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Acceleration of the Orthodontic Tooth Movement

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بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

۞ وَعِندَهُۥ مَفَاتِحُ ٱلْغَيْبِ لَا يَعْلَمُهَآ إِلَّا هُوَ ۚ وَيَعْلَمُ مَا فِى ٱلْبَرِّ
وَٱلْبَحْرِ ۚ وَمَا تَسْقُطُ مِن وَرَقَةٍ إِلَّا يَعْلَمُهَا وَلَا حَبَّةٍ فِى ظُلُمَٰتِ
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صَدَقَ ٱللَّهُ ٱلْعَظِيمُ

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Dedication

To my parents who were their for me in every step of the way with their have love and support…

To my supervisor for his guidance, help and endless support throughout this project…

Mohamed

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Introduction

The term tooth movements based on the principle that if prolonge pressure is applied to the tooth, tooth movement will occur as the bone around tooth remodels that it mean bone is selectively removed is some areas and added in others; so when force is applied to he crown of tooth it is transmitted through the root of the tooth to the periodontal ligament (PDL) and alveolar bone and will lead to tooth movement. Orthodontic tooth movement is typically divided into three phases by clinical observation: the initial phase, the lag phase, and the postlagphase . The initial phase occurs 24–48 h after force application. The lag phase lasts multiple days with little tooth movement. The post-lag phase is when clinically noticeabletooth movement is observed.The alveolar bone, periodontal ligament (PDL)and cementum are intimately related structures in development and functions. Collectively, they form the periodontium that is of critical relevance not only to orthodontic tooth movement, but also periodontal disease. The PDL connects the cementum to the alveolar bone by bundles of type I collagen named Sharpey's fibers. The width of a periodontal ligament in homeostasis is approximately 0.15–0.38 mm, depending on the tooth type. The PDL has two primary functions: (1) to transmit and absorb mechanical stress and (2) to provide vascular supply and nutrients to the cementum, alveolar bone and the PDL itself .Alveolar bone is a mineralized connective tissue and consists of mineral tissue, organic matrix and water. Orthodontic tooth movement is achieved by remodeling processes of the alveolar bone, which are triggered by changes in the stress/strain distribution in the periodontium. Acceleration orthodontic tooth movement can reduce treatment duration and risk of side effects. While acceleration of the orthodontic tooth movement by surgical techniques has been shown to be effective for decades, noninvasive and nonsurgical methods have always been preferred by both the clinicians and the patients. These techniques have ranged from application of biological molecules to innovative technologies such as resonance vibration, cyclic forces, light electrical currents, magnetic field forces, low-intensity laser irradiation and low-level light therapy. Endogenously produced biological have been tested based on their roles in the turnover of alveolar bone in response to orthodontic tooth movement as well as during wound healing. The premise behind this approach is that these exogenously applied compounds will mimic their counterparts produced in vivo. Meanwhile, technologies tested so far target these pathways for the acceleration of the orthodontic tooth movement. All these approaches have shown favorable outcomes with varying success. This presents the current knowledge and a discussion over their limitations with an emphasis on the mechanism of action for each technique.

Surgical techniques for the acceleration of the orthodontic tooth movement have been tested for more than 100 years in clinical practice. Since original methods have been extremely invasive and have been associated with increased tooth morbidity and various other gaps, the research in this field has always followed an episodic trend. Modern approaches represent a well-refined strategy where the concept of the bony block has been abandoned and only a cortical plate around the orthodontic tooth movement has been desired. Selective alveolar decortication has been a reproducible gold standard to this end. Its proposed mechanism has been the induction of rapid orthodontic tooth movement through the involvement of the periodontal ligament. More recent techniques included further refinement of this procedure through less invasive techniques such as the use of piezoelectricity and corticision. Orthodontic tooth movement, in these cases, can synchronize with tissue-engineering principles of periodontal regenerative surgery in order to create rapid orthodorthodontic movement and overcome its side effect.

Methods of Acceleration of the Orthodontic Tooth movement

1. Nonsurgical Methods for the Acceleration of the Orthodontic Tooth Movement

1.1 Systemic/Local Administration of Chemical Substances

A. Epidermal Growth Factor

It has long been demonstrated that epidermal growth factor (EGF) has catabolic effects on bone. In an organ culture study, high concentrations of EGF stimulated bone resorption in fetal rat long bone [(1)]. Administration of EGF at high doses to rats caused an elevation of osteoclastic cell density on the trabecular bone surface. Consistently,in transgenic mice overexpressing human EGF, thinner bones were observed [(2)], suggesting an imbalance in bone modeling or remodeling. In fact, exogenous EGF administration had an additive effect on the rate of osteoclast recruitment producing faster bone resorption and tooth movement. Recently, it has been shown that EGF plays a role in mediating the ability of human bone marrow stromal cells to induce osteoclast differentiation [(3)]. Moreover, the regulatory role of EGF in fibrous tissue remodeling in the periodontal ligament (PDL) has also been demonstrated. Moreover, EGF has also been identified as a participant in the bone-remodeling process during orthodontic movement [(4)].

B. Parathyroid Hormone

Parathyroid hormone (PTH) is the major hormone regulating bone remodeling and calcium homeostasis. By increasing the concentration of calcium in the blood, it stimulates bone resorption [(5)].Although continuous elevation of PTH leads to bone loss, intermittent short elevations of the hormone level can be anabolic for bone [(6)].

Experimental andclinical data has shown that daily administrations of PTH led to increases in bone mass, mineral density and strength [(7)].The effect of PTH on orthodontic tooth movement has been studied in rats [(8)]. A significant stimulation of the rate of orthodontic tooth movement by exogenous PTH administration appeared to occur in a dose-dependent manner. However, this effect was only visible when the hormone was more or less continuously applied, either by systemic infusion [(8)] or frequent local delivery.It is well known that chronic elevation of PTH leads to pathological changes in multiple organs, especially the kidneys and bones [(8)] .local injections of PTH in slow-release formulations did not significantly affect the rate of tooth movement in animals. Consequently, the safety and efficiency of this systemic factor in orthodontic movement acceleration remain to be further investigated.

C. Dihydroxyvitamin D 3

Another agent that has been identified as an important factor in orthodontic tooth movement is 1,25-dihydroxycholecalciferol (1,25-DHCC) [(9)] . This agent is a biologically active form of vitamin D and has a potent role in calcium homeostasis. Animal studies have demonstrated that local injections of 1,25-DHCC accelerate orthodontic tooth movement by about 1.2- to 2.5-fold [(9)] . Histological examinations also showed that 1,25-DHCC stimulates the formation of osteoclasts in a dose-dependent manner andcauses significantly more alveolar bone resorption[(9)] . No obvious clinical, microscopic or biochemical side effects have been noted until now,but the safe use of this systemic factor in orthodontic movement should be further investigated.

