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Review Article

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"Effects of *REGIONAL ACCELERATORY PHENOMENON* in enhancing Orthodontic tooth movement": A Review

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Abstract

Acceleration of tooth movement whilst orthodontic treatment is of escalating demand currently because of patient's concern to get the treatment done in less cross of time and to dwindle the integer of visits. Also, adult orthodontics has more demand as the number of adult patients is getting increased. Surgical techniques are more invasive and costly but are more beneficial with fewer side effects. Hence recent clinical methodologies involving the principle of Regional acceleratory phenomenon like various Corticotomies assisted procedures, Piezocision, micro osteoperforations, and some device assisted therapies in enchaning orthodontic tooth movement has the more demand in future. In this clinical review all the procedures involving the principle of regional acceleratory phenomenon will be dealt in detail.

Keywords: Bone remodelling, bone turnover rate.

Introduction

In 1983 Frost [1] defined the Regional Acceleratory Phenomenon (RAP) as a "complex reaction of mammalian tissues to diverse noxious stimuli" This reaction occurs regionally in the area of injury and involves both hard and soft tissues. It is characterized by an acceleration of most normal vital tissue processes.

Frost 1989 [2] described stages of sequential biological activities that RAP induces in fracture healing:

1. Cells are sensitized and release local messengers.
2. Over two weeks, granulation tissue forms when osteoclasts invade the area to resorb the fracture borders.
3. Callus forms (4 to 16 weeks) as granulation tissue is replaced by osteoid/ chondroid tissue.
4. Lamellar bone is formed and is mineralized.

Orthodontic tooth movement (OTM) is limited by physiologic processes where orthodontic forces were transmitted from the teeth to the periodontal ligament (PDL) within the alveolar bone. Orthodontic tooth movement (OTM) is directly regulated by bone apposition and resorption around the tooth, known as bone remodeling [3,4]. Several hypotheses exist regarding tooth movement [5,6], Mechanotransduction [7,8], bone-bending [9], and pressure tension [10,11]. Perhaps the most accepted tooth movement mechanism and bone remodeling is the tension and compression of the PDL due to forces on the tooth causing deposition and resorption of surrounding alveolar bone, respectively [10,11].Through intention reversible injury to the bone, Osteoclastic resorption can be induced. This has been referred to as Regional Acceleratory Phenomenon (RAP), which is the basis for accelerated Orthodontic tooth movement (OTM) modalities.[12]Consequently, with an intentional injury, the bone metabolism shifts to a more catabolic state. The proliferation of Osteoclasts leads to temporary osteopenia, which decreases bone density and bone volume. This process allows the teeth to move in a more flexible environment and accelerate OTM [13].

Tissue injury using sterile surgical wounding has proven to cause RAP by decreasing bone density and increasing bone turnover [14].

Since then, a few invasive and non-invasive procedures have been discovered, which involved the rapid acceleration phenomenon principle [Fig 1].

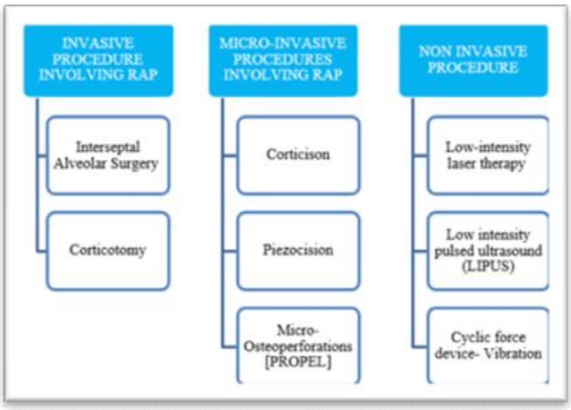

Fig1: Invasive and Non-invasive Procedures in Rapid Acceleration Phenomenon

Biological principle behind mechanism of regional acceleration phenomenon:

In the alveolar bone, the RAP is characterized, at a cellular level, by increased activation of the basic multicellular units (BMUs), thereby increasing the remodeling space. The types of cells managing the bone remodeling cycle form the Basic Multicellular Units (BMU) [15].

Orthodontic tooth movement: the biological response to sustained force:

The pressure-tension theory proposes chemical rather than electric signals as the stimulus for cellular differentiation and tooth movement. This theory suggests that the tooth shifts its position within the PDL space within a few seconds upon force loading, resulting in PDL compression in some areas and PDL stretch or tension in others. If the loading force is sustained, the blood flow alters quickly (in minutes), which changes the oxygen tension (O2: CO2 level). The chemical environment is altered by releasing biologically active agents such as prostaglandins and cytokines (e.g., Interleukin (IL)-1b). These chemical mediators affect cellular activities in the compression vs. tension areas differentially within the PDL, promoting a net outcome of bone resorption at the compression and bone formation at the tension side. Hypoxia is a critical initiator which acts in concert with the loading-induced fluid flowfor orthodontic tissue remodeling [Fig 2]

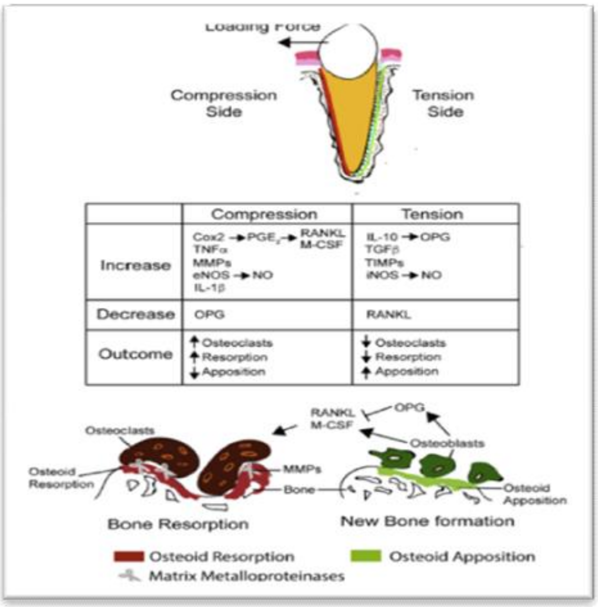

Fig 2: Signalling pathways associated with compression and tension due to orthodontic force.

The fluid flow hypothesis focuses on fibroblast and osteocyte response to strain due to fluid displacement in canaliculi [16].

