T.C.

YEDITEPE UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

DEPARTMENT OF ORTHODONTICS

COMPARISON OF THE EFFECTS OF PIEZOCISION AND MICRO-OSTEOPERFORATIONS ON THE RATE OF ORTHODONTIC TOOTH MOVEMENT DURING MAXILLARY CANINE RETRACTION

DOCTOR OF PHILOSOPHY THESIS

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ONAY

Bu tez Yeditepe Üniversitesi Lisansüstü Eğitim-Öğretim ve Sınav Yönetmeliğinin ilgili maddeleri uyarınca yukarıdaki jüri tarafından uygun görülmüş ve Enstitü Yönetim Kurulu'nun ..30./.12../.2016.. tarih ve 2016/25-04......sayılı kararı ile onaylanmıştır.

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Sağlık Bilimleri Enstitüsü Müdürü

DECLARATION

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.

Date : 20.12.2.106

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DEDICATION

This thesis work is dedicated to my supervisor Prof.Dr. Fulya Özdemir, and my co-supervisor Assis.Prof.Dr. Murat Tozlu. I dedicate this work also to my wife, who has been a constant source of support and encouragement during the challenges of post graduate school and life, also dedicated to my parents, Elhadi and Hana, who have always encouraged me and whose good examples have taught me to work hard for the things that I aspire achieve.

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LIST OF SYMBOLS AND ABBREVIATIONS

a: Angle between the line through mesial and distal of the canine and median raphe

AOO: Accelerated Osteogenic Orthodontics

cAMP: Cyclic Adenosine Monophosphate

CCL: Chemokine C Ligand

Cm^2: Square Centimeter

CO2: Carbon Dioxide

COX: Cyclooxygenase

CXCL: Chemokine X C Ligand

dc: The distance between the tip of the canine and rugae line

dm: The distance between the central fossa of the first molar and the rugae line

ERR External Root Resorption

Er:YAG: Erbium-doped: Yttrium Aluminum Garnet

g: Gram

GT: Gene Therapy

Hz: Hertz

ICC: Intraclass Correlation Coefficient

INF: Interferon

IL: Interleukin

J: Joule

LIPUS: Low Intensity Pulsed Ultrasound

LLLT: Low Level Laser Therapy

M-CSF: Macrophage Colony-Stimulating Factor

MIRO: Minimally Invasive Rapid Orthodontics

mm: Millimeter

MMPs: Metalloproteinases

MOPs: Micro-osteoperforations

MPR: Median Palatine Raphe

N Newton

n: Sample Size

Ni-Ti: Nickel Titanium

OPG: Osteoprotegerin

OTM: Orthodontic Tooth Movement

p: Level of statistical significance

PAOO: Periodontally Accelerated Osteogenic Orthodontics

PDL: Periodontal Ligament

PTH: Parathyroid Hormone

RAP: Regional Acceleratory Phenomenon

RANK: Receptor Activator of Nuclear Factor kB

RANKL: Receptor Activator of Nuclear Factor-Kappa

SAOT: Surgically Assisted Orthodontics

SAP: Systemic Acceleratory Phenomenon

SD: Standard Deviation

TNF: Tumor Necrosis Factor

V: Volt

W: Watt

(°): Degree

ABSTRACT:

Various attempts have been made to shorten time necessary for orthodontic treatment. The use of medications, mechanical and physical stimulations, and surgical interventions have attracted considerable scientific interest. Over the years, several surgical techniques have been developed to reduce the overall treatment time. The aim of this study was to compare the effects of two minimally invasive procedures; the first one being piezocision, and the second micro-osteoperforations, on the rate of orthodontic tooth movement during maxillary canine retraction. The sample consisted of 12 patients exhibiting malocclusion requiring therapeutic extraction of the maxillary premolars, with subsequent retraction of the maxillary canine. One side of the maxillary arch was randomly assigned to receive piezocision, and on the opposite side micro-osteoperforations were performed. Canine retraction was started on both sides 6 months after the extraction of premolars and immediately after the surgical procedures; by using closing coil NiTi spring that applied force of 150 g. Miniscrews were used as anchorage device in both sides. The patients were evaluated every 3 weeks for total follow-up period of 6 weeks. The obtained results showed that the amount of canine distalization on the piezocision side after 3 weeks was1.22±0.15 mm, after 6 weeks of retraction the canine moved distally 2.21±0.3 mm. On the other hand, on micro-osteoperforations side, and after 3 weeks the canine moved distally 0.81±0.24 mm and moved 1.6±0.34 after 6 weeks. The rate of canine retraction was statistically significantly higher on the piezocision side compared to the MOPs side. No significant amounts of anchorage loss or canine rotation were observed in this study.

Key Words: minimally invasive, tooth movement, piezocision, micro-osteoperforations

ABSTRACT (Turkish):

Ortodontik tedavi için gerekli olan sürenin kısaltılabilmesi amacıyla birçok girişimde bulunulmuştur. İlaç kullanımı, mekanik ve fiziksel uyaranlar ve cerrahi girişimler bir bilimsel alanda ilgi çeken yöntemlerdir. Yıllar içerisinde, toplam tedavi süresini azaltmak amacıyla birçok cerrahi teknik geliştirilmiştir. Bu çalışmanın amacı, minimal invaziv yöntemler olan piezoinsizyon ve mikroosteoperforasyon prosedürlerinin maksiller kanin dişi retraksiyonu sırasında ortodontik diş hareketinin hızına olan etkilerinin karşılaştırılmasıdır. Çalışma grubu maksiller premolar dişlerinin tedavi amaçlı çekiminin ardından kanin dişi retraksiyonun endike olduğu maloklüzyona sahip 12 hastadan oluşmaktadır. Maksiller arkın rastgele olarak seçilen bir yarısına piezoinsizyon uygulanırken diğer yarısına ise mikroosteoperforasyon uygulanmıştır. Her iki tarafta da kanin retraksiyonuna premolar dişlerin çekiminden 6 ay sonra ve cerrahi uygulamaların hemen ardından 150 gr. kuvvet uygulayan NiTi yaylar ile başlanmıştır. Her iki tarafta da ankraj ünitesi olarak minividalar kullanılmıştır. Hastalar her 3 haftada bir değerlendirilerek toplam 6 hafta takip edilmiştir. Elde edilen sonuçlara göre, piezoinsizyon tarafında 3 haftanın sonunda kanin distalizasyon miktarı 1,22±0,15 mm iken, 6 hafta retraksiyon sonunda kanin dişi 2,21±0,3 mm distale hareket etmiştir. Öte yandan, mikroosteoperforasyon tarafında 3 hafta sonra kanin dişi 0,81±0,24 mm distale hareket ederken, 6 haftanın sonunda 1,6±0,34 mm hareket etmiştir. Piezoinsizyon tarafindakai kanin dişi distalizasyon MOPs tarafi ile karşılaştırıldığında istatistiksel olarak anlamlı derecede yüksek bulunmuştur. Bu çalışmada anlamlı derecede ankraj kaybı veya kanin dişi rotasyonu gözlenmemiştir.

Anahtar kelimeler: minimal invaziv, diş hareketi, piezoinsizyon, mikroosteoperforasyon

1. INTRODUCTION AND PURPOSE

The goal of orthodontic treatment is to improve the patient life adjustment through enhancement of dentofacial functions and esthetics. Shortening orthodontic treatment duration is an issue of importance particularly for adults. The duration of comprehensive orthodontic treatment can ranges from approximately 12 to 36 months, depending on treatment options and individual characteristics (1) .

To shorten the time necessary for orthodontic tooth movement, various attempts have been made. These attempts mainly fall into three categories. The first is local or systemic application of drugs such as Prostaglandins, interleukins, leukotrienes, and vitamin D. The second category is mechanical or physical stimulation; these include direct electrical current, vibration, pulsed electromagnetic field, and low-energy laser. And lastly, surgical methods include corticotomy, micro-osteoperforations, and Piezocision.

In 1959, Köle (2) described a surgical procedure combining vertical –proximal cortical incisions with subapical horizontal osteotomy cuts from the buccal to the palatal plate. The authors explained that rapid tooth movements observed following surgery were caused by what believed to be bony “block movement” more or less independent of each other. Subsequently, many authors published variants of technique where the subapical osteotomies were removed and only superficial corticotomy incision were realized. However, all explained that rapid tooth movements were allowed by the “bony block”.

In 2009, (3) Wilcko introduced a technique combining alveolar corticotomies and bone grafting to prevent the risk of dehiscence and fenestration. In this approach, cortical incisions circumscribing the roots are made on both the buccal and palatal side following full thickness muco-periosteal flaps; the bone graft is then placed. The authors speculated that the rapid orthodontic orthodontic movements clinically observed in patients who underwent selective decortication might be due to an accelerated demineralization-remineralization process rather than “bony block” movement.

Although effective, corticotomy techniques present significant postoperative discomfort. The aggressive nature of these particular methods related to the elevation of muco-periosteal flaps and to the length of the surgery raised reluctance among both patients and dental community. To reduce these risks and postoperative discomfort, various attempts have been made to accelerate orthodontic tooth movement with minimum invasion and better patient acceptance.

In 2007, Vercelotti (4) reported a reduction of orthodontic treatment time by 60% to 70% after corticotomy performed by means of piezosurgical micro-saw. The technique performed only vestibular incisions but the elevation of a flap prior to the corticotomy was maintained thus only relatively reducing surgical time and postoperative discomfort.

In 2009, Dibart *et al*. (5) described a new minimally invasive procedure that they called Piezocision. This technique combines micro-incisions limited to the buccal gingiva that allow the use of piezoelectric knife to give osseous cuts to the buccal cortex and initiate regional acceleratory phenomenon (RAP) without involving palatal or lingual cortex. The procedure allows for rapid tooth movement without the downside of an extensive and traumatic surgical approach while maintaining the clinical benefit of a bone or soft tissue grafting concomitant with a tunnel approach.

M.Alikhani *et al*(7) in 2013 performed a study to investigate the effect of micro-osteoperforations (MOPs) on the rate of orthodontic tooth movement during maxillary canine retraction in humans. Three small shallow perforations were performed in the extraction space at equal distance from the canine and the second premolar. Each perforation was 1.5 mm wide and 2 to 3 mm deep. They concluded that MOPs significantly increased the expression of cytokines and chemokines known to recruit osteoclast precursors and stimulate osteoclast differentiation. Also they found that MOPs increased the rate of canine retraction 2.3-fold compared to the control group.

In the present study, the effects of two orthodontic tooth movement accelerating methods were compared. The first is flapless Piezocision, which considered as the latest technique in accelerating orthodontic tooth movement. This procedure combines micro incisions and localized piezoelectric surgery. The second is MOPs, which is a process of performing limited shallow perforations of the buccal cortical plate. The effects of these techniques were compared while retracting the maxillary canine toward the space of extracted maxillary first premolars. Both techniques are minimally invasive and performed without muco-periosteal flaps elevation.

2. LITERATURE REVIEW

2.1. Physiology of Orthodontic Tooth Movement

Tooth movement by orthodontic force application is characterized by remodeling changes in dental and paradental tissues, including dental pulp, periodontal ligament (PDL), alveolar bone, and gingiva (8). Orthodontic tooth movement differs markedly from physiological dental drift or tooth eruption. The former is uniquely characterized by the abrupt reaction of compression and tension regions in PDL (9). Orthodontic tooth movement can occur rapidly or slowly, depending on the physical characteristics of the applied force, and the size and the biological response of PDL (10).

Research in the field of orthodontic tooth movement (OTM) have evolved rapidly and changed considerably since the work of Reitan et al in 1950s (9). Moreover, the importance of all tissues including alveolar bone, PDL, root cementum, and associated vascular and neural networks, has been investigated to delineate the role played by them (11). This growing attention given to the biological basis of orthodontics expands current knowledge and augments understanding of the effects produced by mechanical loading over living tissues.

2.1.1. Theories of Orthodontic Tooth Movement

Orthodontic tooth movement has been defined as the result of a biologic response to interface in the physiologic equilibrium of the dentofacial complex by an externally applied force (12).

Pressure –Tension Theory

Classic histologic research about tooth movement by Sandstedt (1904), Oppenheim (1911), and Schwarz (1932) led them to them to hypothesize that a tooth moves in the periodontal space by generating a “pressure side” and a “tension side”. This hypothesis explained that, on the pressure side, the PDL displays disorganization and diminution of fiber production. Here, cell replication decreases seemingly due to vascular constriction. On the tension side, stimulation produced by stretching of PDL fiber bundles results in an increase in cell replication. This enhanced proliferative activity leads eventually to an increase in fiber production (8,13).

Schwarz (14) detailed the concept further, by correlating the tissue response to the magnitude of the applied force with the capillary bed blood pressure. He concluded that the forces delivered as a part of orthodontic treatment should not exceed the capillary bed blood pressure (20-25 g/cm^2 of root surface).

The concept of pressure-tension theory in orthodontic tooth movement was evaluated mainly by histologic study of periodontium. It postulated that width changes in the PDL cause changes in cell population and increase in cellular activity. There is an apparent disruption of collagen fibers in the PDL, with evidence of cell and tissue damage. The first sign of hyalinization is the presence of pyknotic nuclei in cells, followed by areas of acellularity, or cell-free zones. The resolution of the problem starts when cellular elements such as macrophages, foreign body giant cells, and osteoclasts from adjacent undamged areas invade the necrotic tissue. These cells also resorb the underside of bone immediately adjacent to the necrotic tissue. This process is known as undermining resorption (15,16).

Reitan (9) in his classic article on histologic changes after orthodontic force application, reported that hyalinization refers to cell-free areas in the PDL, in which the normal tissue architecture and staining characteristics of collagen in the processed histologic material have been lost. He could observe that; 1) hyalinization occurred in the PDL after the application of even minimal force, meant to obtain a tipping movement; 2) more hyalinization occurred after application of force if a tooth had a short root; 3) during translation of a tooth, very little hyalinization was observed.

The Bone-Bending Theory

Farrar was the first to suggest, in 1888, that alveolar bone bending plays a pivotal role in orthodontic tooth movement (18).This hypothesis was later confirmed with the experiments of Baumrind (13) in rats and Grimm (19) in humans. According to that experiment, when an orthodontic appliance is activated, forces delivered to the tooth are transmitted to all tissues near force application. These forces bend bone, tooth, and the solid structures of the PDL. Bone was found to be more elastic than the other tissues and to bend far more readily in response to force application.

The active biologic processes that follow bone bending involve bone turnover and renewal of cellular and inorganic fractions. These processes are accelerated while the bone is held in the deformed position. These authors stated that “reorganization proceeds not only at lamina dura of the alveolus, but also on the surface of every trabaculum within the corpus of bone”. The force delivered to the tooth is dissipated throughout the bone by development of stress line, and further force application becomes a stimulus for altered biological responses of cells lying perpendicular to the stress lines. The altered activity of cells in turn modifies the shape and internal organization of bone, to accommodate the exogenous forces acting on it.

Experimenting with dog mandibles in vitro and in vivo, Pollak *et al*. (20) demonstrated that orthodontic canine tipping bends the alveolar bone, creating on it concave and convex surfaces, identical to those in long bones. In areas of PDL tension, the interfacing bone surface assumes a concave configuration, in which the molecules are compressed, whereas, in zones of compressed PDL, the adjacent alveolar bone surface becomes convex. Hence there is no contradiction between the response of the alveolar bone and other parts of the skeleton to mechanical loading.

Piezoelectric Signals Theory

In 1962, Bassett and Becker (21) proposed that in response to applied mechanical forces, there is generation of electric potentials in the stressed tissues. These potentials might charge macromolecules that interact with specific sites in cell membranes or mobilize ions across cell membranes. Zengo *et al*. (22) measured the electric potentials in mechanically stressed dog alveolar bone during in-vivo and in-vitro experiments. They demonstrated that the concave side of orthodontically treated bone is electronegative and favors osteoblastic activity, whereas the areas of positivity or electrical neutrality “convex surfaces” showed elevated osteoclastic activity.

Piezoelectricity is a phenomenon observed in many crystalline materials, in which a deformation of a crystal structure produces a flow of electric current as electrons are displaced from 1 part of the lattice to another (8). The 2 unusual properties of piezoelectricity, which seem to not correlate well with orthodontic tooth movement are (1) a quick decay rate, where the electron transfer from 1 area to another after force application reverts back when the force is removed, which does not or should not happen once the orthodontic treatment is over; and (2) production of an equivalent signals in the opposite direction upon force removal(12).

2.1.2. Phases of Orthodontic Tooth Movement

In 1962, Burstone (23) suggested that, if the rates of tooth movement were blotted against time, there would be 3 phases of tooth movement; an initial phase, a lag phase, and a postlag phase.

- The initial phase: characterized by rapid tooth movement immediately after the application of force to the tooth. This rate can be largely attributed to the displacement of tooth in PDL space.
- Lag phase: immediately after the initial phase, there is a lag period with relatively low rates of tooth displacement or no displacement. It has been suggested the lag is produced by hyalinization of the PDL in areas of compression. No further tooth movement occurs until cells complete the removal of all necrotic tissues.
- Post-lag phase: It is the third and last phase of tooth movement. It follows the lag phase period, during which the rate of tooth movement gradually or suddenly increases.

2.1.3 Pathways of Tooth Movement

Based on research in basic biology, as well as clinical observations, Mostafa et al. (24) proposed an integrated hypothetical model for tooth movement. This model consists of two pathways, I and II, which work concurrently to induce tooth movement.

Pathway I

Pathway I state that application of orthodontic force lead to creation of vectors of pressure and tension, leading to bone bending with subsequent generation of tissue bioelectric polarization and bone remodeling. Mostafa et al (24) state that this phenomena, along with membrane electrical polarization by piezoelectric processes, act on cell-surface cyclic nucleotide pathway, leading to changes in the levels of intracellular second messengers. This effect, eventually will lead to alterations in cell proliferations, differentiations, and activation.

Pathway II

In this alternative pathway, Mostafa *et al* (24) stated that the orthodontic tooth movement was attributed to classic inflammatory response following force applications. Inflammatory response is triggered by orthodontic force and the resulted increased vascular permeability and cellular infiltration in the involved dental and paradental tissues. As a result of these processes lymphocytes, monocytes, and macrophages invade these tissues, enhancing prostaglandin release and hydrolytic enzyme secretion. The local increased levels of prostaglandins and a subsequent increase in cellular cAMP concentrations increase osteoclastic activity.