D. L- Thyroxine

Thyroid hormones play an imperative role in the regulation of cellular metabolism, proliferation and differentiation [(10)]. L -Thyroxine is a synthetic thyroid hormone that is chemically identical to thyroxine,Whichis naturally secreted by the thyroid gland and has been used to treat thyroid hormone deficiency. Hyperthyroidism or thyroxine medication can lead to osteoporosis [(11)]. Because of the ability of thyroid hormones to act on the metabolism of nearly every cell in the body and especially of their indirect involvement in bone turnover , the possible effect of 80 -thyroxine on orthodontic tooth movement has also been examined [(12)] in a relevant study on rats. The results showed that administration of 20 μg/kg i.p./day L -thyroxine significantly increased the amount of orthodontic tooth movement. Its use is still on an experimental level in animal models, and no human trials have been conducted so far.

E. Osteocalcin

Osteocalcin (OC) is the most abundant noncollagenous matrix proteinin bone [13]. In studies in rats, it was demonstrated that local injections of purified rat OC accelerated the rate and increased the total amount of tooth movement [13]. Histological examination revealed that this acceleration of tooth movement was caused by an enhanced recruitment of osteoclasts.No other side effects were reported, and no apparent macroscopic inflammation could be detected at the injection sites.

F. Prostaglandins

Prostaglandins (PGs) are an interesting group of multifunctional regulators during orthodontic tooth movement. These lipids are synthesized by arachidonic acid by the sequential actions of cyclooxygenase (COX) and respective synthases. The clinical effect of exogenous PGs on orthodontic tooth movement has been an object of research for a lot of years. Several animal studies have concluded on the fact that local application of PGE 1 , PGE 2 , analogs of PGE 1 , PGE 2 or thromboxane A 2 can increase the speed of orthodontic tooth movement [14] .

Local submucosal injections of PGE 1 in patients were also successful in accelerating orthodontic tooth movement by 1.6-fold. The main side effect associated with local injection of PGs is hyperalgesia, due to the release of noxious agents such as histamine, bradykinin,serotonin, acetylcholine and substance P, from nerve endings both peripherally and centrally [15] . This indicates that although PGs enhance the tooth movement process, their side effects are still too serious to consider it clinical use in orthodonticpatients. Recent research trends are directed towards combining local anesthetics withPGs, in order to reduce pain while injected locally, but research in this regard is still in its preliminary phase.

1.2. Gene Transfer Therapy

In this way, higher and more constant levels of protein expression can be produced in a certain area. Local tooth movement accelerating factors can be 'administered' with this technique. The advantages in this case are that the local concentration of the active factor remains effective due to itscontinuous production by the treated cells and that systemic side effects are avoided at the same time [16] .The role of cytokines of the receptor activator of nuclear factor κ ligand

(RANKL)-RANK/osteoprotegerin (OPG) system in inducing bone remodeling has already been demonstrated [17]. A previous study in rats demonstrated that transfer of the RANKL gene to a periodontal tissue activated osteoclastogenesis and accelerated orthodontic tooth movement without producing any systemic effects [18].Iglesias-Linares et al.[19] also demonstrated in a more recent study that RANKL gene transfer was a more efficient technique for the reduction of total treatment duration in comparison to alveolar corticotomy.

1.3. Relaxin

Relaxin is a naturally occurring hormone with the primary function of widening the pubic symphysis during childbirth and has been proven to be present in craniofacial structures, such as calvarial sutures [20] .The latter actions suggest that relaxin might influence orthodontic tooth movement through alterations of the PDL [21].

In a study in rats, Liu et al. [22] examined the effect of a local administration of human relaxin in orthodontic tooth movement. According to their results, relaxin had a positive influence on the orthodontic movement rate. Nevertheless, in another rat model study, Madan et al. [21]reportedthat relaxin does not affect either the rate or the amount of tooth movement.McGorray et al. [23] reported, in a randomized, blinded clinical trial in human subjects comparing a group who received relaxin injections weekly for 8 weeks with those who received placebo injections that the pattern and amount of tooth movement did not differ. However, they also stated that the local doses of relaxin might have been too low to affect tooth movement. Based on these results, it is more likely that relaxin would find its most significant clinical application in reducing the tendency for post orthodontic tooth relapse and not in the enhancement of orthodontic tooth movement.

1.4. Resonance Vibration

Resonance vibration is based on a frequency equal to the natural frequency of an object, causing the largest amplitude of vibration of this object. The initial response of cells to mechanical stress in vitro appears within 30 min [24] . In a recent study, Nishimura et al.[25]attempted to activate these initial responses at the cellular level by applying resonance vibrational stimulation to a tooth and its periodontal tissue. The applied resonance vibration (60 Hz) to the first molars in rats for 8 min, once a week during orthodontic movement. According to their results, resonance vibration increased tooth movement by 15% compared with the controls, stimulating more expression of RANKL and osteoclast formation in the PDL. Due to the natural frequency of the vibration applied, there is no collateral damage to the periodontal tissues or root resorption of the treated teeth.

Ultrasonic vibration is also a form of vibrational stimulation that is similar to resonance vibration. It has been reported that ultrasonic vibration accelerates tooth movement too [(26)]. However, ultrasonic vibration of teeth might be associated with certain hazards, such as thermal damage to the dental pulp.

Recently, a novel cyclical force device, 'Accele- Dent', has been marketed, with claims that it may increase the rate of orthodontic movement. However,it provides vibration with only one fixed frequency (4 Hz), and there is still no peer-reviewed or long- term study on the biological or the clinical effects of the appliance [(27)].

1.5. Electrical Currents

Another tool that has been used in order to accelerate orthodontic tooth movement is electricity. Since the early observation of Fukada and Yasuda[(28)]that electric potentials are generated by the application of force to bone, many investigators used external electricity to enhance osteogenesis. It was demonstrated that when electrodes are placed into bone osteogenesis will occur around the negative electrode when the current level is between 5 and 20 μA, while resorption of bone may occur around the positive electrode (anode).In a clinical study with orthodontic patients, Kim et al. [(29)] also demonstrated that an electrical current (20 μA for 5 h daily) was capable of accelerating orthodontic tooth movement. Currently, the existing level of evidence is not enough to support whether electrical current could be effective in accelerating orthodontic tooth movement with safety in humans [(30)].

1.6. Static or Pulsed Magnetic Field

Magnetic fields, including static magnetic field [(31)] and pulsed electromagnetic field [(31)], have been proven to increase the speed of orthodontic tooth movement in animal studies. Histological analyses have suggested that alveolar bone remodeling is activated under the influence of magnetic fields as activities of bone cells are elevated, and new bone deposition is increased on the tension side [31]. Hyalinization in the PDL was also reduced in the group treated with the static magnetic field, which also contributed to accelerated tooth movement .According to a more recent study in orthodontic patients, exposure of canines to a pulsed electromagnetic field (1 Hz), during their retraction to first premolar extraction sites, had as a result the acceleration of their movement [32]. However, there were also studies that not only did not agree with the above results in terms of tooth movement rate, but also reported increased root resorption of the treated teeth, prompting concerns about the effectiveness and safety of this method [33]. Therefore, further studies are required to determine the effect of magnetic fields on tooth movement.