The sequence of events initiates a force application which includes [17]:

1) Matrix strain and fluid flow
2) Cell strain
3) Cell activation and differentiation
4) Tissue remodeling

When teeth are loaded, interstitial fluid is forced through the canaliculi and around osteocytes, causing strain on the cell surface and extracellular matrix. Fluid flow applies shear stress to the bone ECM and cell membrane, perturbing Integrins and activating signaling cascades in osteocytes [18] [Fig 3]

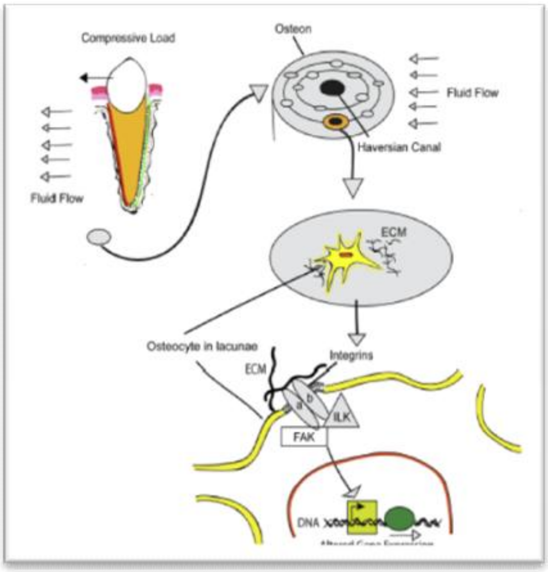

Fig 3: Role of fluid flow in orthodontic tooth movement. Tooth loading causes the flow of interstitial fluid around osteocytes, resulting in strain on the extracellular matrix (ECM) perturbing membrane-bound Integrins. Integrins activate focal adhesion kinase (FAK) and an intracellular signaling cascade culminating in altered gene expression and tissue remodeling.

Role of inflammation in orthodontic tooth movement:

The activated endothelium binds, recruits circulating leukocytes, monocytes, and macrophages to the PDL, signifying the onset of acute inflammation [19]. Leukocytes elaborate prostaglandins, growth factors, cytokines, and colony-stimulating factors that promote tissue remodeling [20]. Inflammation transitions from acute to chronic and proliferative after several days, involving osteoblasts, osteoclasts, fibroblasts, and endothelial cells. Native paradental cells, platelets, and leukocytes release a milieu of inflammatory factors initiating functional units to remodel bone and paradental tissues. Factors include cytokine, Nitric Oxide (NO), Tumour necrosis factor-a (TNF-a), transforming growth factor b (TGF-b), IL-1b, IL-6, IL-10macrophage colony-stimulating factor (M-CSF), Prostaglandins, OPG, and RANKL. In addition, compression and tension zones are associated with specific mediators regulating resorption and deposition, respectively.

Compression leads to elevated Cycloxygenase-2 (COX-2), which catalyzes the production of prostaglandins from arachidonic acid [21]. Prostaglandins boost resorptive activity by acting on osteoclasts, increasing intracellular cAMP concentrations, and [18]. PGE2 stimulates osteoblast differentiation, expression of RANKL [18]. An increase in RANKL and M-CSF and decreased OPG release by osteoblasts collectively favor osteoclast differentiation and bone resorption. Release of cytokines IL-1b and TNF-increase inflammation and matrix metalloprotease (MMP) levels. Cathepsins and MMPsdegrade PDL ECM and the bony organic matrix, allowing osteoclast attachment for resorption [17]. In addition, these factors activate osteoclasts to form resorptive lacunae in the compressive zone [22].

Tooth movement begins once osteoclasts remove necrotic tissue, followed by the creation of osteoid by osteoblasts with new periodontal fibrils embedded in the root cementum and alveolar bone wall. Bone morphogenic protein (BMPs) and Runx2 expression increase osteoblast differentiation and bone mineralization proliferating and active fibroblasts upregulate ECM fiber production [23].

Under tension, alveolar bone deposition predominates, increasing the number of osteoblast numbers and activity. In areas of tension, cytokine IL-10 increases, reducing RANKL production and boosting OPG by osteoblasts; bone deposition is favored by an overall reduction in RANK signaling, favoring bone deposition. TGF-b is also enriched under tension, and induces proliferation and chemotaxis of PDL cells, upregulates COL-I (collagen gene), recruits osteoblast precursors, Down-regulates MMPs induce their differentiation and upregulates tissue inhibitors of metalloproteases (TIMPs) [24]. This resulted in increased osteoblast and reduced osteoclast activity, with bone and remodeled PDL fibers production on the side opposite tooth movement.

Acceleration of the orthodontic tooth movement:

Surgical techniques have been tested for over 100 years in clinical practice to accelerate orthodontic treatment [25].

The initial approaches to create a movable "bony block" includes alveolar osteotomy alone or combined with corticotomy teeth were moved faster by reducing the resistance exerted by the surrounding cortical bone.

The concept of the bony block was abandoned, and the selective alveolar corticotomy has become a reproducible gold standard. More recent techniques include further refinement with minimally invasive procedures that require no flap, such as piezoelectricity and corticision [26]

According to the mechanistic theory, Frost [27] described remodeling, modeling, and RAP according to the bone's loading history.

During orthodontic treatment, the tensile stresses produced by pulling the PDL fibers are transformed into compressive hoop stresses, similar to the Roman arch's principle. Therefore, both tensile and compressive stresses coexist on the 'tension' side. However, on the 'pressure' side, the fibers of the PDL become curled up, and practically no stresses are transferred onto the alveolar wall [Fig 4]. Consequently, the hoop stresses are low as well, and the overall stress concentration becomes much lower as on the 'tension' side. This suggests that compression- tension concept is questionable, and a more reasonable biological model seems to be the one involving loading/non-loading of the alveolar support structures.

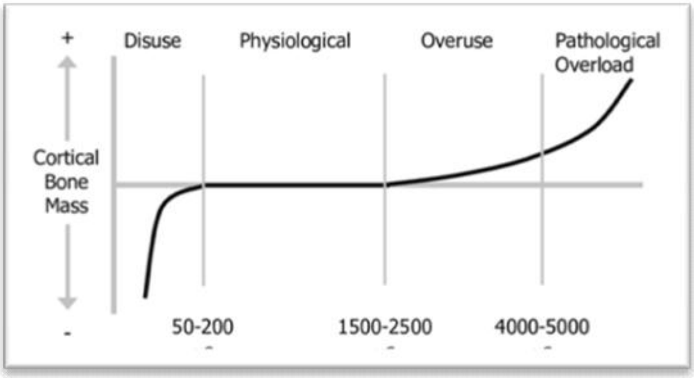

Fig 4: Frost's Mechanostat Theory adaptation of bone to mechanical stimuli

From a loading history perspective [26], this situation can be associated with the disuse window, when bone senses a decreased mechanical loading. Bone turnover increases and resorption activities will prevail. This represents the very first initiation of the bony reaction. Further application of an orthodontic load generates bone reactions that lead to an adaptation to the new mechanical environment, achieving a progressive balance between resorption and formation, as in the 'adapted and mild overload windows' [Fig 5]. This ensures tooth movement with bone, i.e., the movement of the tooth surrounded by the alveolar bone. When some orthodontic appliance applies the sustained mechanical load, the 'pathological overload window' may be reached. Hyalinization of the PDL, ischemia-induced necrosis of the lining cells, and microdamage of the bone in the direction of the force will lead to increased BMU activation frequency and increased remodeling space [28-29] [Fig. 6].