2.2. Cellular and Tissue Reactions to Orthodontic Force

Orthodontists work in a unique biological environment wherein applied forces engender remodeling of both mineralized (alveolar bone) and nonmineralized (PDL and gingiva) paradental tissue, including associated blood vessels and neural elements. Bone remodeling processes begin when an orthodontic treatment applied force is applied over periodontium which, in turn, generates aseptic inflammatory response. This inflammation alters homeostasis and microcirculation of PDL, thereby creating areas of ischemia and vasodilatation, which results in the release of several biological mediators, such as cytokines, chemokines, growth factors, neurotransmitters, metabolites of arachidonic acid and hormones. These molecules trigger a number of cellular responses that will promote bone resorption by osteoclasts in the pressure sites and bone formation by osteoblasts in the tension side (11).

The histological changes which occur when forces are applied to teeth are well documented. Very low forces are capable of moving teeth. Classically, ideal forces in orthodontic tooth movement are those which just overcome capillary blood pressure. In this situation bone resorption is seen on the pressure side and bone deposition on the tension side. Teeth rarely move in this ideal way. Usually force is not applied evenly and teeth move by series of tipping and uprighting movements. In some areas excessive pressure results in hyalinization where the cellular component of periodontal ligament disappears. The hyalinized zone assume a ground glass appearance but this returns to normal once the pressure is reduced and the periodontal ligament repopulated with normal cells. In this situation a different type of resorption is seen whereby osteoclasts appear to “undermine” bone rather than resorbing at the “frontal” edge (25).

Mechanically induced remodeling is not fully understood. The role of periodontal ligament has been questioned since tooth movement can still occur even where the periodontal ligament is not functioning normally. The ligament itself undergoes remodeling and the role of matrix metalloproteinases (MMPs) together with their natural inhibitors, tissue inhibitors of metalloproteinases (TIMPs) are clearly of importance (26).

Osteocytes (osteoblasts incorporated in mineralized bone matrix) are situated in a rigid matrix and are thus ideally positioned to detect changes in mechanical stresses. They could signal to surface lining osteoblasts and thus bone formation and indeed bone resorption may result. Their cellular projections favor communication with neighboring osteocytes, as well as with alveolar bone surface-lining cells and bone marrow cavity cells (8).

Osteoclasts are multinucleated cells derived from precursors in the myeloid/monocyte lineage that circulate in the blood after being formed in the bone marrow. They are only cells in nature that can degrade mineralized bone tissue and are important for physiological remodeling and modeling processes, calcium homeostasis, tooth eruption, and orthodontic tooth movement. Mature osteoclasts attach to bone surface by sealing zone. In this area proton pumps and chloride channels are expressed. They are important for extracellular matrix proteins (27).

When alveolar bone is stimulated to resorb by means of an orthodontic force, a sequence of events is initiated and ultimately results in recruitment, differentiation, activation and maintenance of osteoclasts in bone remodeling sites. Osteoclastogenesis begins with stem cells division and proliferation of osteoclast precursors cells in hematopoietic tissues (bone marrow, spleen, Liver and peripheral blood). The second step is the migration of cells to bone resorption sites where they will be differentiated and activated. Tooth movement is directly linked, quantitatively and qualitatively, to recruitment, differentiation, activation and maintenance of these cells in these sites (28).

Since osteoclasts are bone specific cells, they are recruited from blood stream by chemotactic factors released from components of bone matrix and osteoblasts (11). After proliferation and migration of osteoclast precursors to bone remodeling sites, these progenitors will differentiate when their receptor c-Fms interacts with ligand macrophage colony-stimulating factor (M-CSF), which is also important for osteoclast survival (29). Specific differentiation of osteoclasts is due to activation of RANK (receptor activator of nuclear factor-kB) by RANKL (receptor activator of nuclear factor-kB ligand) expressed by stromal cells in bone marrow and osteoclasts (27,29).

Osteoblasts are of mesenchaymal origin and are responsible for bone formation during embryonic development, growth, bone remodeling and fracture healing. In orthodontics, bone formation begins 40-48 hours after force application PDL tension sites. Osteoblasts, which maintain direct contact with osteocytes respond to the signals and initiate bone apposition (29). Moreover, stretched PDL fiber bundles stimulate cell replication). Stem cells (pericytes) which migrate from blood vessel walls and mesenchymal stem cells differentiate into pre osteblastic cells 10 hours after force application. Chemokines, cytokines, and growth factors are directly involved in this process (11).

Osteoblasts positively regulate osteoclasts activity by expressing cytokines such as RANKL, a key activator of osteoclast differentiation, and negatively by expression of osteoprogerin (OPG), a soluble decoy receptor that inhibits RANKL (28,29). Other cytokines playing a role in bone remodeling induced by orthodontic forces are : tumor necrosis factor (TNF)-α, Interleukins (IL)-1β, IL-2, IL-3, IL-3, IL-4, IL-5, IL-6, IL-10, interferon- γ (INF- γ), tissue biomarkers (matrix metalloproteinases (MMP)-1, MMP-2, MMP-9, tissue inhibitors of MMPs (TIMP)-1 and 2), and chemokines (CCL2, CCL3, CCL5,CCL7,CCL9,CXCL-8,CXCL9, CXCL10,CXCL12), all of which play a central role in trafficking and homing of leukocytes, immune cells and stromal cells (29,30).

Taken all together, chemokines, cytokines, and growth factors (GFs) are the main molecules involved in bone cell recruitment, activation, proliferation, differentiation and survival. These molecules stimulate PDL and bone cells organize an inflammatory response followed by osteoclastogenesis and bone resorption in compression sites, and bone neoformation by osteoblasts at PDL tension sites (31).

Orthodontic tooth movement is a biological response of the dento-alveolar tissue to an intentional application of external forces. This means that mechanical orthodontic therapies should take account of the possibilities and restrictions of this biological system. Orthodontic treatment aims at the highest rate of tooth movement without irreversible damage to roots, alveolar bone, or periodontal ligament (32). Smith and Storey concluded that not a single but a range of forces or pressures resulted in a maximum rate of tooth movement. Forces below this range cause only little movement, and forces exceeding this range slow down tooth movement (33,34).

2.3. Orthodontic versus Orthopedic Force

Orthodontic force has been defined as “force applied to teeth for the purpose of effecting tooth movement, generally having a magnitude lower than an orthopedic force,” whereas orthopedic force is defined as “force of higher magnitude in relation to an orthodontic force, when delivered via teeth for 12 to 16 hours a day, is supposed to produce a skeletal effect on the maxillofacial complex”(8). These definitions show that there is no clear distinction between orthodontic and orthopedic force, even in terms of magnitude; furthermore, many widely variable arbitrary suggestions about the characteristics of orthodontic forces abound in the literature.

Orthodontic mechanotherapy is mainly aimed at tooth movement by remodeling and adaptive changes in paradental tissues. To affect this outcome, only small amounts of force 20 to 150 g per tooth might be required. But craniofacial orthopedics is aimed at delivering higher magnitudes of mechanical forces more than 300 g in attempts to modify the form of craniofacial bones. The appliances, called craniofacial orthopedic devices, deliver macro-scale mechanical forces, which produce micro-structural sutural bone strain and induce cellular growth response in sutures (35).

2.4. Optimum Orthodontic Force

In literature, different opinions can be found about the force level that results in optimal mechanical conditions within the periodontal ligament for orthodontic movement. It is assumed that an optimal force system is important for an adequate biological response in periodontal ligament (36). It has been suggested for a long time that the optimal force is related to the surface area of the root (37,38).

Optimal orthodontic force moves teeth efficiently into desired position, without causing discomfort or tissue damage to the patient. Primarily, an optimal force is based upon proper mechanical principles, which enable the orthodontist to move teeth without traumatizing any dental or paradental tissue without moving dental roots redundantly (round-tripping) or into danger zones (compact plates of alveolar bone) (11).

In the past 70 years, the concept of optimal force has changed considerably. Schwarz (14) proposed the classic concept of the optimal force. He defined optimal continuous force as “the force leading to a change in tissue pressure that approximated the capillary vessels blood pressure thus preventing their occlusion in the compressed periodontal ligament.” According to Schwarz, forces well below the optimal level cause no reaction in the periodontal ligament. Forces exceeding the optimal level would lead to areas of necrosis, preventing frontal bone resorption. Tooth movement would thus be delayed until undermining resorption had eliminated the necrotic tissue obstacle.

The magnitude of force has received significant attention in orthodontics and it is related to other characteristics of the force system and surface area of periodontal ligament over which is dissipated. The forces, which are applied to the crown of teeth, are distributed over the entire supporting structure and so are the stresses and strains. From a cellular point of view, distribution of stress (force per unit area), distortion of periodontal ligament (shear stress, strain), and bone deformation (strain) are critical factors, and the remodeling response is directly related to stress and strain levels within periodontium (39,40).

The current concept of optimal force is based on the hypothesis that a force of a certain magnitude and temporal characteristics (continuous vs intermittent, constant vs declining) would be capable of producing a maximum rate of tooth movement without tissue damage and with maximum patient comfort. The optimal force for tooth movement may differ for each tooth and for each individual patient(12). In order to move the teeth, orthodontic treatment requires an optimum force. This optimum force should result in maximum rate of tooth movement with minimum irreversible damage. Several studies recommended a 150 g as the optimum force for canine retraction (41,42) .

2.5. Duration of Force Application

Clinical experience suggests that successful tooth movement requires a threshold of force duration of about 6h/day. It was determined in an experiment on cats that it takes about 3 h for the appearance of significant elevation in cAMP in extracts of alveolar bone and PDL, following sustained applications of tipping forces to maxillary canines (43). Recent studies have proposed a role of nitric oxide as a marker of vascular signal transduction during the initial phase of orthodontic tooth movement (44). Nitric oxide is produced by various cells and is present in blood vessels and nerves, as well as in PDL fibroblasts. This molecule has been reported to take part in bone remodeling as well as in the regulation of blood vessels and nerves (45). During the initial stages of tooth movement under the influence of light continuous forces, the activity of nitric oxide synthase in paradental tissues was found to increase as early as 1-3 h or within 6 h from the onset of treatment (46).

2.6. Miniscrews as an Anchorage Device in Orthodontic Treatment

For more than 100 years, orthodontists have searched for ideal anchorage that fits two criteria: absolute resistance to unwanted tooth movement and independence from patient compliance. Conventional intra-and extra anchorage systems often fail of providing absolute anchorage. This deficiency has spurred interest in skeletal anchorage system, which appeal to practitioners because they have potential to provide absolute anchorage and don not depend on patient compliance (47). Unlike osseointegrated implants, temporary anchorage device (TADs) are easily inserted and removed, and can be immediately loaded (47,48). They are relatively inexpensive and can be placed in a variety of locations, vastly increasing their versatility (47). Consequently, TADs are quickly becoming the preferred method of skeletal anchorage.

It is well known that, in most orthodontic extraction patients, anchorage reinforcement is a prime importance. Effective and reliable anchorage will dramatically improve the results (49). In this study, miniscrew implants were used as skeletal anchorage during canine retraction because of their simpler placement technique and the possibility of eliminating the reliance of patient compliance.

Thriuvenkatachari *et al*. (49) performed a study to compare and measure the amount of anchorage loss of the molars with and without the use of implant anchorage during canine retraction. The study included 10 orthodontic patients who had therapeutic extraction of all first premolars. The implants used in the study had 1.3 diameter and 9 mm length; the implants were placed between the roots of second premolar and first molar. They found that there is no anchorage loss on the implant side and stated that the implants can function simply and efficiently as anchors for canine retraction when maximum anchorage is demanded.

Gökçe *et al*. (50) compared the effects of conventional molar anchorage and micro-implant anchorage on the rate of canine distalization during extraction treatment. The study included 18 patients who were divided into 2 groups. In the first group, they used microimplants as anchorage device, while used the molar anchorage in the second group. They concluded that the use of microimplants instead of molar teeth during canine retraction provides a safer anchorage control in both maxilla and mandible.

Kuroda *et al*. (51) recommended that the use of miniscrews with diameter of 1.3 mm and a length of 8 mm is very advantageous. The rationale was to optimize the mechanical retention of screws and eliminate any risks of root proximity or contact that might contribute to failure during treatment. Schnelle et al (52) advocated that the placement of miniscrews between the maxillary second premolar and first molar buccally provides a safe placement as this site has a bone stock for proper miniscrews placement in the maxillary arch . Placement of the miniscrews was performed in the attached gingiva rather than the nonkeratinized mucosa because the success rate would be higher, placement and retrieval would be simpler, the likelihood of tissue proliferation around the miniscrews would be eliminated. The fact that the miniscrews were placed in thigh soft tissue, where no incision were required, might have contributed to the relatively high stability of the screws with better patient acceptance to the overall procedure (41). Kuorda et al (53) reported that miniscrews implanted without surgery have higher success rate with less pain and discomfort than those with flap surgery.

2.7. Methods to Accelerate Orthodontic Tooth Movement.

Accelerating the rate of orthodontic tooth movement is desirable to orthodontists because treatment duration has been associated with an increased risk of gingival inflammation, decalcification, dental caries, and, especially, root resorption (54). Shorter treatment duration with consequent lower cost are also important to all patients, particularly to adults who have been increasingly seeking treatment (55).

It has been estimated that teeth move 0.8-1.2 mm/month when continuous force is applied (56). Since the best way to shorten treatment time is to speed up tooth movement, new therapeutic modalities have been reported to this end. Tooth movement has been accelerated by local injection of medication, application of physical stimulator such as laser therapy, and surgically assisted methods like corticotomy.

2.7.1 Medications

Various drugs have been used since long to accelerate orthodontic tooth movement, and have achieved successful results (57,58).

2.7.1.1. Prostaglandins

Prostaglandins (PGs) are inflammatory mediators and a paracrine hormone that acts on nearby cells. They stimulate bone resorption, root resorption, decrease collagen synthesis, and increase cAMP (59). They stimulate bone resorption by increasing directly the number of osteoclasts and activating already existing osteoclasts. A lower concentration of PGE2 (0.1mg) appears to be effective in enhancing tooth movement. Higher concentration leads to root resorption (60).

In literature, in vivo and in vitro experiments were conducted to show clearly the relation between PGs, applied forces, and the acceleration of tooth movement (61). Yamasaki *et al*. (62,63) was among the first to investigate the effect of local administration of prostaglandin on rats and monkeys. In addition experiments done by Leiker *et al.* (64) have shown that injections of exogenous PGE2 over an extended period of time caused acceleration of tooth movement in rats. Furthermore, the acceleration rate was not affected by single or multiple injections or between different concentrations of the injected PGE2. However, root resorption was very clearly related to the different concentrations and number of injections given. It has also been shown that the administration of PGE2 in the presence of calcium stabilizes root resorption while accelerating tooth movement (65). Chemically produced PGE2 has been studied in human trials with split-mouth experiments in the first premolar extraction cases. In these experiments the rate of distal retraction of canines on the study side was 1.6 fold faster than the control side (66).

2.7.1.2. Vitamin D3

Vitamin D3 has attracted the attention of some scientist to its role in the acceleration of tooth movement; 1,25 dihydroxycholecalciferol is a hormonal form of vitamin D and plays an important role in calcium hemostasis with calcitonin and parathyroid hormone(PTH) (61). Vitamin D receptors have been demonstrated not only in osteoblast but also in osteoclast precursors and in active osteoclast (60).

In 1988, a set of investigators has made an experiment where they have injected vitamin D metabolite on the PDL of cats for several weeks; it was found that vitamin D had accelerated tooth movement at 60% more than control group due to the increase of the osteoclasts on the pressure sides detected histologically (67). In 2004, *Kale et al*. (68) observed that local applications of vitamins enhanced the rate of tooth movement in rats due to the well balanced bone turnover induced by vitamin D. Brandi *et al*. (69) reported that rats treated with vitamin D showed increased bone formation on the pressure side of the periodontal ligament after application of orthodontic forces. In 2004, Kawakami *et al*. (70) observed an increase in the mineral appositional rate on the alveolar bone after orthodontic force; they suggested that local application of vitamin D could intensify the reestablishment of supporting alveolar bone, after orthodontic treatment.

2.7.1.3. Parathyroid Hormone

The function of parathyroid (PTH) is to maintain a normal level of diffuse calcium and phosphorus in the blood plasma and to keep constant ratio of these minerals to each other. The parathyroids are important in regulating blood calcium level, but have little or no direct effect on growth or tooth eruption (71,72). PHT affects osteoblast cellular metabolic activity, gene transcriptional activity, and multiple protease secretion. Its effects on osteoclasts occur through the production of RANK-L (receptor activator of nuclear factor kappa- B legend), a protein playing crucial role in osteoclast formation and activity.

In 1970s, Potts *et al.* (73) in an animal studies demonstrated that PTH could induce an increase in bone turnover that would accelerate orthodontic tooth movement. More recently, an increased rate of tooth movement has been observed in rats treated with PTH, whether administrated systemically or locally. Parathyroid hormone affects both bone resorption and formation process. If PTH appears around bone cells, the effect of bone will be resorption. By contrast low level of PTH results in bone formation. When the calcium level in blood decreases, PTH will stimulate osteoclastic activity to increase calcium and phosphate absorption in the gut, and decrease calcium excretion and tubular phosphate reabsorption in the kidney. This plays a role as regulator of calcium hemostasis by PTH (73).

2.7.1.4. Corticosteroids

These drugs are used as anti-inflammatory and immunosuppressive agent in treatment of wide range of chronic medical conditions (59). A low dose (1mg/kg body weight) decreases orthodontic tooth movement by suppressing osteoclastic activity. At high dose (15mg/kg body weight) it increases osteoclastic activity thus produces more rapid orthodontic tooth movement and subsequent relapse. The main effect of corticosteroids on bone tissue is direct inhibition of osteoblstic function and thus the decrease of total bone formation (74). Decrease in bone formation is due to elevated parathyroid hormone levels caused by inhibition of calcium intestinal calcium absorption which are induced by corticosteroids. Corticosteroids increase the rate of tooth movement, and since new bone formation can be difficult in treated patient, the decrease the stability of tooth movement and stability of orthodontic treatment in general (61,74,75).