1.7. Low-Intensity Laser Irradiation Therapy

Various biostimulatory effects of LILT have been shown, including effects on wound healing, fibroblastic and chondral proliferation, collagen synthesis and nerve regeneration. In particular, the acceleration of bone regeneration by laser treatment has been the focus of many studies [34] . In the field of orthodontics, low-energy laser irradiation has been utilized for several types of orthodontic applications, such as the reduction of postappliance adjustment pain [35] or the treatment of traumatic ulcers in the oral mucosa [36].

Aluminum-gallium-arsenide (Ga-Al-As) diode lasers are the ones that are currently most used for these interventions and have been proven to have a higher depth of tissue penetration in comparison to other modalities, therefore providing the clinicians with a suitable penetrative instrument with great efficiency [37]. Saito and Shimizu [38] observed that LILT with a Ga-Al-As infrared diode laser device (wavelength. 830 nm. continuous wave at 100 mW. power density. 35.3 J/s/cm 2) can accelerate bone regeneration in the midpalatal suture of rats during rapid palatal expansion and stimulate the synthesis of collagen, which is the major matrix protein in bone. They also used a Ga-Al-As infrared diode laser device (wavelength. 830 nm. output power. 100– 700 mW, variable. total energy corresponding to a 9-min exposure. 54.0 J). Enhanced bone formation was observed on the pressure side and an increased number of osteoclasts on the compression side, logically as a result of cellular stimulation promoted by low-energy laser irradiation.On the other hand, Limpanichkul et al. [39] reported that

LILT with the use of Ga-Al-As (wavelength. 860 nm. continuous wave power output. 100mW. power density. 1.11 W/cm 2. energy dose. 2.3 J/point. energy density. 25 J/cm 2 / site) was too low to express either a stimulatory effect or inhibitory effect on the rate of orthodontic tooth movement. Cruz et al. [40] were the first to publish research results on the effect of LILT on the duration of dental movement in humans. They conducted a split-mouth design study with 11 subjects, between 12 and 18 years of age, who received mechanical activation for the retraction of their upper canine teeth in the space of extracted premolars every 30 days. Since then, more clinical studies in humans have also revealed a significantly positive effect of low-intensity laser radiation on the acceleration of orthodontic tooth movement. In the case of clinical studies in humans, the subjects were mainly adolescents and young adults, between 12 and 23 years of age. No studies in older adults have been published.

1.8. Photobiomodulation or Low-Level Light Therapy

Photobiomodulation is an emerging medical and dental technique in which exposure to light or LEDs stimulates cellular function leading to beneficial clinical effects. This technique is known as low-level light therapy or LLLT. A Ga-Al-As diode laser produces coherent light, whereas the light produced by the LED is incoherent. This technique has been based on the fact that cytochrome oxidase c or complex IV – an enzyme which mediates the synthesis of ATP in cells – is upregulated by infrared light. During tooth movement, higher ATP availability boosts cell metabolism, leading to an increased remodeling process and accelerated tooth movement [41].LLLT may also be enhancing orthodontic tooth movement due to increased vascular activity, which is also promoted by light [42] and contributes to a more rapid bone turnover.Previous studies have shown that the impact of the LLLT is also dependent on the wavelength and intensity of the emitted light [43]. The results of a large multicenter clinical trial in 90 orthodontic patients, aged from 10 to 36 years of age, however, demonstrated that when photobiomodulation was applied (wavelength. 850 nm. power density. 60 mW/cm 2 for 20/day or 30/day or 60 min/week. total energy densities. 72, 108 and 216 J/cm 2), the rate of tooth movement significantly increased during the initial alignment phase. In particular, the rates of tooth movement in the alignment phase were 1.12 mm/week for those in the photobiomodulation treatment group compared to 0.49 mm in the control group.

2. Surgical Methods for the Acceleration of the Orthodontic Tooth Movement

2.1. Alveolar Osteotomy-Assisted Tooth Movement

Osteotomy is defined as a surgical cut through both the cortical and trabecular bones. This term is frequently used when describing the creation of bone segments.

In orthodontics, osteotomies have been used to enhance and accelerate tooth movement. In 1893, Cunningham presented 'Luxation, or the immediate method in the treatment of irregular teeth' at the International Dental Congress inChicago. He used mesial and distal interseptal osteotomies to reposition palatally inclined maxillary teeth and stabilized them in correct occlusion with wire ligatures or metal splints. The most important feature was the fact that this combined active surgical-orthodontic treatment reduced the procedure time to one third that of conventional treatment and allowed more predictable treatment in older patients [44].

In the 1950s, kole [45] introduced his 'bony block' technique, a surgical procedure involving both osteotomy and corticotomy to accelerate orthodontic tooth movement, based on the concept that teeth move faster when the resistance exerted by the surrounding cortical bone is reduced via a surgical procedure. Kole's procedure involves the reflection of full thickness flaps to expose buccal and lingual alveolar bone, followed by interdental cuts through the cortical bone, barely penetrating the medullary bone [46] .These initial approaches included some types of alveolar osteotomy alone or combined with corticotomy. Traditionally, vertical and horizontal osteotomies have had an increased risk of postoperative tooth devitalization or even bone necrosis, depending on the severity of injury tothe trabecular bone [44] .There is also an increased risk of periodontal damage, mainly in cases in which the interradicular space is less than 2 mm [47].

2.2. Alveolar Corticotomy-Assisted Tooth Movement

Alveolar corticotomies are defined as the surgical interventions where the incision must pierce the cortical layer and, at the same time, penetrate into the bone marrow only minimally [48]. The invasiveness of the corticotomy procedures requiring full mucoperiosteal flaps constituted a serious drawback for their widespread acceptance among orthodontists and patients. Therefore, more conservative flapless corticotomy-restricted techniques have recently been proposed. These procedures can be completed more quickly and might be preferable if patient discomfort is indeed minimized and if treatment efficiency is maintained. Corticotomy has many advantages compared with osteotomy. It prevents injuries of the periodontium, pocket formation and devitalizing of the adjacent teeth. The nutritive function of the bone is also maintained through the spongiosa avoiding the possibility of aseptic bone necrosis [45].