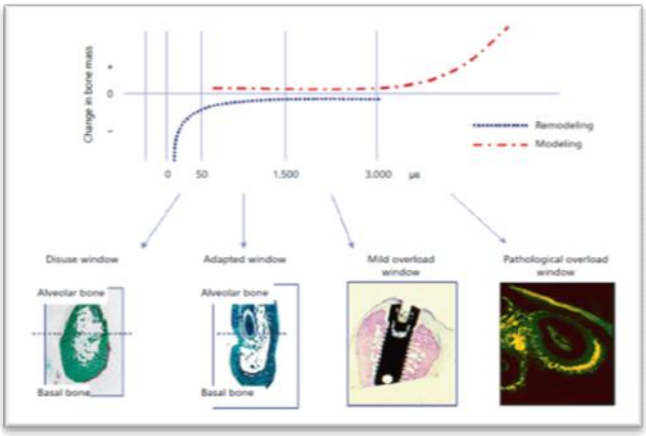

Fig 5: Change on bone mass during remodeling and modeling in
1. Disuse window 2. Adapted window 3. Mild overload window 4. Pathological overload window

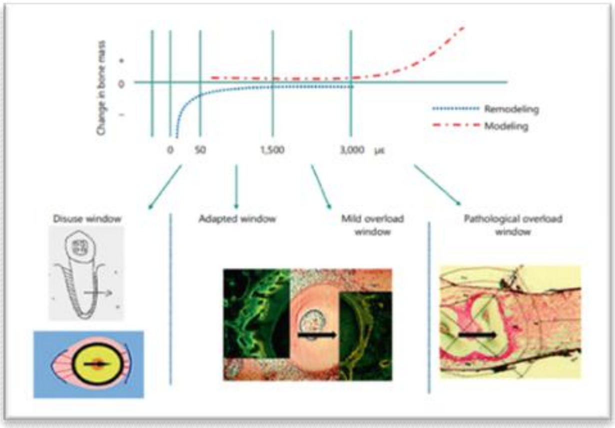

Fig 6: The loading history of the alveolar bone following the application of an orthodontic load

Orthodontic tooth movement can therefore be seen as a modified skeletal wound healing and adaptation, typified by an increased bone remodeling response in addition to an elevated formation of woven bone. In this perspective, the biological principle of the RAP is exploited in surgically facilitated orthodontics [30].

Invasive procedures involving principle rapid acceleration phenomenon:

Interseptal alveolar surgery:

Interseptal alveolar surgery is divided into the distraction of PDL or Dentoalveolar bone; an example of both is the rapid canine distraction Liou et al. (1998) [31] in the rapid canine distraction of PDL, to reduce the resistance on the pressure side, the Interseptal bone distal to the canine is surgically undermined during extraction of the first premolars. tooth movement is easier and quicker as the compact bone is replaced by the woven bone and reduced resistance of the bone. [32].

The horizontal mucosal incision is given parallel to the gingival margin of the canine and premolar beyond the depth of the vestibule. The first premolar is extracted and vertical Osteotomy is made on the anterior aspect of the canine by connecting multiple cortical holes made on the alveolar bone, passing 3 to 5 mm above the canine apex. A similar Osteotomy was done along the posterior aspect between the first premolar buccal root and canine. The first premolar buccal cortical bone is removed. Larger osteotomes are used to fully mobilize the alveolar segment that includes the canine by fracturing the surrounding spongious bone [Fig 7 - 8]. In the maxilla leaving the sinus membrane, the apical bone near the sinus wall is removed.

The 'Transport Dentoalveolar segment' includes the buccal cortex and spongy bone enveloping the canine root. The distractor is now tried on canine and the first molar. the device is activated several millimetres and set back to its original position. [Fig 9] The incision is closed with sutures. The surgical procedure lasts approximately 30 minutes for each canine,with more dissection and osteotomies performed at the vestibule. The rapid canine distraction of the Dentoalveolar bone is done by the principle of the distraction of PDL [33-38].

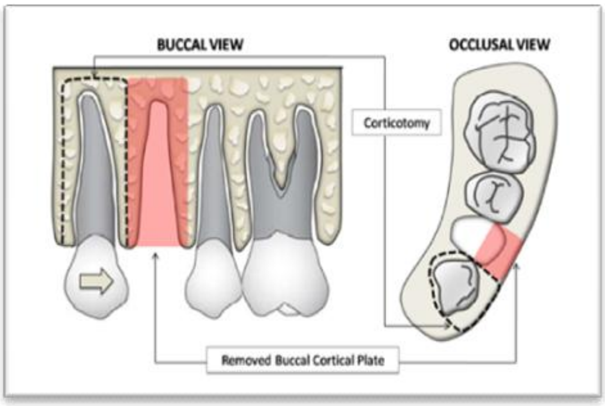

Fig 7: Surgical Techniques involving vertical and horizontal corticotomies after removal of the buccal cortical plate in relation to extraction socket the Dentoalveolar segment will be used as transport unit to carry canine posteriorly

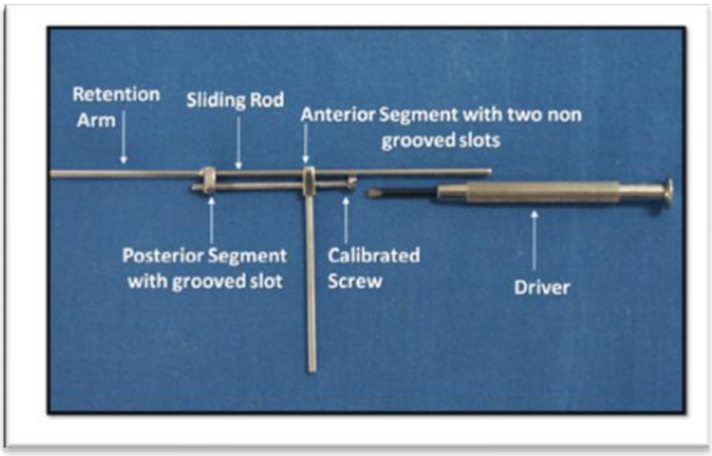

Fig 8: Custom made distractor device

Fig 9: Canine Distraction Appliances

Distraction protocol:

The distractor is activated twice for a total amount of 0.8 mm per day, each consisting of one complete turn of 360^0. The distraction consists of the gradual movement of the vascularized bony segment containing the canine tooth or 'transport disc.' It takes less than two weeks for the canine to come into contact with the second premolar. Then, the distractor is removed, and fixed orthodontic appliance treatment is initiated concurrently to consolidation. Ligatures are placed between the canine and the first molar under the arch wire and are kept at least three months for consolidation (Iseri, Kişnişci, Bzizi & Tuz, 2005[36] [Fig 10].