Kalia *et al.*(76) evaluated the rate of tooth movement in rats during short and long term corticosteroid therapy. They concluded that bone remodeling seemed to slow down in acute administrations, whereas the rate of tooth movement increased in chronic treatment. This suggest that orthodontic treatment should be postponed in in patient undergoing short term corticosteroids whereas, patient with long term corticosteroids therapy treatment can be continued with minimal adverse and more extensive retention may be helpful in retaining these teeth if the dentist decides to proceed with orthodontic treatment.

2.7.1.5. Cytokines

Cytokines are small proteins that are identified as mediators of bone resorption. One cytokine, interferon (IFN)-γ, acts as a bone resorption inhibitor that is opposite to other cytokines. Leukotrienes are a type of eicosanoid which is a product of archidonic acid conversion and are the only eicosanoids that are formed independently from cyclooxygenase (COX). They are produced when arachidonic acid is metabolized by lipoxygenase enzymes (77–79).

High concentration of cytokines such as interleukins IL-1, IL-2, IL-3, IL-6, IL-8, and tumor necrosis factor alpha(TNF) were found to play a major in bone remodeling; moreover interleukin-1 (IL-1) stimulates osteoclast function through its receptor on osteoclasts (80). According to Mohammed AH *et al.* (81) leukotrienes causes increase in orthodontic tooth movement, through bone remodeling whereas, leukotrienes inhibitors work the way round. Therefore, the use of leukorienes inhibitors can delay orthodontic treatment; leukotrienes can be used in future clinical applications that could result in increasing tooth movement.

2.7.2. Gene Therapy

The original premise behind gene therapy (GT) in the 90s was the believe that if a defective gene resulting in a specific disease could be replaced by a healthy one, the disease could be cured (82). However, the potential role of GT as a clinical tool has expanded and it is no longer limited to replacement of defective gene, but rather has become a tool for producing individual proteins to specific tissues and cells.

Numerous reports have described the pharmacological acceleration of orthodontic tooth movement through the activation of osteoclasts. However, due to their rapid flush out by blood circulation, daily systemic administration or daily local injection is needed. Local gene transfer has two advantages. First, it maintains local effective concentration and prolonged protein expression, regardless of blood circulation. Second, proteins expression occurs at a local site, thereby avoiding systemic effects (83).

A previous animal study conducted by Kanzaki *et al*. (84), demonstrated that transfer of RANKL gene to periodontal tissue activated osteoclastogenesis and accelerated orthodontic tooth movement without producing any systemic effects. Local gene therapy has also been used to inhibit orthodontic tooth movement which might be in the future an important tool to enforce the anchorage and unit or increase stability of orthodontic results.

Local OPG gene transfer is also clinically relevant for enhancing external root resorption (ERR) repair during retention. However, the precise biological mechanism behind this finding has not yet been fully elucidated and further studies are required to assess the role of RANK/RANKL/OPG axis in ERR repair (85).

Gene therapy is a pioneering new therapeutic modality based on complex biological system occurring at the leading edge of biomedical knowledge. It offers an alternative method to deliver proteins to a given target tissue, which, in turn, can enhance or inhibit osteoclast recruitment and lead to a more or less orthodontic tooth movement. Nonetheless, further research is needed to determine the safety and efficacy of these techniques.

2.7.3. Physical/Mechanical Methods

2.7.3.1. Direct Electric Current

This technique was tested only on animals by applying direct current to the anode at pressure sides and cathode at the tension side (by 7 V), thus generating local responses and acceleration of bone remodeling as shown by group of investigators (86). Their studies were more successful than the previous attempts because the current was applied as close as possible to the moving tooth. The bulkiness of the devices and the source of electricity made it difficult to be tested clinically. Several attempts were made to develop biocatalytic fuel cells to generate electricity intraorally by the use of enzymes and glucose as fuel (87,88). Further development of the direct device and the biocatalytic fuel cells is needed to be done so that these can be tested clinically.

Kim *et al*. (89) in human study, demonstrated that an electrical current was capable of accelerating orthodontic tooth movement. In this study the electric appliance was set in the maxilla to provide electric current of microns. They evaluated the effects of electric current while distalizing the upper canines. One side was considered as experimental side the other side as control side. The authors showed that the accumulative distance moved was significantly larger in the experimental group after one month.

2.7.3.2. Low-Level Laser Therapy

The term "laser" originated as an acronym for "light amplification by stimulated emission of radiation". It is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation(90). Laser can be classified as low and high-intensity lasers of which main differences are their potency and mechanism of action(91). High-intensity lasers, such as the CO2 laser, Nd laser: Yttrium aluminum garnet (Nd: YAG). Argon laser, Er:YAG laser, and the excimer laser act by increasing the temperature, showing a destructive potential, and are used in surgical procedures. Meanwhile, the low-intensity laser (also known as soft laser, cold laser or laser therapy does not have a destructive potential (92).

Photobiomodulation or low-level laser therapy (LLLT) is one of the most promising approaches today. Laser has a biostimulatory effect on bone regeneration, which has been shown in the midpalatal suture during rapid palatal expansion (93), and also stimulates bone regeneration after bone fractures and extraction sites (94,95). It has been found that laser light stimulates the proliferation of osteoclasts and fibroblasts, and thereby affects bone remodeling and accelerates tooth movement. The mechanism involved in the acceleration of tooth movement is by production of ATP and activation of cytochrome C, that low energy laser radiation enhanced the velocity of tooth movement via RANK/RANKL and the macrophage colony-stimulating factor and its receptor expression (96–98).

Animal experiments have shown that low-level laser can accelerate tooth movement. Furthermore, clinical trial attempts were made in which different intensities of laser were used and different results were obtained (99,100). Low-level laser therapy can be a very useful technique for acceleration of tooth movement since it increases bone remodeling without side effects to the periodontium. Laser wavelength of 800 nm and output power of 0.25 mW have indicated significant stimulation of bone metabolism, rapid ossification, and also acceleration of tooth movement to 1.5 fold in rat experiments (95,101).

In 2004, *Cruz et al*. (102) was first to carry out a human study on the effect of low-level laser therapy on orthodontic tooth movement. They showed that the irradiated canine were retracted at a rate 34% greater than the control canines over 60 days. Doshi-Mehta and

Bhad-Pati (100) in 2013, in a split mouth study, used laser at 800 nm for 10 second on the canines, both bucally and lingually, which had to be distalized after first premolar extraction. There was a highly significant positive difference in the rates of tooth movement on the experimental side compared with the control side. The mean increase in the rates of tooth movement at 3 months was 54% in the maxillary arch and 58% in the mandibular arch.

Limpanichkul *et al.* (99) in 2006, tested the effect of mechanical force combined with low-level laser therapy on the rate of orthodontic tooth movement. The obtained results showed that low level laser had no additive effect on the orthodontic tooth movement. They concluded that the energy density of LLLT used in this study (25J per square centimeter) was too low to express stimulatory effect on the rate of orthodontic tooth movement.

S.Erdem (103) in 2012 evaluated the effect of decortication procedure using ER: YAG laser on tooth movement in rats. They concluded that decortication procedure which is applied transmucousally with the use of Er:YAG laser, contributed favorably to bone remodeling and accelerated tooth movement consequently.

2.7.3.3. Vibration

Tooth movement is closely related to response of the applied orthodontic forces that cause remodeling of periodontal tissue, especially the alveolar bone. Bone is a highly specialized from of connective tissue and consists of a cortical bone that overlies the softer inner structure named cancellous or trabecular bone. Its formation and regeneration involve interaction amongst biochemical, biomechanical, cellular and hormonal signals (11).

Low-intensity pulsed ultrasound (LIPUS) is a clinically established, widely used and FDA (Food and Drug Administration) approved intervention for accelerating bone growth during healing of fractures. LIPUS is a form of physical energy that can be delivered into living tissue as acoustic intensity waves. In vivo and in vitro studies have shown the direct effect of LIPUS on bone cells (91,104).

It also has been shown that LIPUS stimulates accelerate orthodontic tooth movement by increasing osteoclast number and activity, probably by enhancing the expression of RANKL on the pressure site (105,106). These studies have hypothesized that resonance vibration might prevent blood flow obstruction and hyalinization at the compression site.

Furthermore, LIPUS minimizes orthodontically induced tooth resorption by enhancing dentine and cementum deposition, thereby forming a preventive layer against root resorption (107).

In 2008, Nishimara *et al.* (105) used a Ni-Ti expansion spring on the 1st molar of wistar rats, and applied a vibration of 60 Hz, 1m/s^2. They found that the rats that received the vibration showed increased orthodontic tooth movement. In the sectioned samples, they showed increased RANKL expression in the fibroblasts and osteoclasts of the periodontal ligament of the rats that received vibration.

Pavlin *et al* in 2015 (108) have carried out a study on 45 orthodontic patients who were treated with fixed appliance therapy. They concluded that the application of cyclic loading (vibration) of 25 N (25g) at the frequency of 30 Hz, as an adjunct to treatment with a fixed orthodontic appliance, significantly increases the rate of orthodontic tooth movement.

2.7.4. Surgical Methods

2.7.4.1. Regional Acceleratory Phenomenon (RAP)

Orthopedist Herald Frost in 1983 (109,110) recognized that surgical wounding of osseous tissue results in striking reorganizing activity adjacent to the site of injury (in osseous/ soft tissue surgery). He collectively termed this cascade of physiologic healing events "The Regional Acceleratory Phenomenon" (RAP). The RAP is a local response of tissues to noxious stimuli by which tissue regenerates faster than normal in a regional regeneration/remodeling process (111). This response varies directly in duration, size, and intensity with the magnitude of the stimulus. The duration of RAP depends on the type of tissue, and usually lasts about four months in human bone. This phenomenon causes bone healing to occur 10-50 times faster than normal bone turnover (112).

The healing phases of RAP have been studied in the rat tibia. There is an initial stage of woven bone formation, which begins in the periosteal area and then extends to medullary bone, reaching its maximal thickness on seven days. This cortical bridge of woven bone is a fundamental of RAP, providing mechanical stability of bone after injury. From day seven, the woven bone in the cortical area begins to undergo remodeling to lamellar bone, but woven bone in the medullary area undergoes resorption, which means transitory local osteopenia. It seems that medullary bone needs to be recognized and rebuilt after establishment of the new structure of cortical bone, and to adapt to the reestablishment of cortical integrity (three weeks in rats). There is also a systemic acceleratory phenomenon (SAP) of osteogenesis due to systemic release of humoral factors (112).

Yaffe *et al*. (113) evaluated the resulted RAP after mucoperiosteal flap elevation. They reported that RAP begins a few days after the surgery, peaks between 1 and 2 months, and takes from 6 to 24 months to resolve completely. RAP results in a decrease in regional bone densities (osteopenia) in healthy tissues whereas the volume of bone matrix remain constant (109). Orthodontic force application alone is a stimulus sufficient to trigger mild RAP activity. But when tooth movement is combined with selective decortication, RAP is maximized (112,114). Dibart *et al.*(6) reported that the surgically induced high tissue turnover is restricted to the surgical area and effective only for 2 months.

In 2001 Wilcko *et al.* (115) revisited the original technique of bony block movement with some modifications. He attempted two cases with severely crowded dental arches, and speculated that the dynamics of physiologic tooth movement in patients who underwent selective decortication which might be due to a demineralization-remineralization process rather than bony block movement. They suggested that this process would manifest as a part of RAP that involves the alveolar bone after being exposed to injury (corticotomy) and during active tooth movement.

Wilcko *et al*. (114) reported that the remineralization phase of the RAP was remarkably complete in the adolescent at years after post corticotomy surgery. In the adult however the remineralization was not only incomplete at two years post corticotomy surgery, but still incomplete at 12 years post corticotomy surgery with a net loss of alveolar bone. They attributed this net loss of the alveolar bone in the adult to the decreased reparative potential of adult in comparison to adolescent bone.

The two main features of RAP in bone healing include decreased regional bone density and accelerated bone turnover, which are believed to facilitate orthodontic tooth movement (116,117). Goldie and King (118) induced and osteoporosis state by depleting calcium intake in lactating rats and found an increase in the orthodontic tooth movement. In addition, reduced root resorption was demonstrated.

2.7.4.2. Corticotomy

Rapid orthodontic tooth movement with concomitant reduction in treatment time can be attained through a combination of orthodontic treatment and alveolar corticotomies(119–123). Although effective, corticotomy techniques present significant postoperative discomfort. The aggressive nature of these particular methods related to the elevation of muco-periosteal flaps and to length of the surgery raised reluctance among both patients and dental community.

Corticotomy is one of the surgical procedure that is commonly used in which only the cortical bone is cut and perforated but not the medullary bone, suggesting that this will reduce the resistance of the cortical bone and accelerate tooth movement (61). Corticotomy is defined as any intentional surgical injury to cortical bone. In adult patient, this technique has been claimed to dramatically reduce the treatment time because the resistance of dense cortical bone to orthodontic tooth movement is removed (2,119).

The use of Corticotomy to correct malocclusion was first described by Bryan in 1892 and Cunningham in 1893(124). Bryan reported such cases at the Meeting of American Dental Society of Europe and Cunningham presented the possibility of immediate correction of irregular teeth during the Dental Conference in Chicago that year. Bichlmayr (125) in 1939, described a surgical technique for rapid correction of severe maxillary protrusion with orthodontic appliance.

In 1959, Köle (2) used a combination of interradicular corticotomy and supra-apical osteotomies to speed up tooth movement. Köle technique consisted of buccal and lingual interproximal cuts limited to cortical layers, and then connected theses vertical cuts by horizontal osteotomy cuts approximately 1 mm beyond the apices of the roots. He laid the foundation for modern day corticotomy – facilitated orthodontics. Dr. Köle stated that the reduced resistance enhances an *en bloc* movement of the entire alveolar cortical segment. In 1975, Duker (122) performed the first animal study replicating the technique described by Köle.

In 1978, Generson *et al*. (121,126) modified the Köle method by eliminating the subapical osteotomy and described treatment of open-bite malocclusion using selective alveolar decortication and orthodontics. Subsequently, multiple authors reported rapid tooth movement after alveolar decortication and explained the changes as “bony block” movement. In 1991, Suya (127) replaced supraapical horizontal osteotomy with horizontal corticotomy to facilitate luxation of the corticotimized bone blocks.

Until 2001, the “bony block” movement prevailed as misconception, however, Wilcko *et al*. (128) reported that tooth movement was not the result of bony block, but rather a process a process of transient remineralization/demineralization, that is a concept of reversible osteopenia, in the bony alveolar consistent with wound healing pattern of RAP and introduced the term “bone matrix transposition”.

In 2008, Wilcko *et al*. (3) developed an accelerated osteogenic technique involving three distinct steps, namely, full thickness flap reflection, selective alveolar decortication, and bone grafting. They gave this technique the name of Periodontally Accelerated Osteogenic Orthodontics or (PAOO). The technique combines selective alveolar corticotomy, particulate bone grafting, and the application of orthodontic forces.

PAOO is a surgical alteration of the alveolar bone to decrease the treatment time. It has an additional step of alveolar bone grafting. They claimed that decortication combined with augmentation grafting created greater alveolar volume, which eliminate bony dehiscence and fenestration under most circumstances (114). This addition of alveolar bone width may be the cause for enhanced long-term orthodontic stability (129). Also using this technique, Wilcko reported tooth movement was at 3 to 4 times greater than conventional orthodontic tooth movement, also resulted in an increase of alveolar bone width, increased post treatment stability, and decreased amount of apical root resorption (117).

Dentoalveolar surgery such as corticotomies and osteotomies can alter the bone biology of tooth movement (121). For the orthodontists, the combination of minor surgery and orthodontic tooth movement is intriguing because of reports demonstrating rapid and difficult tooth movement (130–132). Corticotomies has recently become popularized which uses bone healing mechanism in combination with orthodontic loads to decrease treatment duration(3).

In a recent studies with a dog model, Lino *et al*. (133) postulated that the alveolar bone turnover in bone marrow cavities increased in corticotomy assisted tooth movement, resulting in quicker tooth movement. Selective alveolar decortication without tooth movement has been shown to induce rapid and increased localized turnover of alveolar spongiosa, the prerequisite condition for rapid tooth movement (134).

In 2006, Park *et al*. (135) introduced the corticocision technique and removed the need for flaps elevation by conducting their incisions directly through the gingiva using a combination of blade and a surgical hammer. This technique significantly reduces the duration of surgery, however it does not provide the benefits of bone graft of the Wilcko technique (117). In addition, The highly aggressive use of the hammer and chisels in the maxilla adds risk of benign paroxysmal positional vertigo (136).

Lee *et al*. (137) Conducted a study on an animal model for corticotomy and osteotomy-assisted tooth movement in the rat. They found that the result of computerized tomograms demonstrated that alveolar corticotomies and osteotomies produced different bone responses. Corticotomies and osteotomies-assisted tooth movement produced transient bone resorption around the dental roots reported as a regional acceleratory.

Aboul-Ela *et al*. (41) performed a study to clinically evaluate miniscrews implant-supported maxillary canine retraction with and without corticotomy facilitated orthodontics. The sample consisted of 13 adult patients exhibiting class II Division 1 malocclusion requiring therapeutic extraction of the maxillary first premolars, with subsequent retraction of the maxillary canines. Corticotomy-facilitated orthodontic was randomly assigned to 1 side of the maxillary arch at the canine premolar region, and the other side served as control. The canine retraction started immediately after the surgery using closed nickel-titanium spring applying 150 g of force per side. The results showed that the average daily rate of canine retraction was significantly higher on the corticotomy side than the control side by 2 times in the first 2 month. The rate of tooth movement declined to only 1.6 times higher in the third month and 1.06 times higher by the end of the fourth month.

Abbas *et al*. (138) conducted a study to evaluate the efficiency of corticotomy-facilitated orthodontics and Piezocision in rapid canine retraction. The sample consisted of 20 patients with suggested treatment plan with extraction of maxillary first premolars. Corticotomy performed in one group while the second group received flapless Piezocision. They concluded that the corticotomy-facilitated orthodontics and Piezocision are effective methods to accelerate tooth movement. Corticotomy-facilitated orthodontics was 1.5 to 2 times faster than conventional orthodontics.