Despite the evolution of clinical methods, the scientific explanation of accelerated tooth movement was still believed, until recently, to be a reduced mechanical resistance after osteotomy or corticotomy, enabling the teeth to be moved en bloc with the tissues surrounding them [48] . This view was challenged by Wilcko et al. [49]. They described an innovative strategy of combining corticotomy alveolar surgery with alveolar grafting in a technique referred to, initially, as accelerated osteogenic orthodontics and, more recently, as periodontally accelerated osteogenic orthodontics.Wilcko's technique combines fixed orthodontic appliances, labial and palatal/lingual corticotomies, and bone grafting with demineralized freeze-dried bone and bovine bone with clindamycin. This procedure involving corticotomy with subsequent bone augmentation has been proposed to increase the volume of the alveolar process, to facilitate arch development,to prevent or even treat fenestrations, and to maximize the metabolic response during orthodontic treatment. Tooth movement can be initiated 2 weeks after surgery. They reported rapid tooth movement at a rate of 3–4 times greater than conventional orthodontic movement [49]. Respectively, according to the results of the same studies, periodontally accelerated osteogenic orthodontics treatment can often be completed in one third to one fourth of the time required for traditional orthodontic treatment [50].Wilcko et al. [49] were first to suggest that tooth movement assisted with corticotomy may be due to a demineralization-remineralization process rather than bony block movement. This process resembled the regional acceleratory phenomenon (RAP), a term initially used to describe rare cases of accelerated fracture healing [51]. It is indeed an exaggerated response from that organism to an injured area to facilitate healing and has been associated with local increased bone turnover and decreased bone density. The tissue response varies in duration, size and intensity, depending on the magnitude of the stimulus [51].However, the RAP in the case of orthodontic tooth movement has also been attributed to the increased chemoattraction of macrophages. These macrophages remove the hyaline zone within 1 week after the application of orthodontic force [52]. This early disappearance of the hyaline zone results in the acceleration of the tooth movement process around the corticotomy alveolar area. Thus, the RAP is influenced by both bone density and the degree of hyalinization of the periodontal ligament. The amount of movement in most of the studies was doubled over the time of corticotomy-assisted treatment at the rate of about 1 mm/month [53].Corticotomy procedures have been reported to significantly accelerate orthodontic molar intrusion , distalization and maxillary arch expansion. There are also case studies reporting a reduction in total orthodontic treatment duration with the aid of alveolar corticotomy. In specific, full cases involving resolution of crowding, skeletalclass II division 2 correction, retraction of mandibular incisors , extraction cases [53] and anterior open bite correction were completedin as little as 6–19 months. Respectively, prospective clinical studies have also reported faster tooth movement and completion of treatment [54] , with the use of alveolar corticotomies.Surgical complications associated mainly with extensive corticotomy sites, such as postoperative pain and swelling and subcutaneous hematomas of the face and neck have been reported and may negatively impact the patients' experiences and acceptance rate of the procedure and the additional cost to orthodontic treatment to cover the surgical procedures can also be a concern.

2.3. Distraction Ontogenesis

Distraction osteogenesis is a method for generating new bone by progressively distracting healing surfaces, following the complete osteotomy of a bone. Essentially it is a bone-modeling procedure that produces perivascular woven bone, which then condenses and remodels to mature lamellar bone [55].

It is suggested that formation of new bone with a width of approximately 1 mm/day can be achieved by this method [56].Distraction ontogenesis was performed in the human mandible by Guerrero [57] in 1990 and McCarthy et al. [58] in 1992.Liou and Huang [59] were the first to apply this concept to orthodontic tooth movement in order to perform rapid canine retraction through distraction osteogenesis of the periodontal ligament. They considered the periodontal ligament as a ‘suture’ between alveolar bone and tooth andinvestigated the accelerated orthodontic tooth movement into newly distracted bone after mandibular distraction osteogenesis in a canine modelin humans. Their results showed that rapid orthodontic tooth movement can be achieved with this technique. No evidence of complications such as root fracture, root resorption, ankylosis or serious soft tissue dehiscence was reported at the end of dentoalveolar distraction, at least in the short term. However, a number of other complications have been associated with the distraction osteogenesis techniques, such as increase in gingival sulcus depth , anchorage loss, tipping of the anchorage and retracted teeth [59] and, more frequently, loss of pulpal vitality [59].

2.4. Orthognathic ‘Surgery-First’ Treatment

Surgery-first orthodontics is a strategy that significantly shortens treatment duration for patients who need orthognathic surgery, by taking advantage of the generalized RAP osseous effect [60] . In addition, the quality of treatment, based on facial esthetics, dental occlusion and stability of the results, is equally satisfactory. Moreover, dental occlusion and facial esthetics usually show immediate improvement after surgery, which is very positive for the patient’s psychology and cooperation. This is a fact that has to be seriously considered in the treatment planning of orthognathic surgery cases. Nevertheless, careful patient selection, precise treatment planning and clinical experience by both the surgeon and the orthodontist in the field of orthognathic surgery are required [60].

2.5. Fiberotomy

Fiberotomy is the surgical detachment of the marginal gingivae from the root surface and therefore separation of the mucoperiosteum from the alveolar bone. According to past and more recent studies in animals, fiberotomy alone may also accelerate orthodontic tooth movement to certain degree [61, 62].

2.6. Piezocision

Keser and Dibart [63] proposed a new and minimally invasive procedure that they named 'piezocision'. Like periodontally accelerated osteogenic orthodontics, it also speeds up tooth movement by alveolar corticotomy, but instead of full-thickness flaps, small vertical cuts through the gingival tissues and periosteum are made to reach the bone cortex. Bone grafts are embedded in tunnels connecting the vertical cuts, it appears that piezocision is similarly effective in accelerating tooth movement and augmenting periodontal tissues with much less trauma [63]. 'Piezopuncture' is another minimally invasive novel perio-orthodontic technique, which enables rapid orthodontic movement. This technique involves puncturing of the cortical bone with a piezosurgical regimen, which induces a local RAP response. This procedure has only been tested in dogs.

In addition, Vercellotti and Podesta[64] proposed the use of a piezoelectric knife instead of a high speed surgical bur in order to decrease the surgical trauma. Because of its micrometric and selective cut, a piezoelectric device produces safe and precise osteotomies without osteonecrotic damage [65].

A. Indications

- Class I malocclusions with moderate-to severe crowding (non extraction)
- Correction of deep bite
- Selected class II malocclusions
- Rapid adult orthodontics
- Rapid intrusion/extrusion of teeth
- Simultaneous correction of osseous and mucogingival defects
- Prevention of mucogingival defects that may occur during or after orthodontic treatment
- Multidisciplinary comprehensive treatments(incorporating generalized or localized Piezocision).

B. Contraindications

- Active periodontal disease
- Ankylosed teeth
- Systemic conditions affecting bone metabolism
- Medications affecting bone metabolism
- Noncompliant patient

C. Description of the Technique

A week after orthodontic appliances are placed, the patient is seen by the periodontist for piezocision surgery. Prior to the surgical appointment, the orthodontist and surgeon have discussed the case in depth, with the orthodontist telling the surgeon which teeth, or group of teeth, need to move and where. A preoperative CT scan is ideal as it will tell the team which teeth need bone grafting as well as give the surgeon information about the location of vital anatomical or critical dental structures (i.e. root form and proximity). This planning will lead to the making of the surgical flow chart (fig. 1) to be used as the blueprint for the surgical procedure. This sheet is carried to the operating room and used as a guide during the surgery.