Both techniques accelerated tooth movement with no significant root resorption, ankylosis, and root fracture in all the studies. However, there were contradictory results regarding the electrical vitality test of the retracted canines. For example, Liou (1997) [31] reported 9 out of 26 teeth showed positive vitality, while Sukurica (2007) [33] said that few teeth showed negative vitality after the sixth month of retraction. So, still, there are some uncertainties regarding this technique.

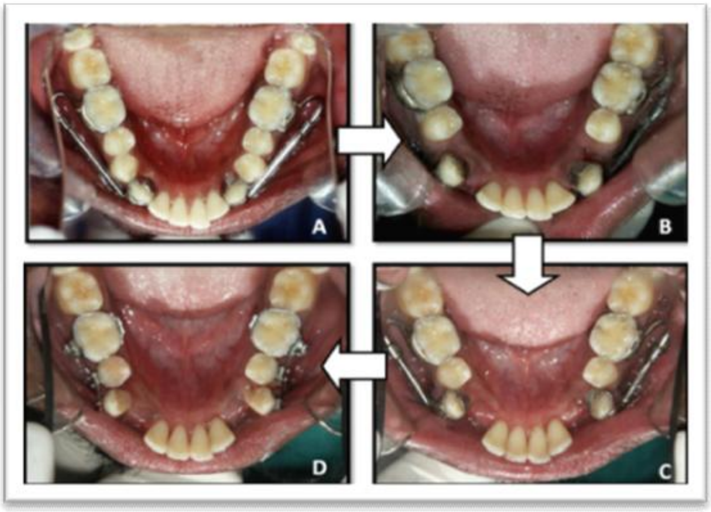

Fig 10: (A) Pre distraction; (B) During distraction phase (6days); (C) & (D) post distraction (14 days)

Corticotomy:

A Corticotomy is a surgical procedure where only the cortical bone is cut, perforated, or mechanically altered without any altered medullary bone, which is performed without medullary bone involvement, unlike osteotomies that involve the thickness of bone.

Procedure: Elevation of the full thickness of buccal and lingual mucoperiosteal flap positioning the Corticotomy cuts using piezo surgical armamentarium or micro motor under irrigation. It is followed by the placement of graft material in required sites to enhance the thickness of the bone [Fig 11].

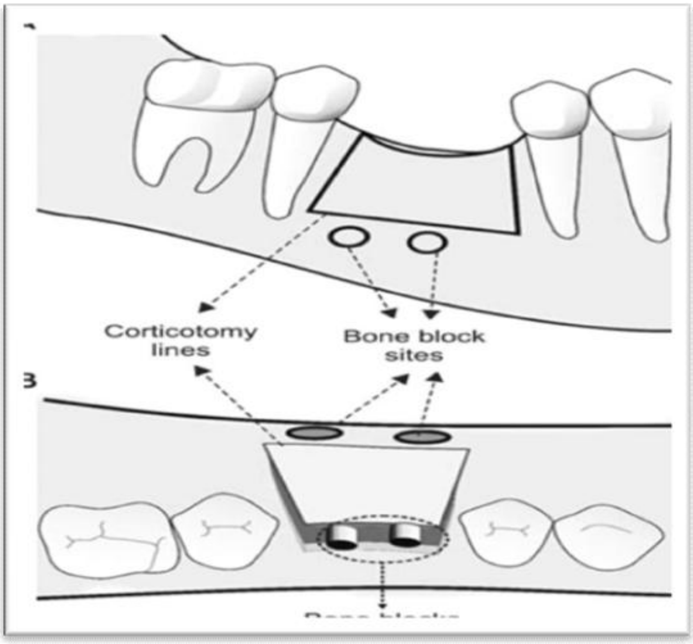

Fig 11: Schematic of the Corticotomy procedure. A: Sagittal view. B: Occlusal view

Advantages [39]

- Bone can be augmented, and periodontal defects would be avoided
- Minimal changes in the periodontal attachment apparatus
- Minimal treatment duration and increased rate of tooth movement
- Less root resorption

Disadvantages: [39]

- Expensive and comparatively invasive procedure.
- May cause post-operative pain and swelling.

Kole (1959) [40] explained that when exposed to orthodontic forces, an en bloc movement of the entire alveolar cortical segment is enhanced due to reduced resistance, which is connected by softer medullary bone, including the confined teeth [41].

Suya (1991) [42] specified that after Corticotomy, most orthodontic treatments should be completed in the first three to four months and before fusion of the tooth-bone units.

Recently, Wilcko (2001 and 2008) [43-44] developed a patented technique called Accelerated Osteogenic Orthodontics (AOO) [43] or Periodontally Accelerated Osteogenic Orthodontics (PAOO) [44]. Except for those selective decortications in the form of lines and points are performed over all of the teeth to be moved; this technique is similar to conventional Corticotomy. In addition, to augment the confining bone, a resorbable bone graft is placed over the surgical sites during tooth movement.

After one or two weeks of the healing period, Orthodontic tooth movement is started and followed up using a faster rate of activation at two-week intervals. Using this technique, Wilcko [43-44] reported rapid tooth movement at a rate of 3 to 4 times greater than conventional orthodontic movement due to a state of reversible osteopenia of the alveolar bone surrounding the involved teeth during the orthodontic movement and not to bony block movement, as claimed by Köle et al. [43].

During corticotomies, to expose the bone, the gingiva and the periosteum are elevated. The Osteotomy cuts are made, and the bone surface will also be perforated between the Osteotomy cuts (Figures 12: B and D). The decorticated bone surfaces are covered with a mixture of demineralized freeze-dried bovine bone and plasma rich in blood platelets (figures 12: C and E).

The surgical flap is sutured. The new volume of bone facilitates a greater scope of tooth movement toward the areas. Within one week after the surgery, orthodontic treatment is started. This is called periodontally accelerated osteogenic orthodontics therapy [PAOO]. This Facilitated tooth movement will occur only close to the corticotomized teeth. According to the Wilcko brothers, treatment time can be reduced from ⅓ or ¼ of the treatment time that is typically required.