Corticotomy procedures are based on the regional acceleratory phenomenon (RAP) and normal bone-healing mechanism (139). Under normal circumstances, any regional noxious stimulus of sufficient magnitude can evoke a RAP. The main effect of RAP appear to be restricted to the region of the stimulus, even areas in close proximity seem to be relatively unaffected by the RAP response (140).

Tissue Reactions to Corticotomy

A study was done by Lei Wang *et al*. (141) in 2009 on rats to assess the tissue responses in corticotomy and osteotomy-assisted tooth movement revealed:

- Under orthodontic tension, corticotomy-assisted tooth movement produced transient resorption of bone surrounding the dental roots.
- The alveolar bone surrounding the dental roots passes through resorptive, replacement, and mineralization phases of recovery.
- The completely freed osteotomy segment produced a different bone resorption that more closely resembled distraction osteogenesis.

Hong *et al*. (142) conducted a study in 2001 on beagle animal model for histologic assessment of the biological effects of corticotomy. In the group that received corticotomy they found that:

- Osteoclasts were not found on the cementum or dentin, although numerous osteoclasts were detected around the alveolar bone.
- In addition, more intact and consistent thickness of PDL space between the surrounding alveolar bone and the root surface was noted.
- There was no evidence of root resorption.
- Greater amount and faster rate of tooth movement was observed in the corticotomy group.

Tooth movement should be faster in less dense alveolar bone which is rapidly remodeled for the same reasons that tooth movement is faster in growing children than in adults (116). Moreover, animal studies showed that corticotomies provide three times as many osteoclasts, three times greater bone apposition rate an a twofold decrease in trabecular bone (116). Moreover, Teixeira *et al* (143) in animal studies, concluded that the perforations in the cortical bone increase the expression of 37 inflammatory cytokines, which leads to more osteoclasts and, consequently, greater bone remodeling process.

Clinical Application of Corticotomy Assisted Orthodontic Treatment

1. **Resolve Crowding and Shorten Treatment Time**

Corticotomy and osteotomy were used in orthodontics primarily to resolve crowding in a shorter period of time. It has been shown that corticotomy is efficient in reducing treatment time to as little as one fourth the time usually required for conventional orthodontics (144). Hajji (145) studied the effects of resolving mandibular anterior dental crowding by comparing non-extraction, extraction, and corticotomy-facilitated non-extraction. The mean active treatment time for the corticotomy-facilitated group was 6.1 months, versus 18.7 months required for non-extraction and 26.6 months for extraction therapy.

2. **Accelerate Canine Retraction after Premolar Extraction**

Canine retraction after premolar extraction is a lengthy step during the extraction stage of orthodontic treatment. Canine retraction was accelerated by corticotomy in two animal studies. Ren *et al.*(123) and Mostafa *et al*. (146) demonstrated faster canine retraction when compared to conventional orthodontic retraction of the canines.

3. **Enhance Post-Orthodontic Stability**

Stability after orthodontic treatment may not always be achievable. Little has shown that 10 years after orthodontic treatment, only 30% of patients had satisfactory alignment of the mandibular incisors(147). Stability was reported as one of the advantages of corticotomy-assisted orthodontics(145). Corticotomy- facilitated orthodontic treatment was found to result in better retention compared to conventional orthodontic treatment(148).

4. **Facilitate Eruption of Impacted Teeth**

Surgical traction of impacted teeth, especially the canines is a frustrating and lengthy procedure. Fischer (149) showed that under the same periodontal conditions, the corticotomy-assisted approach produced faster tooth movement during traction of palatally impacted canines compared to conventional canine traction methods at the end of either treatment.

5. **Facilitate Slow Orthodontic Expansion**

Corticotomy-assisted expansion is an effective technique for the treatment of maxillary transverse deficiency in adults and is assumed to provide greater stability and better periodontal health than conventional expansion(130).

6. **Molar Intrusion and Open Bite Correction**

Corticotomy-assisted orthodontic treatment has also been used in the treatment of severe anterior open bite in conjunction with skeletal anchorage(150).

Moon *et al* (151) achieved sufficient maxillary molar intrusion (3.0 mm intrusion in two months) using corticotomy combined with a skeletal anchorage system with no root resorption and with no patient compliance required.

7. **Manipulation of Anchorage**

Corticotomy-assisted orthodontic treatment was used in the treatment of bimaxillary protrusion as an adjunct to manipulate skeletal anchorage without any adverse side effects in only one-third of the regular treatment time(152).

Contraindications and Limitations

Patients with active periodontal disease or gingival recession are not good candidates for corticotomy-assisted orthodontic treatment. In addition, corticotomy-assisted orthodontic treatment should not be considered as an alternative for surgically-assisted palatal expansion in the treatment of severe posterior cross-bite. Also should not be used in cases where bimaxillary protrusion is accompanied with gummy smile, which might benefit more from segmental osteotomy (153).

Complications and Side Effects

Although corticotomy-assisted orthodontic treatment may be considered a less-invasive procedure than osteotomy-assisted orthodontics or surgically assisted rapid maxillary expansion, there have been several reports regarding adverse effects to the peridontium after corticotomy ranging from no problems to slight interdental bone loss and loss of attached gingiva to periodontal defects observed in some cases with short interdental distance(122,154,155).

No effect on the vitality of the pulps of the teeth in the area of corticotomy was reported(156). Liou *et al* (157) demonstrated normal pulp vitality after rapid tooth movement at a rate of 1.2 mm per week.

It is generally accepted that some root resorption is expected with any orthodontic tooth movement(158). The reduced treatment time of corticotomy-assisted orthodontic treatment may reduce the risk of root resorption. Ren *et al* (146) reported that rapid tooth movement after corticotomy in beagles without any associated root resorption or irreversible pulp injury.

2.7.4.3. Dento-Alveolar Distraction

Distraction osteogenesis is a process of growing new bone by mechanical stretching of the preexisting skeletal tissue(159). It has been most accepted in orthopedic surgery as an effective means of bone lengthening in correction of skeletal deformity and in filling large diaphyseal defects. Distraction osteogenesis has been extensively performed in the craniofacial region and is increasingly becoming a viable treatment option in the correction of craniofacial anomalies. Distraction osteogenesis was first described by in 1905 by Codivilla *et al.*(160) and later popularized by clinical and research studies by Illizarov(161) in Russia. Guerrero *et al*.(162) in 1990 and Macarthy *et al*.(163) et al in 1992 performed distraction osteogenesis in human mandible.

The ability of distraction osteogenesis to reconstruct combined deficiencies in bone and soft tissue makes the process unique and invaluable to all types of reconstructive surgeons. The procedure is now widely used by maxillofacial surgeons for the correction of craniofacial deformities. Initially external devices were used for distraction. Lately devices for intraoral usage are being engineered thereby increasing its potential application in dentistry (164).

The essence of orthodontic treatment is the movement of teeth through alveolar bone to obtain an esthetically ideal occlusion. Many advances have occurred the past century, but relatively little has been done to enhance the rate at which tooth movement occurs and for successful management of complications such as ankylosed teeth (164).

The concept to orthodontic tooth movement and rapid canine retraction through distraction of alveolar bone was first investigated by Liou and Hung, they applied external device for performing distraction osteogenesis(165). Later intraoral devices came into use after the newer techniques were introduced. These intraoral can be tooth born, bone born or both(166–168).

In 1998, Liou and Hung (165) first applied this concept to orthodontic tooth movement and performed rapid canine retraction through distraction, which they termed as "Dental Distraction". They noted that the process of periodontal ligament osteogenesis during tooth movement induced by orthodontic forces is similar to that of the midpalatal suture during rapid palatal expansion performed for crossbite correction. The authors devised a way to stretch the periodontal ligament at the same speed as the midpalatal suture to enable rapid canine movement in patients who required first premolar extraction. This technique has been named dental distraction (DD).

According to Kisnisci *et* a.l (169) the concept of distraction osteogenesis for rapid orthodontic tooth movement is promising and feasible for clinical practice. Iseri *et al*. (131) demonstrated that the dentoalveolar distraction (DAD) technique is an innovative method that reduces overall orthodontic treatment time by 50%. The authors conducted a study that consisted of 20 maxillary canines in 10 subjects, the first premolars were extracted, the dentoalveolar distraction surgical procedure was performed and a custom-made intraoral, rigid, tooth-borne distraction device was applied. The canines were moved rapidly into the extraction sites in 8 to 14 days, at rate of 0.8 mm per day and full retraction was achieved in a mean time of 10.05 days.

Kurt *et al*. (170) reported a 15 years old skeletal and dental class II female patient with an overjet of 9 mm who was treated by DAD osteogenesis. A custom distraction device was used for rapid canine retraction. Osteotomies sourrounding the canines were performed to achieve rapid movement of the canines within the dentoalveolar segment, in compliance with distraction osteogenesis principles. The amount of canine retraction was 7.5 mm in 12 days at a rate of 0.625 mm per day.

2.7.4.4. Piezosurgery

Piezosurgery is based on the piezoelectric effect, first described by Jean and Marie Curie in 1880, which states that certain ceramics and crystals deform when electric current is passed across them, resulting in oscillation of ultrasonic frequency. The vibrations obtained are amplified and transferred to a vibration tip which, when applied with slight pressure on bone tissue, results in a cavitation phenomenon- a mechanical cutting effect that occurs exclusively on mineralized tissue(171).

Within the field of dentistry, ultrasound was first applied in dentistry in 1952, specifically for preparing dental cavities, which was subsequently displaced by introduction of high-speed rotary instrument (172). Drills are the most common bone cutting instruments and until few years ago, they were the sole devices used to cut bone tissue. In recent years, Piezosurgery and erbium laser were introduced in bone surgery(173).

Piezoelectric bone surgery, also simply known as a piezosurgery, is a new technique developed by Italian oral surgeon Tommaso Vercellotti in 1988 utilizing an innovative ultrasonic surgical apparatus, known as the Mectron Piezosurgery device(174).

Piezosurgery was developed in response to the need to reach major levels of precision and intraoperative safety in bone surgery, as compared to that available by the traditional manual and motorized bone cutting instruments. It is promising, meticulous and soft tissue sparing system for bone cutting, based on ultrasonic microvibrations. It was developed to overcome the limits of traditional instrumentation in oral bone surgery modifying and improving conventional ultrasound technology(175).

Piezosurgery's accuracy and selectivity render it superior to conventionally rotating instruments in operations where the area of interest is adjacent to nerves, such as when strongly displaced and impacted wisdom teeth are located in close proximity to the inferior alveolar nerve, in osteotomies performed close to the mental foramen, or in lateral nerve displacement. The advantages of the piezo osteotomy can also be applied to perimplantologic surgery for augmentative purposes(172).

Not only is this technique clinically effective, but histological and histomorphometric evidence of wound healing and bone formation in experimental animal models has shown that tissue response is more favorable in piezosurgery than it is in conventional bone-cutting technique such as diamond or carbide rotary instruments(174). The selective harmless nature of the piezosurgical instruments result in low bleeding tendency and can easily cut the bone without damaging the soft tissue (176).

The most important part of the Piezosurgery device is the hand piece, connected to the main unit, which has holders for the hand piece and irrigation fluids. The frequency of vibrations and power and power of cutting, as well as the amount of irrigation, can be adjusted. The frequency is usually set between 25 and 30 kHz. This frequency causes microvibrations of 60-210 Mm amplitude, providing hand piece with power exceeding 5W.

Compared with conventional burs, the use of piezoelectric knife enhances bone healing without causing osteonecrotic damage and facilitates the preservation of root integrity because of its precise, selective cutting action(177). Furthermore, because the piezoelectric knife works only on mineralized tissues, it spares the soft tissue and their blood supplies. Hard tissue or soft tissue grafting can be combined with Piezocision via selective tunneling, which allows for the correction of gingival recession and bone deficiencies(6).

Tissue Response during Piezocision-Assisted Tooth Movement

In 2014, Dibart *et al*. (178) conducted a study to evaluate the effects of Piezocision on bone with or without movement on a rat model. Their results demonstrated that the Piezocision stimulates the alveolar bone turnover through increased osteoclastic activity as early as 1 day and leads to RAP, which forms the basis of rapid tooth movement compared to the conventional orthodontic treatment. The histological study showed that how the Piezocision and tooth movement lead to faster and more profound demineralization of bone surrounding the teeth when compared to the tooth movement alone. Piezocision-assisted tooth movement also allows to “bypass” the lag phase following displacement phase that is characteristic of tooth movement subjected to conventional orthodontics. Unlike conventional orthodontics and during the course of treatment in the adult patient, a sharp increase in tooth mobility is observed resulting from the transient osteopenia induced by the surgery.

It is the synergistic effect of Piezocision and tooth movement that allows this “this extension of the biological effect in time and space” as the RAP is transient but could be prolonged via the continuous mechanical stimulation of the teeth and bone. The surgically induced bone turnover is restricted to the surgical areas. Attention must be given to perform the bony incisions only around the teeth where tooth movement is planned. As such, the relative anchorage value of the teeth away from the surgical site remains high and anchorage value of teeth adjacent to the surgical site is low.

Application of Piezosurgery in Surgically Assisted Orthodontics (SAOT)

The following is a list of most frequent applications of Piezosurgery in SAOT, which will be reviewed briefly:

- **Piezosurgery for surgically assisted rapid maxillary expansion (SARME)**

In 2007, Robiony *et al*. (179) described the use of piezosurgical instrument as minimally invasive device, to allow surgeons to perform all steps of SARME under local anesthesia. In a recent research Rana *et a*l. (180) in 2013 divided their 30 adult patients who were with an indication for SARME into two groups according to the treatment modality performed. Patients of the first group were treated conventionally, while patients of the second group were treated with a piezoelectric saw. They found that, it is possible to conduct a SARME with the help of piezoelectric saw. Piezosurgery preserves mucous membrane of the maxilla and is at least as effective and as good as the conventional method. Piezosurgery assisted SARME were characterized by very low amount of bleeding observed during surgery, lack of damage to the main vessels and reduction of postoperative consequences (hematoma and swelling).

- **Piezosurgery for exposure of palatally impacted canine**

In 2004 an alternative method was presented that uses piezoelectricity to minimize trauma to the impacted tooth and to the surrounding tissues. They came up with a piezoelectric instrument which controls bleeding during the surgical procedure, ensuring a dry field for bonding to the impacted tooth. Also total surgical time was found to be greatly reduced with this method(181).

- **Piezoosteotomy in orthognathic surgery**

Landes *et al.* (182) in 2008, compared 90 patient's orthognathic procedures with 90 retrospective patients with conventional saw and chisel osteotomy. Piezoosteotomies were individually designed to interdigitate the jaw segments after repositioning. They concluded that piezoelectric osteotomy did not prolong the operation time and reduced blood loss and alveolar impairment.

- **Piezoelectric distraction osteogenesis**

A piezoelectric device used to treat alveolar bone defects was found to permit perfect osteotomy without palatal flap damage. Also abundant vascularization from palatal flap led to successful new bone formation. Furthermore, Piezosurgery is a very convenient device through which it is possible to get direct visibility over entire osteotomies(183).

- **Posterior maxillary segmental osteotomy concomitant with sinus lift**

Posterior maxillary segmental osteotomy was suggested to be an alternative method for correcting severely extruded teeth. It was reported that the incidence of severe complications can be reduced and the entire process can be completed during a single surgical procedure using a piezoelectric device and elevating the sinus membrane(184).

- **Piezosurgery to Accelerate Orthodontic Tooth Movement**

In 2007, Vercelotti and Podesta (4,177) reported a reduction of the orthodontic treatment time by 60 to 70% after corticotomy performed by means of piezosurgical micro-saw. Due to their small size and their precision, piezoelectric cutting insert realize precise osteotomies without risk of osteonecrosis. The authors removed the lingual flap by performing only vestibular incisions but the elevation of a flap prior to corticotomy was maintained thus only relatively reducing surgical time and postoperative discomfort.

In 2012, Abbas and Mouhamed (185) in their study, they divided their sample into two groups; group I (corticotomy group) in which alveolar corticotomies were performed using Piezosurgery and group II (non-corticotomy group) in which non-surgical standard orthodontics technique without corticotomy was performed. They concluded that the alveolar corticotomy procedure increases orthodontic tooth movement with accepted degrees of pain and discomfort. Surgical control for Piezosurgery was easier than conventional surgical burs for selective alveolar corticotomies.

2.7.4.5. Piezocision

In 2009, Dibart *et al.* (5) described a new minimally invasive procedure that they called Piezocision. This technique combines micro-incisions limited to the buccal gingiva that allow the use of piezoelectric knife to give osseous cuts to the buccal cortex and initiate regional acceleratory phenomenon (RAP) without involving palatal or lingual cortex. The procedure allows for rapid tooth movement without the downside of an extensive and traumatic surgical approach while maintaining the clinical benefit of a bone or soft tissue grafting concomitant with a tunnel approach. Piezocision technique did not cause any periodontal damage as reported by Hasan and S. Elbeleidy (186).

To reduce the risks of root damage, Jorge *et al*. in 2013, (187) suggested a method called MIRO (Minimally Invasive Rapid Orthodontic procedure) by using metal wire as a guide to placement of incisions, and subsequently Piezocision cuts. They placed metal guides between each tooth, perpendicular to the main arch wire, and took digital radiographs, to ensure that the metal guides did not project over the tooth roots. Once this was confirmed, incisions and piezoelectric corticotomy was done using the pins as guide.

In 2013, a case was reported by Keser and Dibart (188) to evaluate the effect of the use sequential piezocision in the correction of class III malocclusion. Piezocisions on the maxillary arch were performed 9 days after the initial bracket placement. Two and half months after the maxillary piezocision, the mandible was bonded. Piezocisions on the mandible were done 2 weeks later. They achieved significant results and this case report illustrated how piezocision can be used in selected patient to gain that are both timely and significant.