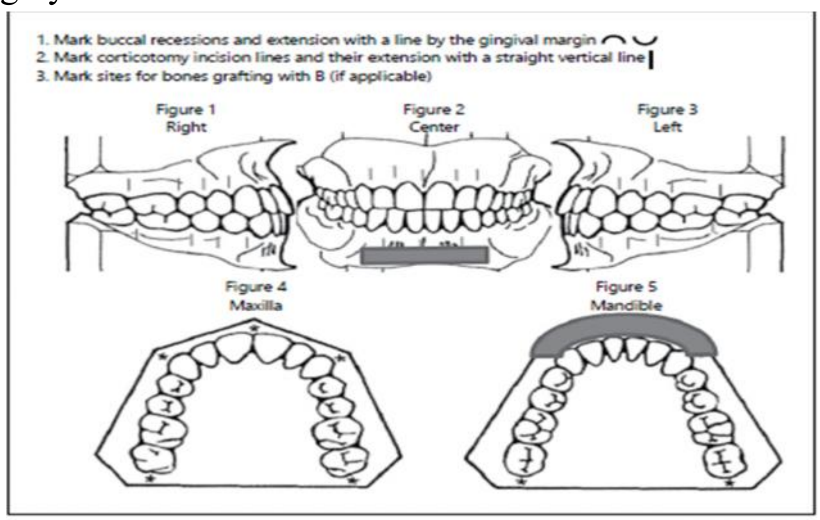

Fig. 1. Surgery Planning Chart {the interproximal Piezocision sites are marked by short vertical lines, and the areas needing bone grafting and shown in grey shading).

The patient is requested to rinse with chlorhexidine gluconate 0.12% for 1 min before being given local anesthesia (fig. 2).

Fig. 2.28-year-old patient presenting with a blocked out canine and a midline shift.

Once anesthesia set , with the help of a scalpel with a blade No. 15interproximal buccal incisions are made in the attached gingiva or alveolar mucosa (this is dependent on the anatomy of the region and the amount of keratinized tissue present). The incisions are small enough to accomodate the diameter of the BS 1 insert of the piezotome. These incisions are started 2–3 mm below the base of the interproximal papillae, keeping in mind that the soft tissues and the underlying periosteum need to be cut to create an opening that will allow for the insertion of the BS 1 insert (fig.3).

Fig. 3.Buccal and interproximal soft tissue incision with blade No. 15. The blade must cut through the periosteum in order to allow for bone decortication with the piezo¬tome (Satelec. Acteongroup, Merignac, France).

Once all the superficial soft tissue incisions are completed, the piezotome is used to create the bone injury that will start the RAP. This is done by inserting the head of the BS1 insert in the gingival openings and decorticate the alveolar bone (fig.4).

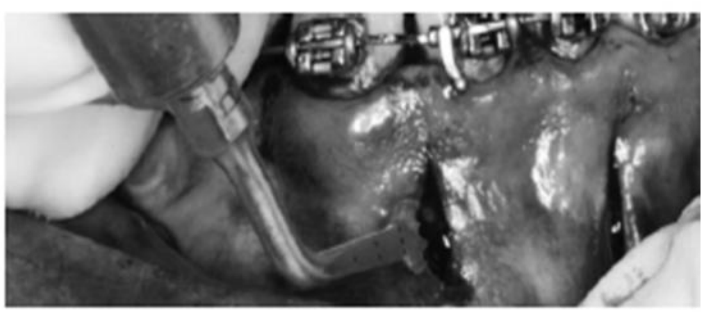

Fig. 4. The piezotome (Satelec Ac- teongroup) with the BS1 insert is used to do the interproximal bony decortication that will start the RAP. Depth of cut;3 mm.

The depth of the cut is 3 mm. At this point, it is very important to pay attention to the direction of the bony cuts so as to not injure the surrounding roots. In the areas where bone augmentation is needed (this has been determined beforehand by the dental team after careful analysis of the preoperative CT scan), a subperiosteal tunneling procedure is performed (fig. 5).

Fig. 5. Tunneling procedure using the periosteaI elevator to create space for the bone graft that will also take place in that region.

This is done by using a small periosteal elevator that is inserted in the vertical opening and below the periosteum. Care must be taken to create enough of a ‘pouch’ to accommodate the bone graft (fig.6).

Fig. 6.A bone allograft (Regenafil, Exactech, Gainsville, Fla.. USA) is being syringed into the prepared tunnel. This will augment the bone volume buccally and allow for anterior tooth movement at minimal risk for recessions.

By the same token, this tunneling procedure can be used to correct a pre-existing mucogingival defect (i.e. gingival recession) and a soft tissue graft from the palate is then inserted into the pouch instead of bone. Once the grafting procedure is completed, only the areas where tunneling was done need to be sutured with 5–0 chromic gut (fig. 7).

Fig. 7.The procedure is completed. The maxillary incisions should have been 50% smaller and not that high in the oral mucosa (as this will result in scarring). The lower anterior area that has been tunneled and grafted requires suturing. Here a few drops of cyanoacrylate glue have been added on top of the sutures.

The other areas (simple incisions withdecortication) do not usually need suturing. The postoperative regimen suggested is as follows.

• antibiotherapy (when bone grafting is done)
• nonsteroidal anti-inflammatory drugs toalleviate discomfort
• ice packs for the first 2 h after surgery
• rinses with chlorhexidinegluconate 0.12%.

D. Follow-Up Visits

There is a 1-week follow-up visit by the surgeon to assess proper healing. As of the second week after surgery, it is the orthodontist who will needto see the patient every 2 weeks for the next 4–6 months. This is critical as we need to maximize tooth movement during this period of time. The RAP that follows bone decortication consists of two successive phases (catabolic and anabolic), and it is important to judiciously use the time during which the bone is demineralized (catabolic phase) in order to achieve the ‘greater bulk’ of tooth movement. This phase is estimated to takeplace 2 weeks after surgery and continue for up to 6 months thereafter.hence, the need to see thepatient very frequently to maximize the use of this window of opportunity that will subsequently lead to early completion of treatment (fig.8,9).

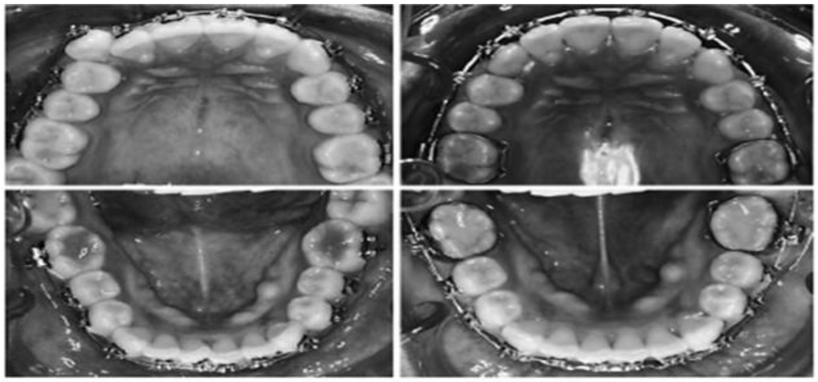

Fig. 8.Occlusal views before and 3.5 months after Piezocision. Notice that the upper right canine is on the arch and crowding has resolved (orthodontist: Dr. J.D. Sebaoun).