Fig 12: Corticotomy surgery

Many studies published on Corticotomy were randomized clinical trials. Among that one study was animal study rest were involved with humans. Recent animal studies have added more evidence to the effect of Corticotomy and Osteotomy assisted tooth movements [CAOT].

Ren *et al.* (2007) [45] evaluated the effects of alveolar Interseptal Corticotomy and extraction on orthodontic tooth movement in beagles. The tooth on the experimental side moved more rapidly than the tooth on the control side, without any root resorption or irreversible pulp injury.

Mostafa *et al.*(2009) [46] reported a doubled rate of tooth movement after Corticotomy in dogs and attributed this to the observed increase in bone turnover and the RAP phenomenon. Two recent histological studies were conducted to evaluate tissue response to decortications.

Sebaoun *et al.* (2008) [47] found an increased turnover of alveolar spongiosa due to alveolar decortications. Three weeks after surgery, the catabolic activity (Osteoclast's count) and anabolic activity (apposition rate) were three times greater, calcified spongiosa decreased By two-fold, and the PDL surface increased two-fold. This dramatic increase in bone turnover decreased to a steady-state by the eleventh week after surgery. The observed effect of Corticotomy was localized to the area immediately adjacent to the decortication's cuts.

Lei Wang *et al.* (2009) [48] explained the sequence of events occurring after Corticotomy in rats. They were found to produce bone resorption around the moving teeth by day 21 after surgery and the area refilled with the bone after 60 days. This study confirms the occurrence of reversible osteopenia during Corticotomy and Osteotomy assisted tooth movements [CAOT].

Applying this technique to clear aligner's therapy allows us to facilitate the most biomechanically complicated movements that must include in a time window of approximately 30 aligners. In fact, after the surgical procedure, can change aligners after four days rather than 14, and this will determine a significant total treatment time reduction of about ten months because it will change 30 aligners in that span of time instead of eight. In addition, the regional acceleratory phenomenon induced by corticotomy results in a decrease in tubercular bone density,a transient increase in bone turnover, which lasts for four months. During this time window, orthodontic movements are accelerated and achieve more stable results [49].

Micro-invasive procedures involving principle of rapid acceleration phenomenon:

Corticision:

Kim and co-workers [50] established a technique called Corticison with minimal surgical intervention, also called minimally invasive rapid orthodontics (MIRO). Corticision was initiated as a supplemental Dento-alveolar surgery in orthodontic therapy to achieve rapid tooth movement with minimal surgical intervention.

Procedure [Fig 13]:

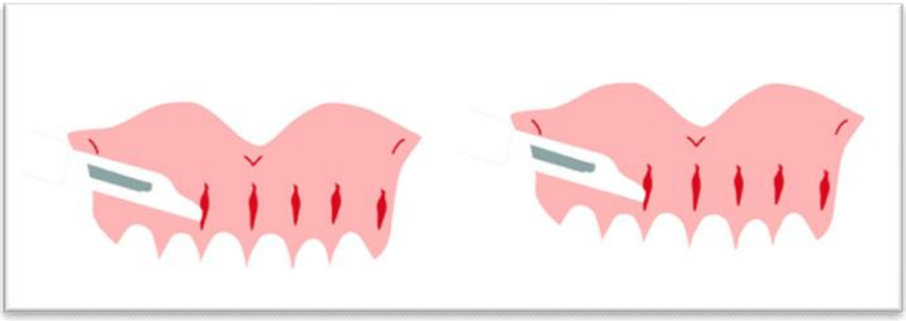

Fig 13: Corticision procedure

Corticison of the inter-proximal cortices with a reinforced scalpel is used as a thin chisel and a mallet transmucosally without reflection a flap. With 45°-60° of inclination to the gingiva of the long axis of the canine, a reinforced surgical blade with a thickness of 400 µm locates the inter-radicular attachment. The surgical injury should be 2 mm from the papillary gingival margin to preserve the alveolar crest and be 1 mm beyond the mucogingival junction. A swing motion should pull the blade out.

Kim and Park in 2009 [50] concluded that extensive direct resorption of the bundle bone with less hyalinization was observed. At 28 days, the mean apposition of new Bone was 3.5-fold higher with no signs of root resorption or other pathologic changes where Corticison was performed. Their explanation of these findings lies in the action of RAP on the lag phase duration. RAP can stimulate the removal of hyalinised tissue, shortening the lag phase of tooth movement. A shorter lag phase allows a decrease in treatment duration.

Murphy in 2014 [51] suggested that low force could cause higher Osteoclast recruitment resulting in greater bone resorption.

Murphy et al. 2016 [52], repeated the experiment with a similar study design to evaluate the effect of corticison with heavy and light orthodontic forces on root resorption. Root resorption was evaluated by identifying discontinuities along the root surface. The root volume was calculated from the micro-CT analysis. Histomorphometric analysis showed that erosion areas were mostly present on the compression side of the root. There was a significant decrease in the eroded area for the corticision groups.

Clinical studies were conducted on humans and animals and concluded corticision accelerates tooth movement similar to Corticotomy.

Piezocision

One of the latest techniques in accelerating orthodontic tooth movement is the Piezocision technique. A minimally invasive procedure involves flapless combining piezo surgical cortical micro-incisions with selective tunneling that allows for softtissue or bone grafting. The use of piezosurgery instead of burs, in conjunction with the conventional flap elevations, creates an environment conducive for rapid tooth movement. However, this technique is quite invasive as it requires extensive flap elevation and osseous surgeries, with post-surgical discomfort. As a result, the patient community has not widely accepted this technique. Subsequently, Dibart et al. [53] introduced Piezocision with less invasiveness to this procedure.

Procedure:

Piezocision™ [Fig 14] was first described in a case report by Dibart et al. (2009, 2010) [Fig 15] [53-54] described a new minimally invasive procedure that they called Piezocision®.

Fig 14: Piezocision™

Fig 15: Case reported by Dibart 2009. A: Pre-treatment frontal view; B: post-treatment frontal view; C: Tunnelling of areas to be grafted with bone; D: bone grafting; E: sutures.

This is a combination of micro incisions limited to the buccal gingiva that allows the use of a piezoelectric knife to give osseous cuts to the buccal cortex and initiate the RAP without involving the palatal or lingual cortex [54]. Thus, the procedure allows for rapid tooth movement without the downside of an extensive and traumatic surgical approach while maintaining the clinical benefit of a softtissue or grafting concomitant with a tunnel approach.