In 2014, Abbas *et al*. (138) held a clinical study to evaluate the efficiency of corticotomy-facilitated orthodontics and piezocision in rapid canine retraction. The sample consisted of 20 patients with suggested treatment plan of extraction of the maxillary first premolars with subsequent canine retraction. One premolar was randomly selected and extracted one day before surgery, and the other was extracted on the day of surgery; this procedure was suggested to spare the patients the stress of having 2 bleeding site at the same time and the discomfort of a prolonged procedure. The sample divided into 2 equal groups. In the first group, 1 side of the maxillary arch was randomly chosen to receive corticotomy; in the second group piezocision treatment was performed. The opposite sides of both groups served as control. Both corticotomy and piezocision were performed with piezosurgery knife, and the canine retraction was initiated immediately in both group immeditaley after surgery using NiTi closing coil spring that applied 150 g of force on each side. The patients were examined over a 3-months period to evaluate the rate of canine crown tip, molar anchorage loss, and canine rotation. The results showed that the rates of canine tip were greater in the experimental sides than in the control sides. Corticotomy-facilitated orthodontics is 1.5 to 2 times faster than the conventional orthodontics. Piezocision was 1.5 times faster than conventional orthodontics.

Gün (189) in her thesis of graduation, performed a study to evaluate the effects of Piezocision on the rate of orthodontic tooth movement during canine distalization. The sample consisted of 31 patients with orthodontic treatment plan necessitating extraction of maxillary first premolars, with subsequent retraction of the canines. Piezocision were performed using piezosurgery knife on one side of the maxilla, while the opposite side served as control. The canine retraction initiated immediately using NiTi closing coil spring that applied a distalizing force of 150 g each side, closing spring were connected from the miniscrews which was used as an anchorage unit, to the hook on the bracket of the canine.. The patiente were observed for a total period of 10 weeks to evaluate the amount of canine movement, rotation and anchorage loss. The results showed that the rate of canine distalization at the Piezocision side was 3.11 mm which was significantly higher than the controls side which was only 2.11 mm. No significant anchorage loss was observed on both sides. Rotation of canine on both sides were found to be statistically significant on both sides

Aksakalli *et al.* (190) in a clinical study, compared the extent of canine distalization and the transversal changes between patients who were undergoing orthodontic treatment involving upper premolar extraction with and without piezocision. The sample included 10 patients with total number of 20 canines were included in the study. The patients were divided in 2 groups, experimental group and control group. In the experimental group, before canine distalization, piezocision was performed on the experimental side, the piezocision performed on the mesiobuccal and distobuccal sides of maxillary canine using piezosurgery knife.The depth of cortical alveolar incisions were 3 mm, and the depth verified by the millimetric signs on the piezosurgery knife. The distalization phase initiated after piezocision on the experimental side using elastomeric chain with an approximate force of 150 g. For control side, distalization was started at the same time with the same mechanics. Patients were evaluated at 2-week intervals, and the elastomeric chains were replaced at each appointment until ideal Class I canine relationships were established. Pre- and post-distalization model casts were scanned using 3Shape scanning machine. The models were superimposed, and the changes in the models were evaluated for canine distalization changes. The results showed that the piezocision-assisted canine distalization increases the velocity of canine distalization and decreases the overall treatment duration. They also concluded that the piezocision can be used safely without any narrowing of the transversal dimensions.

Piezocision has successfully been used for the rapid treatment of Class II and Class III patients and has been combined with lingual orthodontics and the Invisalign system to achieve both esthetic results and rapid orthodontic tooth movement (6,191,192).

Piezocision can be defined as another tool for creating differential anchorage (193). Previous researches showed that the density of bone around Piezocision cuts is less (6,178), the anchorage values of the teeth at the decortication site would be different. Piezocision can be done selectively around the teeth that are going to be moved and the anchorage values of these teeth can be decreased. Therefore we can eliminate the need for additional anchorage devices and it is possible to design the alveolar decortication according to the desired tooth movement (193).

Clinical applications of Piezocision

Piezocision can be applied in a generalized, localized, or sequential manner

- Generalized: Application of Piezocision in both arches and in all segments, in cases where correction of malocclusion requires moving all of the teeth (188).
- Localized: In cases where malocclusion affects only one part of the dentition or one arch (i.e., a crowding localized only in anterior segment with a perfect posterior occlusion, single tooth extrusion, etc) (188).
- Sequential: In some cases, correction of malocclusion requires a “staged” approach, where Piezocision is applied to selected areas or segment of the arch at different times during orthodontic treatment to help achieve specific results (188).

Advantages of Piezoelectric surgery

The following are the advantages of piezosurgical units(174,176):

- Allows very precise cutting
- Avoids bone cutting using osteotome
- Faster to reduce thickness of the alveolar wall
- Losses of bone tissue is minimal during sinus lifting procedure
- Reduced indirect thermal damage to the bone surface and adjacent structures, such as teeth
- Produces less vibration and noise
- Blood loss is significantly reduced

Disadvantages of piezoelectric surgery

- According to some authors, the technique demanded longer operative time (194).
- Another factor is the power of the equipment and the characteristics of the bone to be cut, it is evident that more compact bones require the use of more powerful equipment and suitable parameters (194).
- Moreover, this new technology demands that the operator must be trained, in order to obtain the maximum benefit of the technological resources available (194).

2.7.4.6. Micro-Osteoperforations (MOPs)

Micro-osteoperforation (MOPs) is an effective, comfortable, safe procedure to accelerate tooth movement and reduce significantly the orthodontic treatment time. MOPs can be defined as limited and shallow perforations of the buccal cortical plate of the maxilla (195).

Teixeira *et al*. (143) has shown that biological principles can be activated to accelerate bone remodeling using micro-osteperforations (MOP). In particular, by increasing the local levels of cytokine activity around a tooth, the rate of movement during orthodontic can be increased. Increased cytokine activity has been well documented to increase bone remodeling. In animal studies when clinicians create micro-osteoperforations in the alveolar bone, the cytokine cascade is activated, resulting in marked increase in osteoclast activity. When any type of orthodontic force is applied immediately following micro-osteoperforation, the teeth will move easily through the treated area.

The ideal treatment device for micro-osteoperforation should be able to provide ergonomic control by the using clinician, and remain sharp through multiple perforations, and have a depth limiter to ensure penetration to the minimal effective depth. Temporary anchorage devices, miniplants, and burs are not alternatives to performing micro-osteoperforation in a private practice setting. Recently, a new device like (Propel) has become available which seems to show promise.

Pervious animal studies demonstrate that by delivering micro-osteoperforation in the bone near the teeth, bone remodeling enables a greater rate of tooth movement (196). Based on the referenced animal studies, it was demonstrated that this highly invasive surgical procedure can be simplified and replaced with minimal shallow, small micro-osteoperforations in the alveolar bone without the need for soft tissue flaps, bone grafting, or any suturing (197).

Micro-osteoperforations harnesses the body's own biology to create a cytokine effect that induces remodeling and allows teeth to be moved into the clinically desired position in a more predictable and faster manner. The induction of the cytokine cascade is modulated and controlled by the design of appliance itself. Basic bone biology research, animal studies and controlled clinical trials have demonstrated the safety and efficacy of the MOP treatment (143).

In fact, the result of both animal and clinical studies have demonstrated that micro-osteoperforation decreases orthodontic treatment in combination with any type of orthodontic treatment(195). There are multiple benefits of using the MOP in the office including reducing treatment time, economic benefits, and greater patient satisfaction with orthodontic treatment.

An animal study that conducted by Tsi *et al*. (198) to investigate the effects of flapless micro-osteoperforation and corticocision on the rate of orthodontic tooth movement in rats. The obtained results showed that, the two minimally invasive technique techniques increased bone remodeling and osteoclast activity and induced faster orthodontic tooth movement. No obvious differences were observed between flapless micro-osteoperforation and corticocision.

M.Alikhani *et al*. (7) in 2013 performed a study to investigate the effect of micro-osteoperforations on the rate of orthodontic tooth movement during maxillary canine retraction in humans. Twenty adults with Class II Division 1 malocclusion were divided into control and experimental groups. The control group did not receive micro-osteoperforations, and the experimental group received micro-osteoperforations on 1 side of the maxilla. Three small MOPs were performed in the extraction space at equal distance from the canine and the second premolar using hand held appliance (Propel). Each perforation was 1.5 mm wide and 2 to 3 mm deep. Both maxillary canines were retracted using NiTi closing coil spring delivering a constant force of 100 g connected from a temporary anchorage device to a power arm on the canine bracket. Patients were evaluated 28 days later to measure the amounts of distal movement of the canines. They concluded that MOPs significantly increased the expression of cytokines and chemokines known to recruit osteoclast precursors and stimulate osteoclast differentiation. Also they found that MOPs increased the rate of canine retraction 2.3-fold compared to the control group.

Azimova (199) in 2015 , clinically evaluated the effects of transmucosal decortication procedure on the rate of tooth movement during maxillary canine retraction toward premolar extraction space. The sample included 9 patients that required therapeutic extraction of maxillary first premolars with subsequent canine retraction. After completion of leveling and alignment phase and before canine retraction, transmucosal decortication procedure was performed using manual driller. Cortical perforation with depth of 2-3 mm and width of 1.2 were performed on one side while the other side served as control. Canine retraction was started immediately using NiTi closing coil spring with applied force of 150 g each side. The patients were evaluated every 3 weeks to monitor the amount of tooth movement and check the applied force. They concluded that transmucosal decortication procedure made by using manual drill device is effective in accelerating orthodontic tooth movement.

In 2016, T.Mahmoudi (200) in his thesis of graduation, performed a study to determine whether micro-osteoperforation of the cortical bone produces accelerated tooth movement during space closure in adult patients. The obtained results showed that 50 % of subjects had faster canine retraction rate on the experimental side when compared to control.

When compared to other surgical approaches to accelerate tooth movement, it is obvious that MOPs offer a number of advantages. This procedure is minimally invasive and flapless, allowing treatment to take place in the orthodontic chair. Corticotomies, on the other hand, require the reflection of a full-thickness flap to expose the buccal and lingual alveolar bone, followed by interdental cuts through the cortical bone. MOPs offer a practical and minimally invasive procedure that can be repeated as needed. In addition, MOP can be incorporated into daily mechanics and at different stages of treatment. MOP can be placed selectively in the areas where tooth movement is desired and away from teeth or segments used as anchorage (201).

Clinical Application of Micro-osteoperforation:

- Molar uprighting
- Lower anterior crowding
- Canine impactions
- Forced eruption
- Space closure
- Rotations
- Intrusion
- Correction of curve of spee
- Pre-surgical orthodontics

3. MATERIALS AND METHODS

3.1 Sample:

The sample consisted of 12 patients (7 male, 5 female; mean age, 19.75±4.27 years) with suggested orthodontic treatment plan requiring therapeutic extraction of the maxillary first premolars, with subsequent retraction of the maxillary canine. The subjects were selected from the outpatient clinic Department of Orthodontics, Faculty of Dentistry, Yeditepe University. All the patients had to fulfill the following criteria:

- Orthodontic patients with treatment plan necessitating therapeutic extraction of maxillary first premolars with maximum anchorage.
- The upper canines should not be infrapositioned.
- No previous orthodontic or orthopedic treatment.
- Absence of any systemic disease or chronic illness.
- The patient should have good oral hygiene.
- The patient should not have any extra or missing teeth.
- No signs and symptoms of periodontal disease.
- No signs and symptoms of bruxism, or parafunctional habits.

Patients with the following criteria were excluded from the study:

- Patients who have missing permanent teeth.
- Patients who have medical problems affect bone metabolism and tooth movement.
- Patients with poor oral hygiene.
- Patients who refused or failed to provide oral and written consent to participate.
- Patients with age less than 14 years.

Ethic approval was obtained from the Ethic Review Committee of Yeditepe University, Istanbul, Turkey. All patients were informed about the procedure and signed an informed consent (**App 7.3**).

3.2. Equipment Used in the Study

- 0.022 slot Roth system brackets (American Orthodontics, Wisconsin, USA)
- 0.016 x 0.022 inch stainless steel wire (American Orthodontics, Wisconsin, USA)
- 1.2 mm X 8 mm miniscrews (Totalanchor, Istanbul, Turkey)
- Sonic Suregeon 300 piezosurgery (Dong il technology, Hwasung, South Korea)
- Manual drilling appliance (diameter of 1.2 mm) (Totalanchor,Istanbul, Turkey)
- Bard Parker handle (Paragon, Sheffield, United Kingdom)
- Scalpel blade no : 15 (Broche Medical, Istanbul , Turkey)
- Nickel-Titanium closing coil spring (American Orthodontics, Wisconsin, USA)
- Dynamometer (Force Gauge) (Correx force gauge, Switzerland)
- Digital caliper with an accuracy of 0.01 mm (MahrCal,Gottingen Germany)
- Specially designed canine bracket (American Orthodontics, Wisconsin, USA) with 0.7 mm stainless steel power arm(BEALL METAL, Shanghai, China)
- Laser welding machine (EVO 100, Evo Series, Verona, Italy).

3.3. Methods

3.3.1. Treatment Protocol

Patients who met the selection criteria and completed an informed consent form were included in the study group. Our study was designed to be a Cohort study, so that in the same patient MOPs and Piezocision were randomly assigned on either right or left sides to eliminate the possibility of uneven occlusal forces because of habitual occlusion predominantly on one side. Patients with file number ends with an even number had peiezocision procedure performed on the right side and MOPs procedure on the left side. Patients that their files number ends with an odd number had MOPs procedure performed on the right side and piezocision on the left side

Patients were referred for extraction of maxillary first premolars. All extraction procedures were performed in the clinics of Department of Oral Surgery, Faculty of Dentistry, Yeditepe University.

The initial phase of leveling and alignment of orthodontic treatment was completed with a straight wire by bonding fixed appliances in both arches (0.022 inch slot Roth system bracket) with specially designed maxillary canine brackets with auxiliary power arm made from 0.7 mm diameter stainless steel wire **(Figure 3.10)**. These brackets were fabricated using laser welding machine at Orthodontic laboratory, Department of Orthodontics, Yeditepe University. The modified maxillary canine brackets allowed the application of the force closer to the center of resistance of the tooth that is found at the middle of the root. Leveling was achieved by using 0.014, 0.016, 0.016 x 0.016, 0.016 x 0.022 inch NiTi wires respectively. After leveling phase finished 0.016 x 0.022 inch stainless steel wire was placed and canine retraction phase was started.

3.3.2. Placement of Miniscrews as an Anchorage Device

After completion of the leveling and alignment phase, miniscrew implants (Totalanchor. Istanbul, Turkey; diameter 1.3 mm; length;8 mm), used as skeletal anchorage units, were placed bilaterally between the maxillary second premolar and the first molar. The procedures of miniscrews placement were performed under local anesthesia.

Figure 3.1.a: Miniscrew used in the study (1.2 mm x 8 mm) (Totalanchor, Istanbul, Turkey)

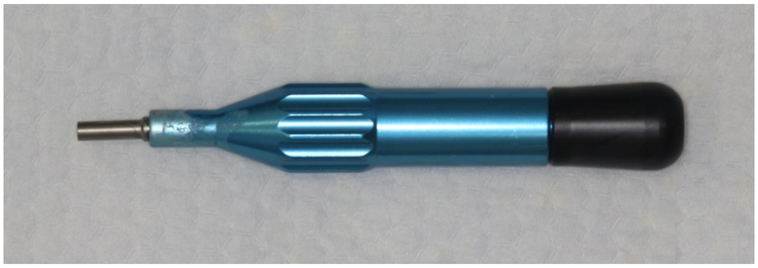

Figure 3.1.b: Screwdriver used in the study (Totalachor, Istanbul, Turkey)

3.3.3. Surgical Procedures

The surgical procedures were randomly assigned; the patients with file number ends with an even number had peiezocision procedure performed on the right side and MOPs procedure on the left side. The patients that their files number ends with an odd number had MOPs procedure performed on the right side and piezocision on the left side.

Piezocision:

Before canine distalization and after alignment and leveling phases, piezocision was performed on one side. Piezocision involves gingival microincisions and vertical cortical cuts without flap reflection. Following the induction of local anesthesia, two vertical interproximal incisions were performed through the gingiva of the mesiobuccal and distobuccal line angles of the canine with a number 15 blade in Bard Parker handle **(Figure 3.4).** The incisions were made 5 mm below the papilla to preserve the papilla. Incisions lengths were approximately 10 mm apically. A piezosurgery knife (Sonic Surgeon 300, Dong il technology, Hwasung, South Korea) was used to create the cortical bone incisions through the gingival opening to a depth of approximately 3 mm **(Figure 3.5).** The depths were verified by millimetric signs on the Piezosurgery knife. No sutures were needed after the surgery. The patient reported no pain or discomfort. Surgical area was fully healed after 1 week from operation.

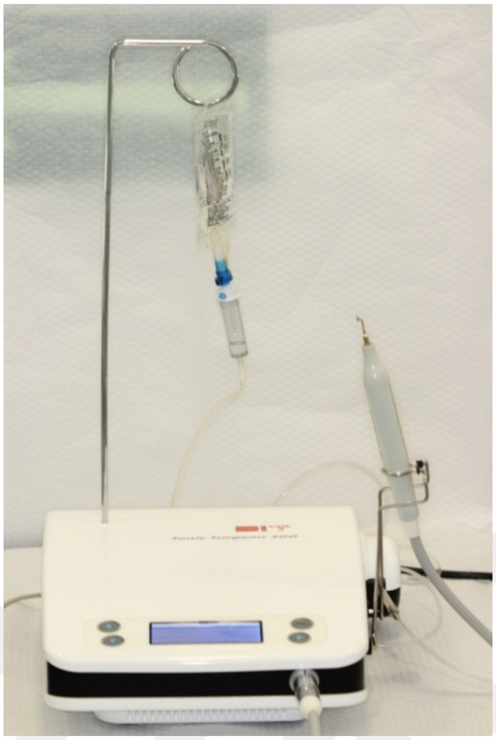

Figure 3.2: Piezosurgery used in the study (Sonic surgeon 300, Dong il Technology, Hwasung, South Korea)

Figure 3.3: Piezosurgery tip BS1 with millimetric calibration (Sonic surgeon 300, Dong il Technology, Hwasung, South Korea)

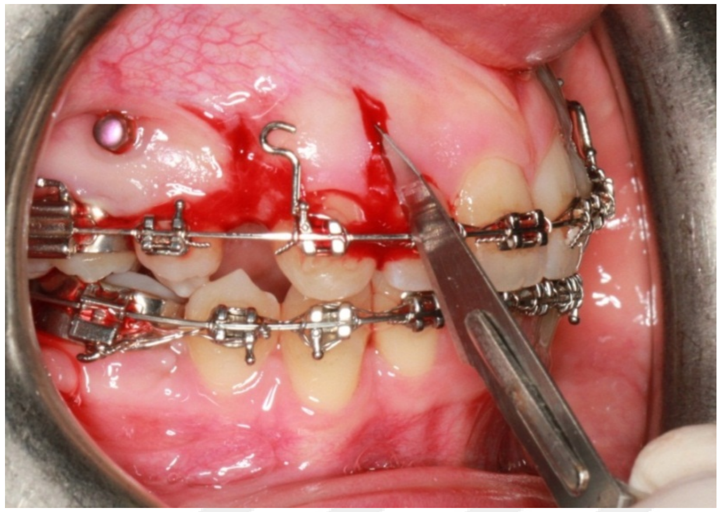

Figure 3.4: Using a blade to perform gingival microincision

Figure 3.5: Using Piezosurgery knife to do cortical incisions with depth of approximately 3 mm

Microosteoperforations (MOPs):

In the same patient, the contralateral side received MOPs that are limited shallow perforations of the buccal cortical plate of the maxilla using a manual drilling appliance. The procedure was performed under local infilterative anesthesia. Three MOPs were performed in the extraction space at equal distances from the canine and the second premolar and before the canine retraction using a manual driller (Total Anchorage System, Trimed, Ankara, Turkey) **(Figure 3.6) (Figure 3.7).** Each perforation was 1.2 mm wide and 2 to 3 mm deep from the surface of the bone. The patients did not report significant pain or discomfort during or after the procedure, or any other complications.