Fig. 9.Eight months after Piezocision the treatment is completed (orthodontist; Dr. J.D. Sebaoun).

E. Sequential Piezocision

In some cases, Piezocision can be used twice in the course of a single treatment, usually toward the end of the orthodontic treatment, once theRAP effect has long subsided and the orthodontist needs a ‘booster’ to finish the case. This is done in some areas of the dentition where specific and localized corrections are required (sequential Piezocision).

2.7. Corticision

Recently, Kim et al. [66] also introduced the 'corticision' technique as a minimally invasive alternative to corticotomy, creating a surgical injury to the bone without flap reflection. In this technique, a reinforced scalpel and a mallet were used in order to access the cortical bone, without raising flaps.

This surgical injury was evaluated as adequate to induce the RAP effect and make the teeth move more rapidly during orthodontic treatment. This technique, although innovative, has a few major drawbacks. the inability to graft soft or hard tissues during the procedure to correct osseous and soft tissue deficiencies and reinforce the periodontium, and, in some cases, transient postsurgical dizziness from the repeated malleting during the surgery.

A. Technical Procedure

The armamentarium involves a reinforced scalpel and an ordinary scalpel holder as well as a surgical mallet, as shown in (fig. 10).

Fig. 10.Armamentarium for the Corticision.

Panoramic X-rays or serial periapical radiograms are mandatory to check the available interradicular room for carrying out the procedure. A preoperative antiseptic mouth rinse is recommended for prevention of potential infection. After infiltration anesthesia, position the scalpel on the interradicular attached gingiva at an inclination of 45–60° to the long axis of the tooth to be moved (fig. 11), and insert it gradually into the bone marrow by tapping the scalpel holder with the surgical mallet, passing through the overlying gingiva and cortical bone, and into the cancellous bone.

Fig. 11. Place the blade at a right angle to the gingival surface, then turn obliquely at 4S-600 down towards the apex, which helps the longer cut into the medullary bone with minimal soft tissue (gingival) injury.

The vertical cut leaves 5 mm of the papillary gingiva to avoid bone loss of the alveolar crest and consequent development of the ‘black triangle’and damage of the adjacent dental root (fig.12).

Fig. 12. The scalpel penetrates about 10 mm in depth to obtain a cortical bone as well as a cancellous bone cut. The Corticision begins 5 mm downwards to the papillary gingiva to keep the papillary gingiva intact.

The depth of alveolar penetration with the scalpel is about 10 mm for the sake of beneficial cancellous bone osteotomy, which is expected to generate new blood vessels and enhance trabecular bone remodeling. Since the length of the vertical cut in the interradicular attached gingiva is not necessarily the entire root length, 2/3 of the root length is sufficient to evoke rapid toothmovement. After the Corticision receives its sufficient vertical cut, pull out the scalpel with a gentle swing motion.

Figure 13, describes that there is no conspicuous bleeding or troubled soft tissue left, thereby not requiring any postoperative dressing such as suture or periodontal pack. As the final step, mild irrigation with normal saline for a couple of minutes is required until the cessation of bleeding or oozing. When the 'Corticision' is planned at the beginning of the treatment, the procedure is preferred to be accomplished immediately after bonding in order to avoid a moistened enamel surface. Upon finishing, place the initial archwire with comfort.

Fig.13 , Immediately after the Corticision. Note there is no conspicuous postoperative bleeding.

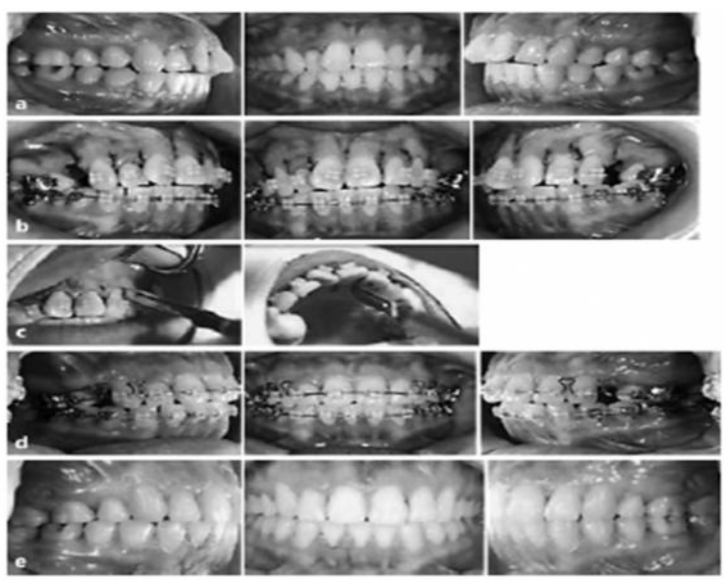

Fig. 14 Intraoral photos of a case. 21 -year-old female, with crowding and anterior protrusion before (a)u at bonding and upper b»cusp«d extraction (b)u at Corticision (c). 3 months after treatment (d) and at debonding 10 months after treatment (e). The Cortcision was performed on the upper arch at the beginning of treatement-

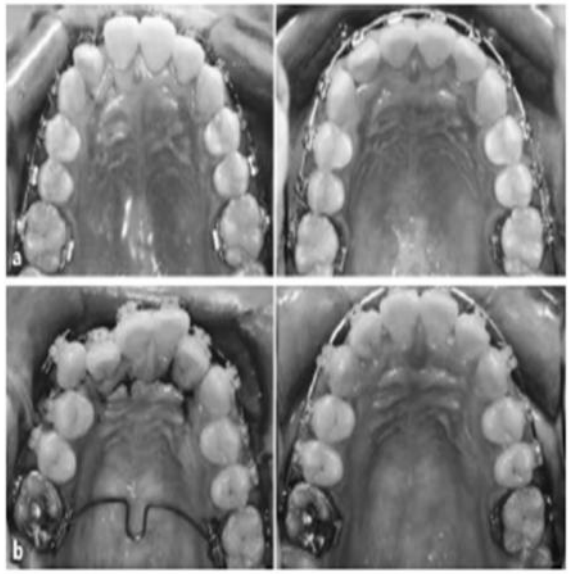

Fig-15. Intraoral photos before and after the Corticision. Mild crowding was completely relieved in 3 weeks (a], while moderate crowding took 9 weeks for complete alleviation (b).

The overall effect from the Corticision reaches at its peak at 2 months and drops at 3 months when the procedure is carried out. During the 3 months of this effective period, the patients are advised to visit every other week inorder to keep the Corticision gap by the woven bone open, otherwise the woven bone transforms into mature lamellar bone at 3 weeks after gap formation, leading to a sharp decline of the effects.