Keser and Dibart in 2013 [55] that sequential Piezocision to correct class III malocclusion significantly reduced the treatment time. A patient with class III malocclusion was given the option to have Orthognathic surgery but refused. Treatment is started by bonding the maxillary arch from the second molar to the second molar, excluding the left maxillary incisors for lack of space, and performing the Piezocision surgery nine days later. After Piezocision, orthodontic appointments were scheduled every two weeks instead of every four weeks. Ten weeks later, the mandible was bonded, and Piezocision was done after 14 days. In 8 months, orthodontic treatment was completed, and fixed retainers were placed. Thus, Piezocision was successfully used sequentially to correct a challenging class III malocclusion without orthognathic surgery.

Milano 2014[56] published a case with Piezocision with the use of a surgical guide to avoiding the risk involved with the surgery in case of root proximity by three-dimensional planning of the position of the bone incisions on a digital model of the arches created with the superimposition of the CT-scan of the patient and his three-dimensional models. The x-ray was taken with the patient wearing a customized tray with radiopaque markers [Fig 16].

Fig 16: Surgical stent digitally created to guide Piezocision surgery

Human studies

Aksakalli, in 2016 [57], investigated the effectiveness of Piezocision in canine distalization using three-dimensional measurements. He evaluated the transversal changes, the post distalization gingival status, and mobility scores. Piezocision-assisted canine distalization decreased the total treatment duration and anchorage loss in the molar region. No differences were found in mobility and gingival indices. Piezocision-assisted canine distalization decreased canine distalization time by half and maintained good molar anchorage with no dangerous effects on the periodontium [Fig 17].

Charavet in 2016 [58] to determine the effect of Piezocision-assisted orthodontic treatment on treatment duration time, periodontal health, alveolar crest changes analgesic intake. The overall treatment time was significantly lower, on average 43% faster. Periodontal and radiographic parameters were similar. Patient satisfaction was significantly higher for the patients who received Piezocision+

Animal studies:

Dibart in 2014 [59] studied the biological mechanism underlying Piezocision and observed that Piezocision increased the rate of bone resorption beginning on day three and continuing until day 14. After day 14, the tooth movement was the driving force for bone resorption. Piezocision leads to an increase in Osteoclastic activity starting as soon as one day after the surgery and lasting up to 7 days, suggesting a contributory effect of tooth movement. The transient osteopenia induced by the surgery seemed to help to bypass the lag phase following the displacement phase of orthodontic tooth movement hence the rapid acceleration of tooth movement.

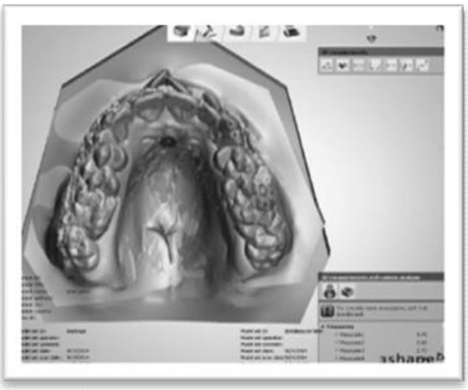

Fig 17: Superimposition of pre and post distalization digital impression from Aksakalli publication

Micro-osteoperforation

A device called Propel ™ was launched by Propel Orthodontics to further reduce the invasive nature of surgical irritation of bone, and this procedure was popularized as alveocentesis, which translates to puncturing bone [Fig 18][60].

The Micro-osteo perforation [PROPEL] device is available in 3 types [Fig 19]

Fig 18: Micro-Osteoperforation screwdriver and its application

Fig 19: The Propel device

1- **Excellerator**: it comprises of single-use tip and a fine grip handle. It consists ofan adjustable depth dial with the markings of 0mm, 3mm, 5mm, and 7mm. It can be fixed at the desired depth by rotating in a clockwise direction. In addition, the LED light depth indicator adds to its user-friendly design. However, the device is meant for single-use and cannot be sterilized, which adds to the cost of the treatment.

2-**Excellerator RT kit** comprises one large handle, one open tip, and two closed tips. The handle has a textured grip and can be sterilized. The two disposable closed tips have depth graduations at 3mm, 5mm, and 7mm, while the open tip does not show depth graduations.

3- **Excellerator PT kit**: it comprises a powered handpiece, charging unit, a contra-angled head attachment, and disposable tips. The headpiece has a digital display that shows the battery level, speed in rpm, torque, and the forward or reverse mode. The accessibility in the entire mouth is made easy with the help of attachment of contra angled head. Greater rotational speed makes the tips easily enter through the cortical bone without any need for pressure application.

Mechanism of action:

Micro osteoperforation is safe, minimally invasive by increasing the intensity of the body's natural inflammatory response through physical trauma. It involves controlled micro-trauma to the bone using micro-osteoperforation [61]. Microtrauma to the bone increases the expression of cytokines and chemokines that are usually released due to orthodontic forces. This results in an increased number of Osteoclasts being recruited to the area. As a result, there is a decrease in bone density and bone resorption resulting in faster and easier tooth movement. this process of faster bone remodeling is around the affected area and extends to the surrounding tissues. Therefore, the micro osteoperforation may not necessarily be placed very close to the tooth to be moved [62] [Fig 20].

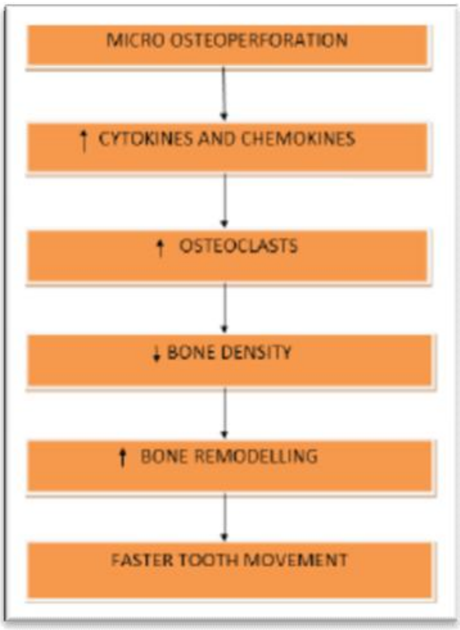

Figure 20: Mechanism Underlying Micro-osteoperforation

Method of use:

One day before the procedure patient is advised to use Chlorhexidine mouth wash twice a day. The patient is asked to rinse using 0.12 % Chlorhexidine digluconate for 1 minute. Before the procedure, the placement and depth of the micro-osteoperforations should be determined. Local anesthesia should be achieved using local infiltration. A depth of 3mm, 5mm, or 7 mm is set on the device by rotating the depth dial in the clockwise direction for anterior, premolar, and molar regions, respectively. The device is positioned with a tipperpendicular at the point of contact, and gentle pressure is applied.

The device should be removed once the LED indicator turns red once the desired depth is obtained, rotating counter-clockwise. One to three micro-osteoperforations are done either on the buccal or the lingual aspect of the interdental bone.