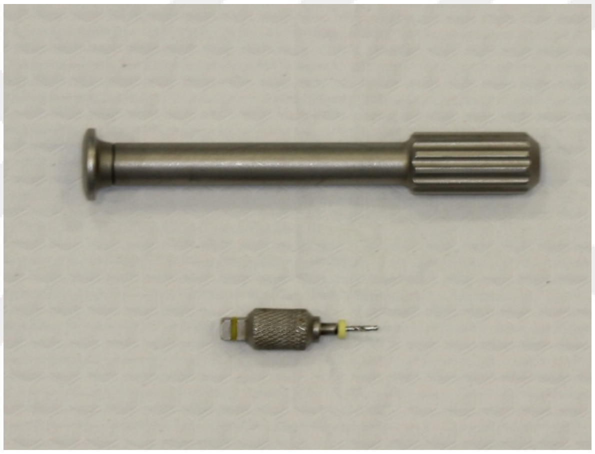

Figure 3.6: Manual drilling appliance with diameter of 1.2 mm (Totalanchor, Istanbul,Turkey)

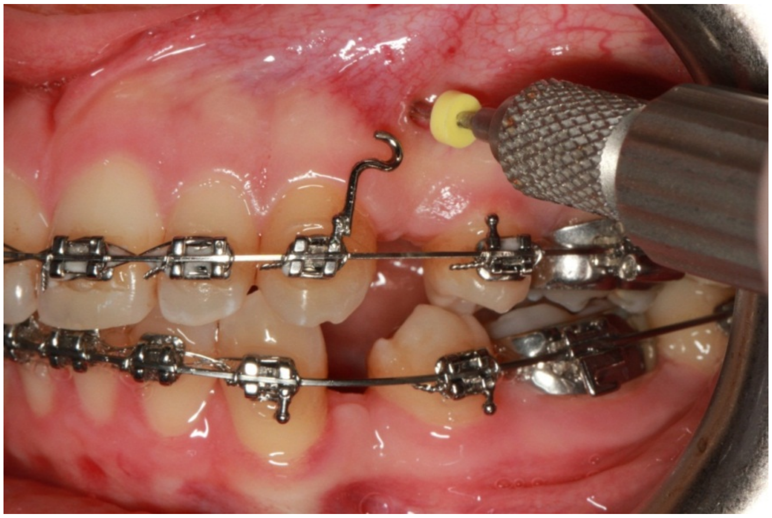

Figure 3.7: Using manual driller to perform cortical perforations with depth of 2-3 mm and width of 1.2 mm

3.3.4. Canine Retraction Procedure

Canine retraction began immediately after the surgery to take the advantage of RAP induced by bone injury. 0.016 x 0.022-in stainless steel wire that was already tied in the previous appointment was removed during the surgery; it was tied in the place immediately after surgery. After the operation, canine retraction in both sides was achieved using nickel-titanium closing-coil springs (American Orthodontics, Wisconsin, USA) that were extended from the hook of canine bracket to the miniscrew in the same side. The hook was specifically fabricated by using 0.7 mm satinless steel wire which was welded to the bracket of canine using laser welding machine (Evo 100, Evo Series, Verona, Italy) **(Figure 3.8)**. The aim of using hooks is to apply the retraction force closer to the center of resistance of the tooth. Springs applied an approximate force of 150 g each side for canine retraction. The applied forces were measured using a force gauge (Correx force gauge, Switzerland)), and the force was calibrated for readjustment at each visit (every 3 weeks) **(Figure 3.11) (Figure 3.12)**.

Figure3.8: Laser welding machine (Evo 100, Evo Series, Verona, Italy)

Figure 3.9: Preparing of the specially designed canine bracket with power arm

Figure 3.10: Specially designed canine bracket with power arm

Figure 3.11: Measurement of the applied force with force gauge (Correx force gauge, Switzerland)

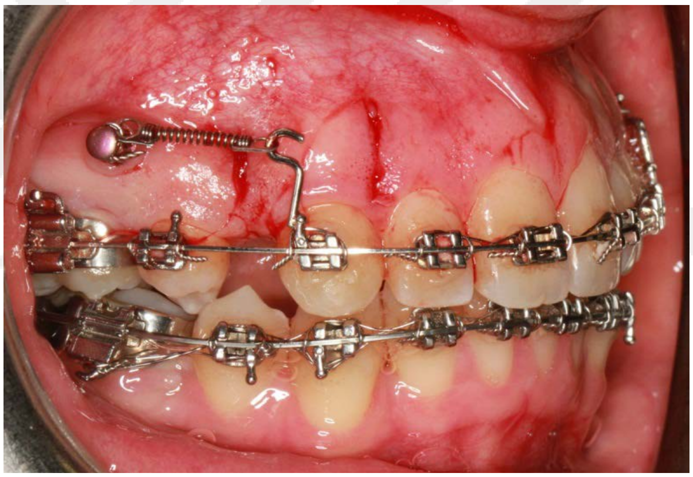

Figure 3.12: Application of the canine retraction force from miniscrews to hook on the canine bracket using NiTi closing coil spring (Piezocision side)

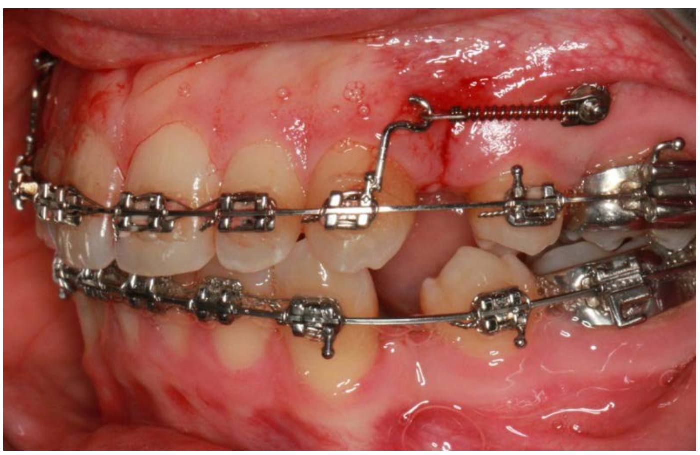

Figure 3.13: Application of the canine retraction force (MOPs side)

3.3.5. Measurement of canine distalization, rotation, and anchorage loss

Patients were evaluated at the beginning of the study, immediately after surgery and before canine retraction (T0), 3 weeks (T1), and 6 weeks later (T2) to monitor the rate of tooth movement. At each appointment impressions of upper jaw were taken with alginate to obtain the dental casts. The casts were scanned using flatbed scanner and the measurements of tooth movement were performed on the scanned image of the dental cast. The medial end of the third palatal rugae was selected as reference point **(Figure 3.14).** The canine and molar points were defined in the scanned images, and the pre- and postretraction distances were measured. In the scanned image, the midpalatine raphe and medial end of the third rugae were defined. Rugae line is formed by drawing horizontal line from the medial end of the third rugae to median palatine raphe. The amount of distal canine movement was evaluated by measuring the distance between the tip of canine and rugae line by calculating the differences between sequential measurements (T0-T1, T1-T2). The total amount of movement was considered to be the difference between the values of T0 and T2.

The anterior movement of the first molars (Anchorage loss) was evaluated by measuring the distance between the mesial central fossa of the maxillary first molar to rugae line. The total amount of anchorage loss was calculated by the difference between the values of T0 and T2.

The rotation of upper canines was measured by the angle formed between the median palatine raphe and a line passing through the mesial and distal contact points of the canines. The total rotation was considered to be the differences between values of T0 and T2. The measurements were performed using electronic digital caliper with sensitivity of 0.01mm (**Figure 3.15).** All measurements were repeated again few days later to check the reproducibility.

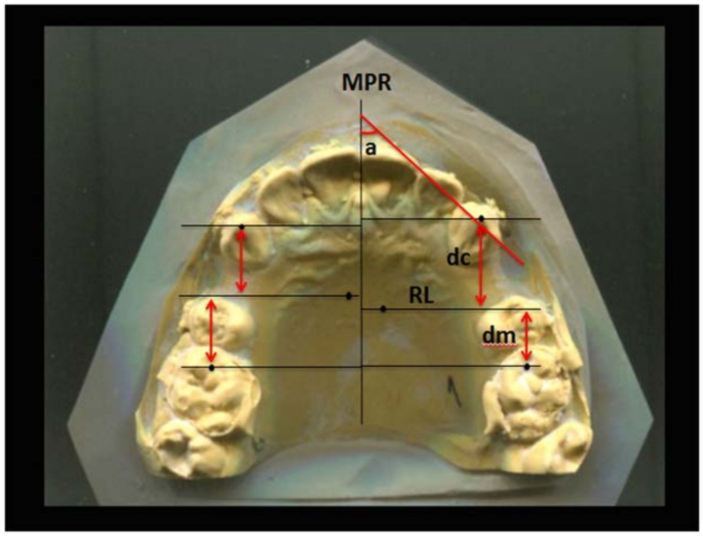

Figure 3.14: Measurement of tooth movement on the scanned image of a dental cast. Median palatine raphe (MPR) and the rugae line (RL) formed by a projection from the most medial point on the third right rugae. (dc) the distance between the cusp tip of the canine and the rugae line used to measure the anterior-posterior canine movement; (dm) the distance between the mesial central fossa of the maxillary first permanent molar and rugae line used to measure mesial molar movement (anchorage loss); (a) the angle between the median palatine raphe and the line through the mesial and distal contact points of the canine used to measure canine rotation.

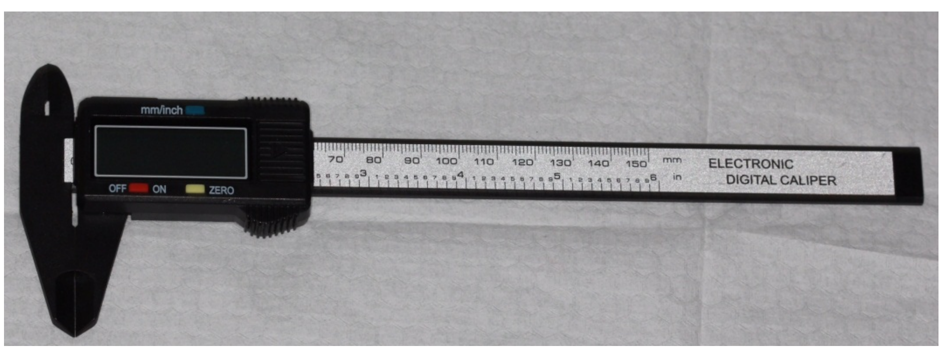

Figure 3.15: Electronic digital caliper used for measurement (MahrCal, Gottingen, Germany)

3.4. Statistical Analysis

The statistical analysis in this study was performed using NCSS (Number Cruncher Statistical System) 2007 Statistical Software (Utah, USA).

The collected data was analyzed using descriptive statistical methods (mean, standard deviation) and distributions of variables were evaluated using Kolmogorow Simirnov test. In T0, T1 and T2, for variables with normal distribution paired variance analysis was used. Newman Keuls Multiple Comparison test was used in sub group comparison, paired t test was used for T0 and T1 comparison; in dual group comparison independent t test was used. For variables that did not have normal distribution, dual group comparisons were made using Mann Whitney U test. The results were evaluated at a significance level of $p<0.05$.

4. RESULTS

4.1 Method Errors Evaluation

Intraclass Correlation Coefficient (ICC) was used for measurement reliability. All measurements were above the limit value of 0.700. The correlation coefficients of the repeated measurements in the samples were found between 0.985 and 0.998, which means, they were highly correlated (**Table 4.1**).

Table 4.1: Method errors evaluation for the measurements of the distance between the rugae line and the tip of the canine, loss of molar anchorage and rotation of canine.

	Intraclass Correlation Coefficient (ICC)	%95 (CI)
The Distance between the Rugae Line and the Tip of the Canine at T0	0.998	0.975-1.000
The Distance between the Rugae Line and the Tip of the Canine at T1	0.985	0.988-1.000
The Distance between the Rugae Line and the Tip of the Canine at T2	0.998	0.987-1.000
Loss of Molar Anchorage T0	0.997	0.967-0.999
Loss of Molar Anchorage T2	0.998	0.985-1.000
Rotation of Canine T0	0.986	0.953-0.998
Rotation of Canine T2	0.998	0.982-1.000

4.2. Age and gender

The mean age of the participants was 19.75 ± 4.27 years with minimum age of 14.51years and maximum age of 27.14 years.

7 of the participants (%58.33 of the total participants) were male with mean age of 17.67±2.48 years, with minimum age of 14.51 years and maximum age of 21.05 years.

5 of the participants (%41.67 of the total participants) were female with mean age of 22.67±4.67 years, with minimum age of 16.93 years and maximum age of 27.14 years **(Table 4.2).**

Table 4.2. The of age and gender of the patients included in the study

	N	**Age (Mean±SD)**	**Minimum**	**Maximum**
Male	**7**	17.67±2.48	14.51	21.05
Female	**5**	22.67±4.76	16.93	27.14
All Patients	12	19.75±4.27	14.51	27.14

4.3 The Distance between the Rugae Line and the Tip of the Canine (evaluation of the anterior posterior position of the canine)

At the beginning of canine retraction T0, on both piezo side and MOPs side, no statistically significant difference was observed between the means of distances between the rugae line and the tip of the canine (p= 0.233) (**Table 4.2).**

Table 4.3: The distance between the rugae line and the tip of the canine at the beginning of the retraction T0, 3 weeks T1 and 6 weeks later T2. (Piezo: Piezocision, MOPs: Microosteoperforations).

The Distance between the Rugae Line and the Tip of the Canine (mm)	**Piezo Side**	**MOPs Side**	**p***
	Mean±SD	**Mean±SD**	
T0	11.88±1.64	11.17±1.19	0.233
T1	10.67±1.56	10.36±1.1	0.582
T2	9.68±1.61	9.57±0.99	0.845
p+	**0.0001**	**0.0001**	

*** Independent t test** **+ Paired analysis of variance** **SD: Standard deviation**

Table 4.4: Comparison of the means of the distances between the ruage line and the the tip of the canine at different stages.

Newman Keuls Multiple Comparison Test	**Piezo Side**	**MOPs Side**
T0 / T1	**0.0001**	**0.0001**
T0 / T2	**0.0001**	**0.0001**
T1 / T2	**0.0001**	**0.0001**

In piezo side and MOPs side at T0, T1 and T2 the means of the distances between the rugae line and the tip of the canine showed statistically significant changes (p=0.0001). The mean of distance at T0 was significantly higher than the means of distances at T1 and T2 (p=0.0001). At T1 the mean of distance was significantly higher than the mean of distance at T2 (p=0.0001).

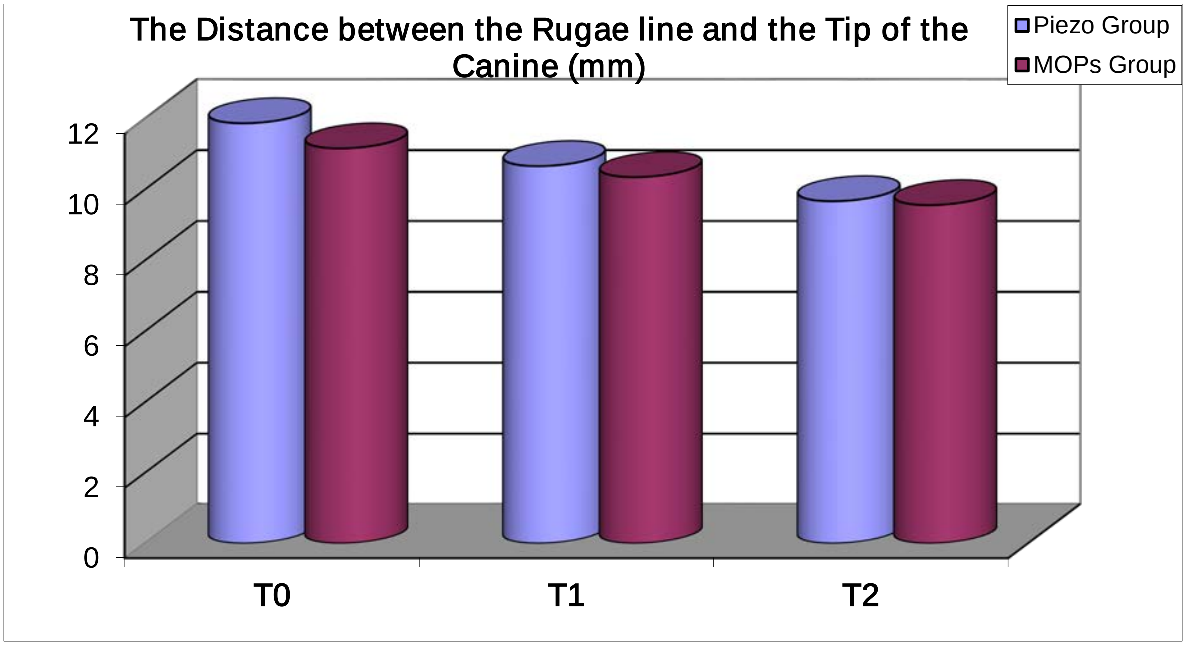

Figure 4.1: Graphic representation of the changes of the distance between the rugae line and the tip of the canine at different stages T0, T1 and T2.