B. Risk Management

The Corticision is classified as the high risk level of infection according to the 'Consensus document on the use of antibiotic prophylaxis in dental surgery and procedure' by the Center for Disease Control and Prevention (US) in 2006. This denotes that the prescription of prophylactic, broad-spectrum antibiotics such as amoxicillin with the appropriate analgesics is mandatory. Special consideration in choice of pain killer is imperative since nonsteroidal anti-inflammatory drugs (NSAIDs) are consequently known to inhibit bone resorption and retard tooth movement, whereas acetaminophen has been proven to not affect the rate of tooth movement. The best choice of drug to control postoperative pain/discomfort is Tylenol TM. There is hardly an opportunity to observe any scarring in the oral mucosa or to follow any detrimental sequelae due to fibrous scar banding.

3. Conclusion and Future Directions

Accelerated orthodontic tooth movement is not simply the outcome of an increased application of forces. Such an approach will only result in ankylosis and root resorption, arresting the migration of the teeth in the alveolar bone. Recognition of this critical notion has led researchers to investigate the biological basis of orthodontic treatment. A thorough understanding requires a holistic approach to the entire tissue architecture, its vascularization and neuronal regulation, the impact of hormones and age, and how biomechanics affect these processes. All these events happen in themost sophisticated organ system in mammalians where hard and soft tissues meet in an environment exposed to the largest number of species ina biofilm known to exist in humans. Needless to add, we are just scratching the surface of understanding this complex biology. Our goal in this volume was to present and discuss the recent advances in this field. This required an outstanding team of experts, who presented both the basic science concepts and their relationship with the clinical practice. It is our hope that our contribution will set the stage for future research and researchers, who would take the full advantage of this exciting era where high-throughput methods of assessment of biological processes will be incorporated into the clinical practice of accelerated orthodontics.

References

1.Raisz LG, et al. Direct stimulation of bone resorption by epidermal growth factor. Endocrinology 1980. 107. 270–273.

2. Chan SY, Wong RW. Expression of epidermal growth factor in transgenic mice causes growth retardation. J BiolChem 2000. 275. 38693–38698.

3.Normanno N, et al. Gefitinib inhibits the ability of human bone marrow stromal cells to induce osteoclast differentiation. implications for the pathogenesis and treatment of bone metastasis. EndocrRelat Cancer 2005. 12. 471–482.

4. Dolce C, et al. Effects of sialoadenectomy and exogenous EGF on molar drift and orthodontic tooth movement in rats. Am J Physiol1994. 266.E731–E738.

5. Takahashi N, et al. Osteoclast-like cell formation and its regulation by osteotropic hormones in mouse bone marrow cultures. Endocrinology1988.122. 1373– 1382.

6. Potts JT, Gardella TJ. Progress, paradox, and potential. parathyroid hormone research over five decades. Ann N Y AcadSci 2007. 1117. 196–208.

7. Rodan GA, Martin TJ. Therapeutic approaches to bone diseases. Science 2000.289.1508–1514.

8. Soma S, et al. Effects of continuous infusion of PTH on experimental tooth movement in rats. J Bone Miner Res 1999.14. 546–554.

9. Collins MK, Sinclair PM. The local use of vitamin D to increase the rate of orthodontic tooth movement. Am J OrthodDentofacialOrthop 1988. 94. 278–284.

10. Meng R, et al. Crosstalk between integrin alphavbeta3 and estrogen receptor alpha is involved in thyroid hormone induced proliferation in human lung carcinoma cells. PLoS One 2011.6.e27547.

11. Bartzela T, et al. Medication effects on the rate of orthodontic tooth movement. a systematic literature review. Am J OrthodDentofacialOrthop 2009. 135. 16–26.

12. Shirazi M, Dehpour AR, Jafari F. The effect of thyroid hormone on orthodontic tooth movement inrats.JClinPediatr Dent 1999. 23. 259–264.

13. Hashimoto F, et al. Administration of osteocalcin accelerates orthodontic tooth movement induced by a closed coil spring in rats. Eur J Orthod 2001.23. 535–545.

14. Leiker BJ, et al. The effects of exogenous prostaglandins on orthodontic tooth movement in rats. Am J OrthodDentofacialOrthop 1995. 108. 380–388.

15. Yamasaki K, et al. Clinical application of prostaglandin E 1 (PGE 1) upon orthodontic tooth movement. Am J Orthod1984. 85. 508–518.

16. Blessing M, Schirmacher P, Kaiser S: Overexpression of bone morphogenetic protein-6 (BMP-6) in the epidermis of transgenic mice: inhibition or stimulation of proliferation depending on the pattern of transgene expression and formation of psoriatic lesions. J Cell Biol 1996; 135: 227–239.

17. Drugarin D, Drugarin M, Negru S, Cioace R: RANK-RANKL/OPG molecular complex – control factors in bone remodeling. TMJ 2003; 53: 296–302.

18. Kanzaki H, et al: Local RANKL gene transfer to the periodontal tissue accelerates orthodontic tooth movement. Gene Ther 2006; 13: 678–685.

19. Iglesias-Linares A, et al. The use of gene therapy vs corticotomy surgery in accelerating orthodontic tooth movement.OrthodCraniofac Res 2011. 14. 138–148.

20.Nicozisis JL, Nah-Cederquist HD, Tuncay OC. Relaxin affects the dentofacial sutural tissues. ClinOrthod Res 2000. 3. 192–201.

21.Madan MS, et al. Effects of human relaxin on orthodontic tooth movement and periodontal ligaments in rats. Am J OrthodDentofacialOrthop 2007. 131. 8.e1–e10.

22. Liu ZJ, et al. Does human relaxin accelerate orthodontic tooth movement in rats? Ann N Y AcadSci 2005. 1041. 388–394.

23.McGorray SP, et al. A randomized, placebo- controlled clinical trial on the effects of recombinant human relaxin on tooth movement and short-term stability. Am J OrthodDentofacialOrthop 2012. 141. 196–203.

24. Blessing M, Schirmacher P, Kaiser S. Overexpression of bone morphogenetic protein-6 (BMP-6) in the epidermis of transgenic mice. inhibition or stimulation of proliferation depending on the pattern of transgene expression and formation of psoriatic lesions. J Cell Biol 1996. 135. 227–239.

25. Nishimura M, et al. Periodontal tissue activation by vibration. intermittent stimulation by resonance vibration accelerates experimental tooth movement in rats. Am J OrthodDentofacialOrthop 2008.133.572–583.

26. Ohmae M, Saito S, Morohashi T, Qu H, Seki K, Kurabayashi H, et al. Biomechanical acceleration of experimental tooth movement by ultrasonic vibration in vivo. 1. Homo-directional application of ultrasonication to orthodontic force. Orthod Waves 2001. 60. 201–212.

27. Trenter SC, Landini G, Walmsley AD: Effect of loading on the vibration characteristics of thin magnetostrictive ultrasonic scaler inserts. J Periodontol 2003; 74: 1308–1315.