Indications:

Micro-osteoperforations can be used to increase the rate of tooth movement around teeth that are required to be moved long distances, such as forced eruption, ectopic canines, edentulous space closing, etc.

Contraindications:

Micro-osteoperforation should not be used nearby anchorage devices such as temporary anchorage devices like implants and anchor teeth. It causes a reduction in the density of the bone in the involved area and can cause loss of anchorage. In addition, it cannot be used in patients with medical conditions such as seizures, hematological disorders, diabetes, etc.

Advantages:

It increases the rate of bone remodeling, thereby reducing the orthodontic treatment time. It is performed under local infiltration anesthesia; hence there is no pain during the procedure. It does not cause external root resorption.

Disadvantages:

The increase in cytokine activity decreases after two months. Hence, the procedure has to be repeated every one or two months. In addition, the micro osteoperforation device is expensive, which increases the cost of the treatment.

Studies:

Alikhani [63] concluded that MOP therapy is a safe, effective, and comfortable procedure that accelerates OTM and can reduce treatment time by 62%. However, several other studies found no clinically significant acceleration in OTM. Swapp et al. [64] believed that MOPs did not cause accelerated OTM on foxhounds because the MOPs only perforated the cortical bone and did not affect the medullary bone. Cramer et al. [65] believed that the MOPs did not accelerate OTM on seven beagle dogs because the extent of RAP only occurred within 3mm of the MOP. Mahmoudi et al. [66] came to the same conclusion that MOPs did not accelerate OTM, contributing the confounding results to patient variation in biologic response.

Non-invasive procedures involving the principle of rapid acceleration phenomenon

Low-level laser therapy

Low-level laser therapy or Photo-biomodulation is a form of light therapy which involves the therapeutic application of light in the visible, near-infrared spectrum. Positive biological outcomes are seen with light in the red to near-infrared range (600–1000nm). Photo biomodulation improves mitochondrial metabolism, promotes wound healing and angiogenesis in the skin, bone, nerve, and skeletal muscle in primary neurons [67]. The optical window lies between 600-1200nmfor biological tissues [Fig 21].

Fig 21: Corticotomy. Mucoperiosteal flaps are raised and corticotomy is carried out on buccal and palatal surfaces. Monocortical perforations are performed in areas of intended tooth movement

Mechanism of action

It is reported that following the application of light, cytochrome C oxidase (CCO) in mitochondria of cells absorb photons which leads to proton pumping and increased adenosine triphosphate (ATP) production. Increased energy to the cells in ATP increases cellular metabolism and accelerates bone remodeling [68]. Few *in vitro* studies on bone metabolism have shown that low-level light increases proliferation and differentiation of osteoblasts, increases bone nodule formation, the activity of alkaline phosphatase (ALP), and gene expression, and also enhances osteoblastic and Osteoclastic activity [69]

Effect on tooth movement

Animal studies showed that wavelengths between 650 and 940nm increased tooth movement rate two to three times compared with the controls, which were supported by histological evidence. [70-71]. Shaughnessy et al. [72] studied the effects of intraoral photo-biomodulation on the initial alignment phase. They found that photo-biomodulation increased the rate of tooth movement by three folds and decreased the duration by 54% during initial alignment.

Effect of photobiomodulation on root resorption:

Nimeriet al. [73] showed no significant root resorption in the photobiomodulation group, one of the common sequelae of orthodontic treatment. On the other hand, Ekizer et al. [74] showed a significant reduction of root resorption with photo-biomodulation.

Effect on pain modulation:

Recently proposed theories offer insights into the phototransduction processes associated with laser-induced analgesia. Successful clinical trials involved applications at multiple points at the apices and around the crown of the tooth.

Safe range for therapeutic exposure:

a safe range for therapeutic exposure is 10–30 J/cm2low-power output and exposure of less than 500 mW/cm2[75].Baxter and Diamantopoulos (1995) [76] stated that laser wavelength and energy density are the most important factors determining the tissue response.

Mester et al. (1985) [77] stated that the most effective energy density rangeis.5-4 J/cm2 is atthe start of a photobiological tissue reaction. Esnouf et al. (2007) [78] stated that to reach the photoreactive parameters of low-level laser therapy, factors including light intensity, power output, power density, total irradiation, and energy density are important. Van Breugel et al. (1992) [79] reported that power density is more important than the total dose atthe start of bio modulation. Sommer et al. (2001) [80] believe that energy density and light intensity are more important Biomodulation factors.

Kujawa et al. (2003, 2004) [81-82] reported that an increase in acetylcholinesterase and internal protein storage following LLLT results in increased cellular longevity.

Yasaei et al. [83] concluded that the LLLT increases RANK-L and macrophage colony-stimulating factor (M-CSF), increasing osteoclastogenesis and accelerating orthodontic tooth movement.

Cyclic force device- vibration:

The cyclic vibratory method is to give light alternating forces on the teeth via mechanical radiations. The response of cells to mechanical stress appears within 30 minutes.

Procedure:

A vibration-imposed system device consists of a vibration controller, charge amplifier, force sensor, and accelerometer. The Signals get transferred into the vibration controller from the force sensor and the accelerometer then the amplified signal is transferred to the vibrator. Vibration controller, when applied, the control signal through the power amplifier is controlled by the output signal from the accelerometer to maintaining the acceleration at 1.0 meters per square second (m/s2). The adhesive is used to fix the top of the vibrator on the tooth. The vibration tests were carried out for 5 minutes; the resonance curves were displayed on the monitor of the vibration controller as frequency-force relationships.

Clinical trials were conducted by various researchers [83-87] on the human population using oral vibrating devices such as Accledent ™Electric toothbrushes to increase the rate of tooth movement.

Shapiro et al. [87] were the first to introduce pulsating forces in orthodontics to stimulate tooth movement. Kurz [88] devised dental vibrations applying apparatus and claimed that it shortens the orthodontic treatment period.

Mechanism of action:

Cellular signaling pathways in bone are initiated by mechanical loading and osteocytes are considered mechano responsive cells triggered by shear stress and bone bendingduring the vibrational stimulus. It is followed by the differentiation of osteoblasts and stimulation of bone genes [89]. Vibrational stimulant enhances interleukin1β secretion, which induces receptor activator of nuclear factor kappa-B ligand (RANKL) expression in osteoblasts and periodontal ligament and promotes differentiation preosteoclasts [90]. In addition, orthodontic tooth movement is accelerated as vibrations encourage osteoclast formation and alveolar bone remodeling [91].