4.5. Evaluation of the Amount of Canine Distalization

Table 4.5: The amount of distal canine movement

Distal Movement of the Canine (mm)	**Piezo Side**	**MOPs Side**	**P***
	Mean±SD	**Mean±SD**	
T0-T1	1.22±0.15	0.81±0.24	**0.0001**
T1-T2	0.99±0.18	0.79±0.15	**0.008**
T0-T2	2.21±0.3	1.6±0.34	**0.0001**

*** Independent t test** **SD: Standard deviation**

The amount of distal movement between T0 and T1 was statistically significantly higher in piezo side than that in MOPs side (p=0.0001)**.** Similarly, statistically significantly higher amount of distal canine movement was observed on piezo group than MOPs group between T1 and T2 (p=0.0008). The total amount of canine movement T0-T2 was statistically significantly higher on piezo side than MOPs side **(Table 4.5)**.

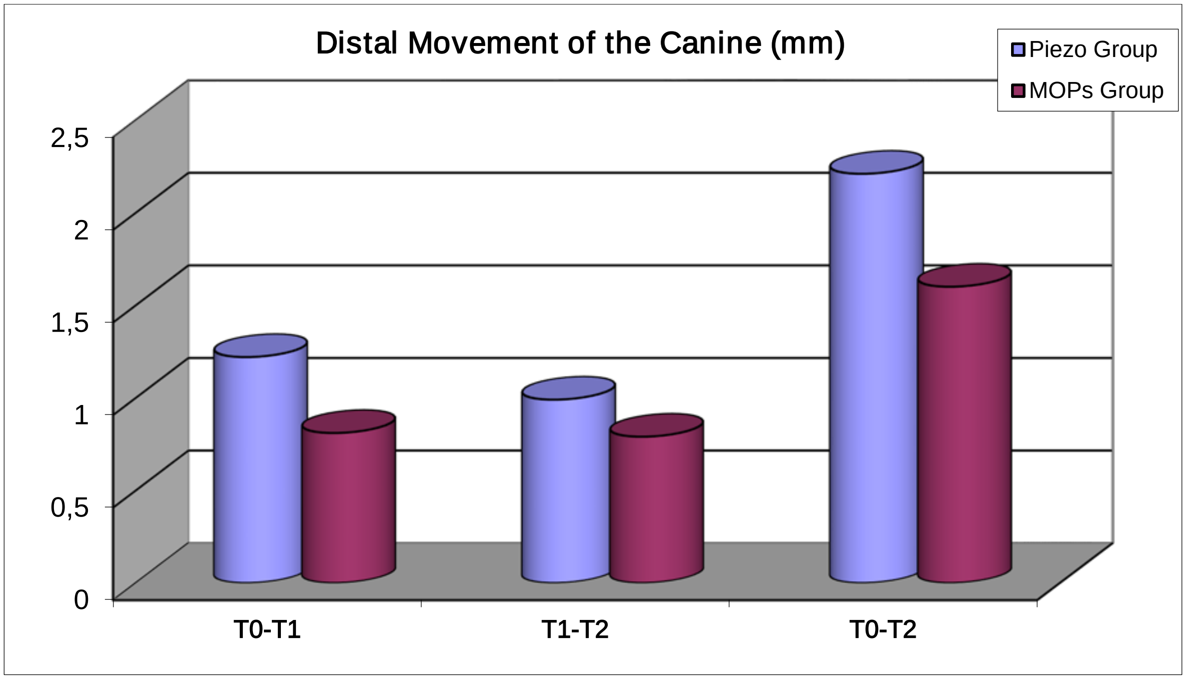

Figure 4.2: Graphic representation of the amount of distal canine movement

4.6 Loss of Anchorage of the Molars (The Distance between the Ruage Line and the Central Fossa of the First Permanent Molar)

Table 4.6: The changes of the distance between the rugae line and mesial central fossa of the maxillary first permanent molar.

The Distance between the Rugae line and the central fossa of the first permanent molar (mm)	**Piezo Side**	**MOPs Side**	**P***
	Mean±SD	**Mean±SD**	
T0	7.20±1.08	7.21±1.15	0.986
T2	7.19±1.09	7.20±1.16	0.981
P+	0.339	0.336	

* **Independent t test** + **Paired analysis of variance** **SD: Standard deviation**

Neither on piezo side nor on MOPs side there were no significant changes of the means of the distances between the rugae line and the mesial central fossa of the maxillary first permanent molar at T0 and T2 (p=0.339 and p=0.336 respectively) **(Table 4.6).**

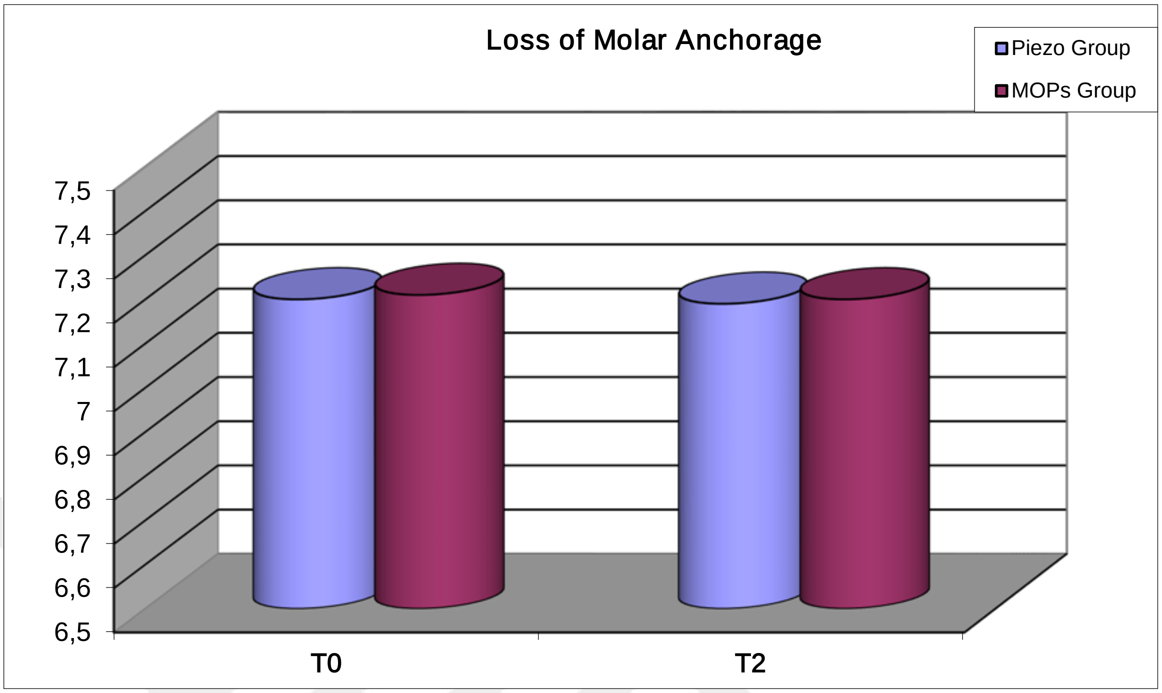

Figure 4.3: Graphic representation of the amount of anchorage loss

Table 4.7: Loss of molar anchorage

Anchorage loss (mm)	Piezo Side	MOPs Side	P*
	Mean±SD	Mean±SD	
T0-T2	0.008±0.028	0.008±0.027	0.999

* **Mann Whitney U test** **SD: Standard deviation**

No statistically significant difference was observed between the anchorage loss on both Piezo side and MOPs side (p=0.999) **(Table 4.7)**.

4.7. The Angle between the Median Palatine Raphe and the Line through the Mesial and the Distal Contact Points of the Canine.

Table 4.8: Changes in the rotation of canines.

Rotation of Canine (°)	Piezo Group	MOPs Group	P*
	Mean±SD	Mean±SD	
T0	37.73±2.66	38.92±3.41	0.350
T2	36.91±2.75	37.55±3.15	0.601
P+	0.123	0.118	

*** Independent t test** **+ Paired analysis of variance** **SD: Standard deviation**

In both piezo side and MOPs side no statistically significant changes of the rotation of the canines were observed at T0 and T2. They were (p=0.123 and p=0.118) respectively **(Table 4.8)**.

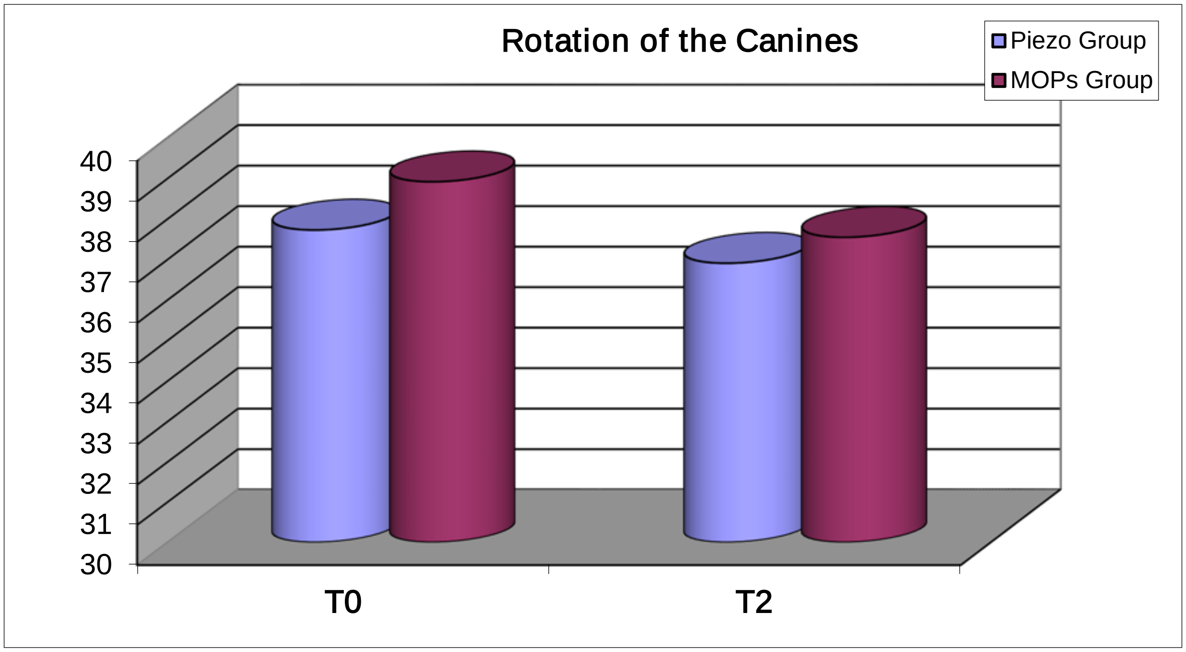

Figure 4.4: Graphic representation of the changes in the rotation of the canines.

Table 4.9: Comparison of the changes in the rotation of the canines after 6 weeks

Canine Rotation(°)	Piezo Side	MOPs Side	P*
	Mean±SD	Mean±SD	
T0-T2	0.816±0.329	1.367±2.794	0.103

* **Mann Whitney U test** **SD: Standard deviation**

After 6 weeks of canine distalization, no statistically significant changes of canine rotation were observed between Piezo group and MOPs group **(Table 4.9)**.

5. DISCUSSION and CONCLUSION

5.1. Discussion of Aim of the Study

The aim of this study is to compare the effects of flapless piezocision and micro-osteoperforation on the rate of orthodontic tooth movement. Piezocision procedure involves micro-incisions limited to the buccal gingiva and localized decortication of the buccal cortex using Piezosurgery. Micro-osteoperforations is a process of performing limited shallow perforations of the buccal cortical plate using a manual drilling appliance. The effects of these techniques were compared while retracting the maxillary canines toward the spaces of extracted maxillary first premolars. Both techniques were described to be minimally invasive to achieve rapid orthodontic tooth movement without the risks and drawbacks accompanied the other surgical approaches. We compared these techniques in order to evaluate which technique is more efficient to accelerate orthodontic tooth movement, and to find out more conservative and less aggressive alternative to decrease the time required for canine retraction. In the literature, there are studies where the effects of these protocols have been investigated; however, there are no comparisons between effects of piezocision and micro-osteoperforations to date. Aksakalli *et al*.(190) evaluated the effect of piezocision on the rate of tooth movement during retraction of maxillary canine. M.Alikhani *et al*.(7) studied the effects of micro-osteopeforations on the rate of distal canine movement. We aimed to evaluate the effects of both Piezocision and micro-osteoperforations on the rate of orthodontic tooth movement and we compared the effects of both of them

5.2. Discussion of Materials and Methods

The long duration of orthodontic treatment is one of the most frequent complaints of orthodontic patients; so that reducing orthodontic treatment duration is an issue of importance particularly for adults. The length of comprehensive orthodontic treatment can range from approximately 12 to 36 months, depending on treatment options and individual characteristics (1).

Rapid orthodontic tooth movement and reduction of treatment time can be achieved by combination of orthodontic treatment and surgical alveolar corticotomies (2,123). Many studies showed that the regional acceleratory phenomenon (RAP) induced by surgical trauma has considerable effect for reducing orthodontic treatment time (117). Wilcko *et al* (3,117) have combined alveolar corticotomies with bone augmentation to accelerate tooth movement, the increased rate of tooth movement after corticotomy-facilitated orthodontics was attributed to RAP, which characterized by greater bone turnover. Liou and Haung (165) proposed alveolar distraction to accelerate canine retraction, and Iseri *et al* (131) reported the rapid canine retraction with dentoalveolar distraction osteogenesis. Although these surgical techniques reported to be effective in reducing clinical orthodontic treatment time, the procedures were accompanied with many drawbacks such as the aggressive nature of these procedures, increasing postoperative discomfort, and the risks of complications (5,198,202).

In the literature, various attempts have been made to accelerate orthodontic tooth movement with more conservative methods and to overcome the disadvantages accompanied with conventional corticotomy techniques. In 2009, Dibart *et al*.(5) Introduced new and minimally invasive procedure that was called “piezocsision”, which combines gingival microincisions and decortication of the alveolar bone using piezoelectric knife. M.Akikhani *et al*.(7) evaluated the effects of micro-osteoperforations (MOPs) on the rate of the rate of tooth movement, the procedure included performing shallow cortical perforations of the alveolar bone using a device called (Propel). In this study, the effects of piezocision and MOPs techniques to accelerate orthodontic tooth movement were compared while the maxillary canines were being retracting distally to the extracted first premolar spaces. Distal movement of canine toward extraction spaces is a time consuming procedure in premolar extraction patients. Conventional methods results in retraction rates of 0.5 to 1 mm per month. Therefore, full canine retraction can require 5 to 9 months. Conventional treatments with fixed appliances are likely to require 1.5 to 2 years. In the literature, most of studies targeting acceleration of tooth movement are performed while the canine is being retracted toward the extraction spaces. Aboul-Ela et al (41), Abbas et al (138), Aksakalli et al (190), and Azimova (199) all observed the effects of different methods to accelerate orthodontic tooth movement while retracting the maxillary canine toward premolar extraction space.

In the present study, the sample consisted of 12 patients (6 male, 6 female; mean age; 19.75± 4.27 years) exhibiting various malocclusions that necessitated extractions of maxillary premolars and subsequent canine retraction. The patients included in the study were selected according to the following criteria; the canines should not be infrapositioned, no previous orthodontic or orthopedic treatment, absence of systemic disease and chronic illness, the patient should have good oral hygiene and the patient should not have any signs or symptoms of periodontal diseases. The patients with extra or missing tooth were not included in the study, to avoid the negative effects of these conditions on the occlusion. The criteria of selection were compatible with the criteria of other studies performed by Aboul-Ela *et al*. (41), Gün (189), Aksakalli *et al*. (190), Abbas *et al*. (138) and Azimova (199).

Age can play a significant role in the rate of tooth movement. It has been related to bone density or rate of osteoclast recruitment or activation (203). To eliminate the effect of the age on the rate of tooth movement, in the same patient the two procedures were randomly assigned to both right and left side of the maxilla. Abbas *et al*.(185) evaluated the effects of corticotomy-facilitated orthodontics and piezocision in rapid canine retraction; the sample included 20 patients with age range of 15-25 years. Gün (189) evaluated the effects of piezocision on the rate of distal canine movement; the sample included 31 patients with age range of 12-22 with mean age of 17 years 5 months. Aksakalli *et al*.(190) performed a study to accelerate orthodontic tooth movement during retraction of maxillary canine using piezocision; the sample included 10 patients with mean age of 16 years. Azimova (199) evaluated the effect of transmucosal decortication on the rate of tooth movement, the sample 9 patients with mean age of 17 years 1 month. The mean age of the selected sample in our study is in accordance with mean age in the studies that we mentioned above (185,189,190,199).

Our study was designed to be a Cohort study, so that before canine distalization and after alignment and leveling phase, in the same patient piezocision and MOPs were randomly assigned on either right or left sides to eliminate the possibility of uneven occlusal forces because habitual occlusal predominantly on one side (7). Krishan and Davidovitch (8) reported that the rate of tooth movement is significantly affected by individual metabolic and physiologic factors, so that performing both procedures in the same patient will eliminate these factors and comparison can be achieved with more reliable results. In some studies, it has been reported that elevation of mucoperiosteal flap is traumatic enough to induce RAP (5), based on this facts; both procedures that we performed were done without elevation of mucoperiosteal flaps. Wilcko *et al* (117) assumed that the RAP induced by buccal corticotomy may involve the noncorticomized palatal side, based on this assumption, in this study, the surgeries were performed only on the buccal cortical plate of the bone without reflection of mucoperiosteal flaps. Also, this conservative technique has advantages such as reduced operation time as well as postoperative patient discomfort.