28.Fukada E, Yasuda I. On the piezoelectric effect of bone. J PhysSoc Japan 1957. 12. 1158–1162.
29. Kim D-H, Park Y-G, Kang S-G. The effects of electrical current from a microelectrical device on tooth movement. Korean J Orthod 2008. 5. 337–346.
30.Abdallah MN, Flores-Mir C. Are interventions for accelerating orthodontic tooth movement effective? Evid Based Dent 2014. 15. 116–117.
31. Darendeliler MA, Sinclair PM, Kusy RP. The effects of samarium-cobalt magnets and pulsed electromagnetic fields on tooth movement. Am J OrthodDentofacialOrthop 1995. 107. 578–588.
32. Showkatbakhsh R, Jamilian A, Showkatbakhsh M. The effect of pulsed electromagnetic fields on the acceleration of tooth movement. World J Orthod 2010. 11.e52–e56.
33. Tengku BS, et al. Effect of a static magnetic field on orthodontic tooth movement in the rat. Eur J Orthod 2000.22.475–487.
34.Trelles MA, Mayayo E. Bone fracture consolidates faster with low-power laser. Lasers Surg Med 1987. 7. 36–45.
35. Lim HM, Lew KK, Tay DK.A clinical investigation of the efficacy of low level laser therapy in reducing orthodontic post adjustment pain. Am J Orthod DentofacialOrthop 1995. 108. 614–622.
36. Sun X, et al. Effects of low energy laser on tooth movement and remodeling of alveolar bone in rabbits (in Chinese). Hua Xi Kou Qiang Yi XueZaZhi 2001. 19. 290–293. 35. 117–120.
37. Youssef M, et al.The effect of low-level laser therapy during orthodontic movement. a preliminary study. Lasers Med Sci 2008. 23. 27–33.
38.Saito S, Shimizu N. Stimulatory effects of low-power laser irradiation on bone regeneration in midpalatal suture during expansion in the rat.Am J Orthod Dentofacial Orthop 1997. 111. 525–532.
39. Limpanichkul W, et al. Effects of lowlevel laser therapy on the rate of orthodontic tooth movement. Orthod Craniofac Res 2006. 9. 38–43.
40. Cruz DR, et al. Effects of low-intensity laser therapy on the orthodontic movement velocity of human teeth. a preliminary study. Lasers Surg Med 2004.
41. Kau CH: Biotechnology in orthodontics photo biomodulation. Dentistry 2012; 2:e108.

42. Tuby H, Maltz L, Oron U: Low-level laser irradiation (LLLI) promotes proliferation of mesenchymal and cardiac stem cells in culture. Lasers Surg Med 2007; 39: 373–378.
43. Vinck EM, Cagnie BJ, Cornelissen MJ, Declercq HA, Cambier DC: Increased fibroblast proliferation induced by light emitting diode and low power laser irradiation. Lasers Med Sci 2003; 18: 95–99.
44. Merrill RG, Pedersen GW: Interdental osteotomy for immediate repositioning of dental-osseous elements. J Oral Surg 1976; 34: 118–125.
45.Kole H. Surgical operations on the alveolar ridge to correct occlusal abnormalities. Oral Surg Oral Med Oral Pathol 1959. 12. 515–529.
46.Amit G, et al.Periodontally accelerated osteogenic orthodontics (PAOO) – a review. J ClinExp Dent 2012.4.e292– e296.
47. Murphy NC, Wilcko MT, Bissada NF, Davidovitch Z, Enlow DH, Dashe J: Corticotomy- facilitated orthodontics: clarion call or siren song; in Brugnami F, Caiazzo A (eds): Orthodontically Driven Corticotomy: Tissue Engineering to Enhance Orthodontic and Multidisciplinary Treatment. Hoboken, Wiley-Blackwell, 2014, pp 1–39.
48. Cano J, et al. Corticotomy-assisted orthodontics. J ClinExp Dent 2012.4.e54–e59.
49.Wilcko WM, et al. Rapid orthodontics with alveolar reshaping. two case reports of decrowding. Int J Periodontics Restorative Dent 2001. 21. 9–19.
50. Al-Naoum F, Hajeer MY, Al-Jundi A: Does alveolar corticotomy accelerate orthodontic tooth movement when retracting upper canines? A split-mouth design randomized controlled trial. J Oral Maxillofac Surg 2014; 72: 1880– 1889.
51. Frost HM: The biology of fracture healing. An overview for clinicians. Part I. Clin Orthop Relat Res 1989; 248: 283– 293
52. Kim SJ, Park YG, Kang SG: Effects of corticision on paradental remodeling in orthodontic tooth movement. Angle Orthod 2009; 79: 284–291.
53. Wilcko W, Wilcko MT: Accelerating tooth movement: the case for corticotomy- induced orthodontics. Am J Orthod Dentofacial Orthop 2013; 144: 4–12.
54. Lee W, et al: Corticotomy-/osteotomyassisted tooth movement microCTs differ. J Dent Res 2008; 87: 861–867

55. Baloul SS, et al: Mechanism of action and morphologic changes in the alveolar bone in response to selective alveolar decortication-facilitated tooth movement. Am J Orthod Dentofacial Orthop 2011; 139(suppl):S83–S101.
56. Ren A, et al: Rapid orthodontic tooth movement aided by alveolar surgery in beagles. Am J Orthod Dentofacial Orthop 2007; 131: 160.
57. Guerrero C. Expansion mandibular quirurgica. Rev VenezOrtod 1990.1–2. 48–50.
58. McCarthy JG, et al. Lengthening the human mandible by gradual distraction.
59. Liou EJ, Huang CS: Rapid canine retraction through distraction of the periodontal ligament. Am J Orthod Dentofacial Orthop 1998; 114: 372–382PlastReconstrSurg 1992. 89. 1–8.discussion 9–10.
60. Hernandez-Alfaro F, et al: 'Surgery first' in bimaxillary orthognathic surgery. J Oral Maxillofac Surg 2011; 69:e201– e207.
61. Yaffe A, Fine N, Binderman I: Regional accelerated phenomenon in the mandible following mucoperiosteal flap surgery. J Periodontol 1994; 65: 79–83.
62. Leethanakul C, et al: Interseptal bone reduction on the rate of maxillary canine retraction. Angle Orthod 2014; 84: 839–845.
63.Keser EI, Dibart S. Piezocision-assisted Invisalign treatment. Compend Contin Educ Dent 2011. 32. 46–48, 50–51.
64.Vercellotti T, Podesta A. Orthodontic microsurgery. a new surgically guided technique for dental movement. Int J Periodontics Restorative Dent 2007. 27. 325–331.
65.Kotrikova B, et al. Piezosurgery – a new safe technique in cranial osteoplasty? IntJ Oral MaxillofacSurg 2006. 35. 461–465.
66. Kim SJ, Park YG, Kang SG: Effects of corticision on paradental remodeling in orthodontic tooth movement. Angle Orthod 2009; 79: 284–291.