Effect on tooth movement:

Kau et al. [92] used the Accledent device (Orthoaccel Technologies, California) regularly for the 6-months study period. The rate of displacement of teeth was used to assess the rate found significantly higher than normal rates of tooth movement. Bowman [93], in his study, found that on average, there was a 30% increase in the rate of tooth movement compared to controls.

Pavlin and Gluhak-Heinrich [94] using Accledent device, the rate of orthodontic tooth movement can be increased, ultimately reducing the overall treatment time. In addition, a double-blind, randomized, controlled trial was conducted by Dubravko Pavlin et al. [95] concluded that vibrations accelerate the rate of orthodontic tooth movement.

Effect on pain perception:

Miles et al. [96] and Woodhouse et al. found no significant difference in pain intensities between the Accledent and control groups using a visual analog scale. On the contrary, Lobre et al. [97] evaluated the pain intensities during four months treatment period and concluded that patients using acceledent perceived pains of lower intensities during the treatment period.

Effect on duration of treatment:

The study concluded thatin Class II non-extraction treatment, the amount of time required in achieving both dental alignment and leveling was reduced by using an Accledent device to apply vibration.

Y Chung How Kau [98] concluded that there was a significant increase in the rate of tooth movement in patients receiving vibrations, and patient compliance with the use of the device was 67%. In addition, patient acceptance with the device was clinically significant.

In a study where 60Hz of vibration was applied to molars, Nishimura significantly accelerated OTM and less root resorption during expansion. The belief that the vibratory resonance may stimulate RANK-L expression in the PDL.[99] In a systematic review by Jing and Xiao, it was concluded that 25% of the studies showed accelerated canine retraction while 50% of the studies found no accelerated tooth alignment. The systematic review concluded that more quality research needs to be conducted. [100]

Indications:

- To reduce the treatment time of fixed orthodontic treatment
- As an adjunct to clear aligners
- Management of mild to moderate cases

Contraindications:

- Patients on osteoporosis drugs
- Case with poor oral hygiene
- Presence of periodontal disease

Advantages:

- Ease of use
- Performed easily by a layman
- Non-invasive
- Readily accepted by patients
- Decreases the overall treatment time
- Decreases the pain
- Minimal side effects

Disadvantages:

- Following are the disadvantages of vibrations
- Requirement of special equipment for use
- Requires patient compliance
- Used regularly for appropriate results
- Combined with orthodontic therapy such as clear aligners or braces

Low-intensity pulsed ultrasound ultrasound:

Low-intensity pulsed ultrasound (LIPUS) is one of the non-invasive, non-pharmacological methods to accelerate OTM that has been used in the medical field for six decades as in sports medicine, myofunctional therapy, joint stiffness reduction, increase muscle mobility, and healing of non-healing bone fractures [101].It is a form of mechanical energy transmitted as acoustic pressure waves beyond the range of human hearing when it passes through the living tissues, causes micromechanical strain, resulting in cascades of molecular events [102]. LIPUS with intensities between 30 and 100 W/cm2 induces biochemical changes at a cellular and molecular level. It is not thermal. It does not use ionizing radiation[103]. At different intensities, it can be used for both diagnostic and therapeutic purposes. To bring out beneficial effects of LIPUS has to be used with certain parameters, including a 1.5-MHz frequency repeated at 1kHz,30-mW/ cm2 intensity and a pulse width of 200 μs administered for 20min each day[104] [Fig 22].

Fig 22: Low-intensity pulsed ultrasound (LIPUS) device (Aevo System). (A): Handheld electronics; (B): mouthpieces; and (C): ultrasound coupling gel.

Mechanism of action:

Many studies elucidated the therapeutic benefits of LIPUS. LIPUS possesses a bio stimulatory effect. Following the application of LIPUS, It induces micro stream signals and mechanical stresses, stimulates cell membranes, cytoskeleton leading to gene transcription and signal transduction.[105] LIPUS increases the response of certain markers such as Interleukin-8 (IL-8), vascular endothelial growth factor (VEGF), transforming growth factor beta (TGF-β),Basic fibroblastic growth factor (BFGF), ALP, and suppresses Osteoclastic markers[106]. LIPUS augments orthodontic tooth movement by elevation of the Runt-related transcription factor2 (RUNX2)/Hepatocyte Growth factor (HGF)/ Bone Morphogenic Protein-2 (BMP-2) signaling pathway gene expression and RANKL expression, results in an increase in the rate of alveolar bone remodeling.[105]

Effect on tooth movement

A study performed by Xueet al. [107] on 48 male Wistar rats showed that the rate of orthodontic tooth movement in the LIPUS application group was increased by approximately 45% compared to the control group. In vitro study by Hu et al. [108] from the isolated periodontal ligament tissue from the extracted premolars, LIPUS application showed that LIPUS facilitates the Osteogenic differentiation of human periodontal ligament cells and helps in periodontal regeneration. El- Bialy et al. [109] concluded that there is an29 percent increase in tooth movement.

Effect on root resorption:

LIPUS has shown decreased root resorption in humans. In addition, it enhances cementum and pre-dentin formation and increases sub-odontoblasts and periodontal ligament cell numbers.

Raza et al. [110] evaluated the effects of LIPUS on Orthodontically induced root resorption in human subjects. Less resorption lacunae were seen in LIPUS treated teeth compared with the controls, statistically and clinically significant.

In in-vitro, animals and human studies, LIPUS minimized orthodontically induced tooth root resorption (OITRR), accelerate orthodontic tooth movement and increased expression of collagen 1 (Col1), alkaline phosphatase (ALP), osteoprotegerin (OPG), and receptor activator of nuclear factor-kappa-ligand (RANK-L) [111-116].

Conclusion

Acceleration of tooth movement is increasing demand now because of patients' interest in getting the treatment completed in less time span and fewer visits. Surgical techniques are more invasive but have fewer side effects. Less invasive surgical techniques can be used to accelerate tooth movement With increasing patient compliance. Accelerating orthodontic techniques in every technique being used can be highly useful for fastening the treatment, increasing the rate of tooth movement and decreasing the treatment time.

Clinical application for the future:

In the physical approach, low-level laser therapy is the most promising method; however, contradictory results were shown. This is due to the different experimental designs. Piezocision technique is one of the newest techniques, and it also has a good clinical outcome and the least invasive in the surgical approach. Due to the lack of standardized protocols, however, evidence-based conclusions cannot be made. Limited evidence is available regarding the effectiveness of surgically accelerated orthodontics. Micro-osteoperforation is considered the best surgical approaches because of their promising results in orthodontic tooth movement [OTM] acceleration and non-invasive nature; clinical studies are warranted for identifying the best method to accelerate OTM, with due attention to the application protocols, adverse effects, and cost-benefit analysis and the inclusion of a higher number of samples.

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