory processes in response to application of orthodontic forces. Increasing the applied force in order to accelerate OTM is proven useless because this approach led to many adverse effects including ankylosis, arrested tooth movement within the alveolar bone and root resorption rather than tooth motion acceleration. Alternatively, research was directed towards introducing local mediators or injuries to the alveolar bone in an attempt to reduce orthodontic treatment time. The systemic administration of medicines/chemical substances carries the risk of systemic side effects^{18,39}.

Being less invasive, non-surgical methods represent the most preferable approach by the patients; yet methods requiring local injections impose discomfort to the patients due to the painful needle injection³⁹. Local administration of vitamins and hormones, e.g. calcitriol and parathyroid hormone, is effective in accelerating tooth motion; however, monitoring the systemic level is mandatory as long-term elevations can adversely affect other organs²². In addition, further research is needed to determine the safest dosage potency, dosage form suitable for administration, and proper frequency of administration.

In spite of attempting a wide variety of device-assisted treatments, evidence is insufficient so far to justify their popular use in the daily-based clinical practice⁴⁰. A novel cyclical force device premised on ultrasonic vibration, named *Accele-Dent*, has been studied with claims that it may increase the rate of OTM. This device delivers a high-frequency vibration (30 Hz) to the teeth for approximately 20 minutes per day to enhance tooth motion, yet the reduction in treatment time was non-significant without evidence about the long-term biological or clinical effects of the device^{10,40}.

Different wavelengths and energy outputs of laser devices have

been tested in different studies. Kawasaki and Shimizu (2000) reported that orthodontic movement of low-intensity laser-irradiated rat teeth was 30% faster than that of the teeth in a control non-irradiated group of rats⁴¹. Clinical studies in humans have also revealed a significantly positive effect of low-intensity laser radiation on the acceleration of OTM^{39,42}. However, more research is needed to establish the most efficient protocol that would enhance the effect and reduce the frequency of irradiation sessions.

The surgical approach provides favorable long-term effect and can be utilized in a regular clinical setup without the need for general anesthesia. Surgical intervention or corticotomy was successfully used for rapid canine retraction without increasing the risk of root resorption and localized osteoporosis⁵. Nevertheless, the invasive nature of these techniques, possible injury to vital tissues, and the cost limited their popular use. Corticotomy complications include whitening of the gingiva after reflection of large flaps and fenestration of incisor roots after labial movement of these teeth, which may take place even after placing particulate bone grafts. The invasiveness of the corticotomy procedures constituted a serious drawback for their widespread acceptance among orthodontists and patients. Therefore, more conservative flapless corticotomy-restricted techniques are recommended¹⁰. It has also been reported that vertical and horizontal osteotomies increase the risk of postoperative tooth devitalization or even bone necrosis, depending on the severity of injury to the trabecular bone. There is also an increased risk of PDL damage, mainly in cases in which the interradicular space is less than 2 mm³⁹.

Piezocision seems to be less discomforting method compared to other surgical procedures and this might render them more commonly used procedures in future³⁵. However, evidence is needed to investigate its suitability for different age groups and examine the potential long-term side effects. The piezocision procedure that initiates the regional acceleratory phenomenon may increase the iatrogenic root resorption when used in conjunction with orthodontic forces. Piezocision applied close to the roots may cause iatrogenic damage to the neighboring roots and should be used with caution⁴³.

Finally, more studies and investigations on humans are mandatory to understand all aspects and nature of mechanisms behind the acceleration of OTM by either enhancing the effectiveness of existing methods or developing new techniques with a higher clinical efficiency, lowest side effects, cost-benefit and more comfortable to the patient.

CONCLUSIONS

1. Successful finishing of orthodontic treatment within a short period of time is still a relatively new horizon. Decisions on which method to be used depend largely on the orthodontist's preference, patient's acceptance and willingness; taking into consideration the cost, age and general health status of the patient.

2. The most recent and the least invasive methods like lasers, mechanical vibration, piezocision and microosteoperforations provide favorable results with a minimal side effect, unlike the aggressive surgical methods that accelerate tooth movement effectively but induce unfavorable effects locally or systemically.

3. Randomized controlled studies are required to compare between different methods and identify the best techniques to shorten orthodontic treatment time with minimal potential side effects.

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