Piezocision is a flapless procedure which involves gingival micro incision and vertical cortical cuts using piezosurgery knife. In the present study, this procedure was applied to one side of the maxillary arch. It is a minimally invasive surgical technique performed only from the buccal side; there is no need for intervention from the lingual or palatal side. The use of piezoelectrical knife enhances bone healing without causing osteonecrotic damage and preservation of root integrity because of its precise, selective cutting action (177). The piezoelectrical knife works only on mineralized tissues, so it doesn't affect the soft tissue and their blood supply. No sutures were needed after the surgery and the surgical areas were fully healed after one week. The procedure has many advantages which include the simplicity and reduced aggressiveness when compared to conventional corticotomy techniques. Dibart et al (5) in 2009, was the first to describe minimally invasive procedure to accelerate tooth movement and called it Piezocision. This approach combines micro incisions to the buccal gingivae that allow for the use of the piezoelectric knife to decorticate the alveolar bone to initiate regional acceleratory phenomenon. Abbas et al. (138), Gün (189), Aksakalli et al. (190) in their studies, evaluated the effects of Piezocision on the rate of tooth movement by performing decortication procedure with depth of 3 mm mesial and distal to the canines using Piezosurgery knife.

Micro-osteoperforations were applied to the other side of maxillary arch, they are limited shallow perforations of the buccal cortical bone of the maxilla using a manual drilling appliance, and it is also considered as a minimally invasive procedure to accelerate orthodontic tooth movement. The procedure did not involve elevation of soft tissue flaps, bone grafting, or any suturing, allowing the treatment to take place in the orthodontic chair (7,143). It is comfortable and safe procedure and no discomforts were experienced by the patients. M.Alikhani *et al* (7) evaluated the effects of micro-osteoperforations on the rate of tooth movement during maxillary canine retraction. Three MOPs were performed distal to the canine using a disposable MOPs device (Propel) with diameter of 1.5 mm and 2 to 3 mm deep. Azimova (199) monitored the rate of tooth movement during maxillary canine retraction after drilling 3 mm deep and 1.2 mm wide perforations on the buccal cortical plate using manual driller.

The aggressive nature of corticotomy procedures related to the elevation of muco-periosteal flaps and relatively the long time needed to perform the surgery raised hesitation among both the patients and dental community. In addition, during the corticotomy procedures, the cortical incisions are performed using a bone bur that could potentially damage the roots of neighboring teeth and bone, and also may cause potential marginal osteonecrosis, and impair bone regeneration (204,205). Different attempts have been made to identify minimally invasive surgical procedures for inducing RAP, and it could be induced by piezocision (5) and micro-osteoperforations (7).

Space closure after premolar extraction is an important stage in comprehensive orthodontic treatment. Anchorage control is very important to obtain satisfactory treatment results (206). In cases with maximum anchorage demands, specifically designed orthodontic miniscrews have been successfully used as a source for absolute anchorage. In this study, miniscrews implants were used as a skeletal anchorage during retraction of the canine. The use of mini-screws as anchorage device has many advantages including their simpler placement technique and the possibility of eliminating the reliance on the patient compliance. Thiruvenkatachari et al. (49) concluded that the use of mini-screws as anchorage device during retraction of canines is a viable alternative to conventional molar anchorage. We placed the miniscrews between the maxillary second premolar and the first molar buccally, this placement was selected based on recommendations of Schnelle et al. (52), who advocated this site as bone stock for miniscrew placement in the maxillary arch. The placement of miniscrews was performed in the attached gingiva to achieve higher success rate and less tissue proliferation around the miniscrews. The mini-screws that we selected had a diameter of 1.3 mm and a length of 8 mm based on recommendations by Kuroda et al. (51), they suggested that this dimensions are adequate to obtain mechanical retention of the screws and eliminate any root proximity that might contribute to failure during treatment. Gökçe et al (50) conducted a study to compare between the conventional molar anchorage and the mini-screws during distalization of maxillary and mandibular canines. They concluded that the use of mini-screws as an anchorage mean instead of molars provides safer anchorage control and greater amount of canine distalization in both maxilla and mandible. The protocol of using miniscrews as anchorage device was followed in many studies, Aboul-Ela et al (41), M.Alikhani et al (7), Azimova (199) and Gün (189) all preferred the use of miniscrews as anchorage unit during retraction of maxillary canine.

The magnitude of force that we applied to retract the canines was around 150 g per side using NiTi closing coil springs.The springs were connected from mini-screws to a power arm on the canine bracket.The aim of using power arm was to allow application of the force closer to the center of resistance of the tooth; thus achieving more bodily movement and decreasing the amount of tipping. In the literature, there is no true agreement about the optimal force levels for canine retraction, several force magnitude have been advocated. Studies of Story and Smith (37) and Reitan (9) advocated that the use of light forces are more efficient and more biologic and it is less painful. In previous researches, force magnitude have been reported to be approximately 50-500 gr (38,207,208). Several studies recommended a 150 g as an optimum force magnitude for retraction of the canines (42). In studies of Abbas *et al*. (138), Aksakalli *et al*. (190), and Azimova (199) to evaluate the effect different methods to accelerate orthodontic tooth movement, all applied 150 g force to retract the maxillary canines in both working and control sides. maxillary canines with magnitude of applied force around 150 gr. M.Alikhani *et al*.(7) in a study to evaluate the effect of micro-osteoperforations on the rate of orthodontic tooth movement, the force that they applied to retract the canine was around of 100 g. In our study the canine retraction force was applied using NiTi closing coil spring connected from a miniscrew to a power arm on the canine bracket. Retraction of canine can be achieved using NiTi closing coil spring, power chain or elastic threads, and are all able to provide optimum force (209). Dixon *et al*. (210) studied the efficiency of power chains and NiTi spring as methods for orthodontic space closure and they concluded that NiTi coil spring provides more rapid tooth movement. Another study performed by Nattrass *et al.* (211) to study the effect of environmental factors on elastomeric chain and NiTi spring, the obtained results revealed that NiTi spring provide a steady constant force and lose its force in less rate than elastics.

In order to achieve bodily movement and reduce tipping during canine retraction, the force has to be applied closer to the center of resistance of the canine tooth. Based on this; we applied the force using a NiTi closing coil spring that was connected from the miniscrews to a power arm on the canine bracket. The power arm was specifically fabricated using 0.7 mm stainless steel wire which welded to canine bracket using laser welding machine (EVO 100, Evo Series, Verona, Italy). Park and Kown (212) conducted a clinical report of 3 cases to evaluate the efficiency of miniscrews as an anchorage device during retraction of six anterior teeth after extraction of premolars. They used hooks to apply the retraction forces closer to the center of resistance of the anterior teeth. In a study performed by Azimova (199), the force was applied using a closing open coil connected from the miniscrews to the power arm on the canine bracket. The achieved tooth movement showed that there was minimum amount of canine tipping and rotation. M.Alikhani et al. (7) suggested application of canine retraction force to a power arm on the canine bracket to allow application of the force closer to the center of resistance of the canine. They concluded that the canine was tipped slightly but the amount of tipping was not statistically significant. In studies conducted by Gün (189), Aboul-Ela *et al.*(41) and Abbas *et al.* (185) the force to retract the canine was applied directly to the brackets and no power arm was used. The obtained results showed that the amounts of rotation and tipping of the canine were obviously significant. Increased tipping of the canine may affect the accuracy of evaluating the amount of tooth movement.

The rate of tooth movement can be changed by extractions; the reason of this effect can be attributed to the increased the activity of inflammatory markers caused by extraction (7). Hassler *et al.* (213) compared the rate of maxillary canine retraction into healed and recent extraction sites. They concluded that the canine on the recent extraction side moved faster than that on the healed side. In our study, in order to minimize the possibility of these effects, extractions were performed at the beginning of our study, 6 months before canine retraction. We followed the same protocol in the studies of M.Alikhani *et al*. (7), Azimova (199), and Gün (189). In these studies, tooth extractions were performed at the beginning of the treatment followed by initial phase of leveling and alignment, and then the retraction of canine was started. In other studies by Aboul-Ela *et al*. (41) and Abbas *et al.* (185) to evaluate the effects of the corticotomy and piezocision on the rate of tooth movement, the authors suggested that in order to reduce the aggressiveness of the procedure and reduce the patient stress of having 2 bleeding sites at the same time, one premolar was randomly selected and extracted on the day before surgery, and the other premolar was extracted on the day of surgery. In this situation the rate of tooth movement was affected also by RAP that waas induced by tooth extractions, which in consequence obscure the exact outcome of the method that was used to investigate the acceleration of orthodontic tooth movement.

In the present study, canine retraction was started immediately after the surgery in order to take the advantage of the RAP induced by bone injury and the patients were evaluated every 3 weeks for a total period of 6 weeks. This was based on the fact that the RAP is a transient phenomenon and its effects can diminish with decrease in tooth movement velocity over time (5,136). Yaffe *et al*.(113) reported that RAP begins a few days after the surgery, peaks between 1 and 2 months, takes from 6 to 24 months to resolve completely. Dibart *et al*.(6) assumed that the RAP as transient, but continuous mechanical stimulation of the teeth would prolong the osteopenic effect induced by the procedure. In the studies of Aboul-Ela *et al.* (41), Abbas *et al*.(185) and Aksakalli *et al.* (190) the canine retraction was started immediately after the surgery, the total follow-up period after the start of canine retraction was until canine Class I relationship was achieved, which took about 3.5 months.They evaluated the patients every 2 weeks and observed that the antero-posterior changes in the position of canines were significantly higher during the first and second months after surgery and declined gradually. Gün (189) evaluated the effects of piezocisison on the rate of canine distalizaion for a total period of 10 weeks, the patients were evaluated every 2 weeks. The greatest amount of canine distalization on the piezocision side was observed during the first 2 weeks and decreased gradually but still higher than the control side till 6^{th} week, after that until the 10^{th} weeks there were no differences between the amounts of canine movement on both sides. This gradual declination of tooth movement was attributed to the transient nature of RAP.

To monitor the rate of tooth movement, the patients were evaluated at the beginning of the study immediately after the surgery and before canine retraction (T0), 3 weeks (T1), and 6 weeks later (T2). At each appointment, impressions of the upper jaw were taken with alginate to obtain the dental casts. The casts were scanned using flatbed scanner and the measurements were performed on the scanned image of the dental casts using an electrical digital caliper with accuracy of 0.01 mm. The measurements were done by selecting the medial end of the third palatine ruga as reference points. The antero-posterior movements of the canine were assessed at 3 time points. The scanned images were also used to assess the anchorage loss of the first molars and the rotation of the canines. The use of the third rugae as a stable point to assess antero-posterior tooth movement has been advocated by many researchers. Hoggan and Sadowsky (214) and Almeida *et al.* (215) assumed that rugae landmarks can be used as reliable point to assess antero-posterior tooth movement. Other study conducted by Bailey *et al* (216) to determine the stability of the palatal rugae after orthodontic treatment with and without extraction, they concluded that the medial and lateral end of the third ruga appear to be stable landmarks for cast analysis. Aboul-Ela *et al.*(41), Abbas *et al*.(138), and Aksakalli *et al*.(190) used scanned images of the dental casts to measure the amount of canine distalization, they also selected the medial end of the third palatine rugae as reference points to measure the distalization of the canine, mesialization of the molars (anchorage loss), and canine rotation. M.Alikhani et al.(7), Azimova (199), and Gün (189) they all used the dental cast to measure the distalization of canine. Although the use of dental casts to assess antero-posterior tooth movement is very simple and cheap method, it has many drawbacks, these include; it is very difficult to take stable anatomical landmark as reference point which subsequently affect the reliability of the obtained results.

5.3. Discussion of the Results

The results of the current study have demonstrated that the achieved amount of canine distalization on the piezocision side after 3 weeks of retraction was 1.22±0.15 mm, after 6 weeks of retraction, the achieved of canine movement was 2.21±0.3 mm. On the other hand, on MOPs side, and after 3 weeks of retraction, the canine moved distally 0.81±0.24 mm and moved 1.6±0.34 after 6 weeks.

Aboul-Ela *et al*. (41) in a human study evaluated the effect of corticotomy-facilitated orthodontic on the rate of tooth movement during maxillary canine retraction. Corticotomy-facilitated orthodontics was performed on one side of the maxillary arch, and the other side served as the control. On the day before the corticotomy surgery, 1 maxillary first premolar was extracted on a random basis. When the patient was scheduled for the surgery, the other premolar was extracted. The corticotomy procedure involved elevation of full-thickness mucoperiosteal flap extended from the mesial surface of the maxillary lateral incisor to the mesial surface of the maxillary second premolar. The obtained results showed that the rate of canine retraction was significantly higher on the corticotomy side than the control side by 2 times, after one month of canine retraction the canine on corticotomy side moved 1.89 mm, on control side moved 0.75, in the second month of retraction the canine on corticotomy side moved 1.83 mm, on the control side moved 0.86, in the third month the canine moved 1.07 on the corticotomy side and 0.93 on the control side, in the fourth month both sides moved almost the same distance, on corticotomy side the canine moved 0.89 mm, and moved 0.85 on the working side.

Corticotomy procedure applied in the above mentioned study present significant postoperative discomfort. The aggressive nature of these methods related to the elevation of mucoperiosteal flaps and to the length of surgery raised hesitation among both patient and dental community. Also, extraction protocol followed in this study can change the rate of tooth movement by increasing the activity of inflammatory markers. Finally, the canine retraction force was applied using NiTi closing coil springs, which was directly connected from the miniscrews to the bracket of canine, so that the force was applied away from the center of resistance. Based on this fact we can suppose that the amount of tipping movement achieved in this study was significantly higher, which can make a doubt about the achieved distance that the canine moved distally. If we consider the factors that were mentioned above, the results that were achieved in the present study are comparable, and that we have additional advantage because the procedure that we applied was less aggressive and did not require long operation time.

Abbas *et al*.(138) performed a clinical study to evaluate the corticotomy-facilitated orthodontics and piezocision in rapid canine retraction. The sample included 20 patients with full complement of permanent teeth that necessitated maxillary first premolar extraction and subsequent canine retraction. The sample was assigned into 2 equal groups. In the first group, one side of the maxillary arch was randomly chosen for treatment with corticotomy, and in the second group, piezocision treatment was used. The contralateral sides of both groups served as control. Extraction protocol followed in this study was similar to that in the study of Abou-Ela *et al*.(41). On the day before the surgery, 1 maxillary premolar was randomly selected and extracted, and the other premolar was extracted on the day of surgery. In corticotomy group, the corticotomy procedure was accomplished after elevation of full-thickness mucoperisoteal flap which extended from the mesial surface of the maxillary lateral incisor to the mesial surface of the maxillary second premolar. The results revealed that the corticotomy facilitated orthodontics is 1.5 to 2 times faster than conventional orthodontics and piezocision was 1.5 times faster than conventional orthodontics. Based on the conclusion of this study, we can suppose that the piezocision technique resulted in a clinical outcome that were similar to those of classic corticotomy approach, but the piezocision technique has additional advantages of being minimally invasive, precise, less traumatic to the patients.

In our study, we gained 2.21 mm of distal canine movement on the piezocision side, which is in accordance to the results achieved by Gün (189). In her thesis of graduation, Gün (189)evaluated the effect of piezocision on the velocity of tooth movement during retraction of the maxillary canine. The sample included 31 patients who required extraction of first premolar and subsequent canine retraction. Piezocision was performed on one side, and the opposite side served as control. The patients were evaluated every 2 weeks for total period of 10 weeks to monitor the amount of distal canine movement. The results showed that the amount of canine distalization after 10 weeks of observation was 3.11 mm on the piezocision side, and 2.11 mm on the control side. After 6 weeks of retraction, they achieved 2.07 mm of distal canine movement on the piezocision side.

In our study, and on the piezocision side, we applied the piezocision procedure in a similar way to the methods followed by Aksakalli et al.(190), and the amounts of distal canine movement that we achieved on the piezocision side was 2.21 mm which were comparable to the amounts that they achieved. Aksakalli *et al*.(190) in a clinical study monitored the effect of piezocision on the rate of tooth movement during maxillary canine distalization, and also evaluated if there was any transversal changes accompanied with the procedure. The sample included 10 patients who required therapeutic extraction of maxillary first premolar and subsequent canine distalization. The patients were evaluated with split mouth design; one side was randomly selected to receive the piezocision procedure and the opposite side served as control. Canine distalization procedure was started immediately after surgery with distalization force of 150 g applied using elastomeric chain. Patients were evaluated every 2 weeks until ideal Class I canine relationships were established. The results showed that the amount of canine distalization after 1 month was 1.53±0.67 mm on the piezocision side, on control side the amount was 0.78±0.24 mm, after 2 months the canine on the piezocision the total distal movement of the canine was 2.90±0.86 mm, while the canine on the control side moved 1.73±0.72 mm.

The amount of canine distalization that we gained on the micro-osteoperforation side after 3 weeks was 0.81±0.24 mm , and after 6 weeks was1.6±0.34 mm , these were almost the same to those achieved by Azimova(199). In her thesis of graduation, Azimova (199) evaluated the effect of trasnmucosal decortication procedure on the rate of distal canine movement. Manual driller was used to perform cortical perforations with depth of 2-3 mm and width of 1.2 mm. Canine retraction was started immediately after surgery using NiTi closing coil spring that applied distalizing force of 150 g. The patients were evaluated every 3 weeks to monitor the amount of distal canine movement and to adjust the force. The canines on the decortication side showed greater amount of movement compared to the control side, after 3 weeks the canine on the study side moved 0.73 mm, and the canine on the control side moved 0.56 mm, after 6 weeks of retraction, the total amount of canine movement on the study side was 1.5 mm, the canine on the control side moved 0.93 mm.

In our study, after 6 weeks of canine retraction on the MOPs side we achieved1.6±0.34 mm of distal movement of the canine. M.Alikhani *et al* (7) carried out similar study to evaluate the effects of MOPs on the rate of orthodontic tooth movement during retraction of maxillary canine. After 28 days, they concluded that MOPs increased the rate of canine retraction 2.3-fold compared with the control group. M.Alikhani *et* al.(7) expressed the rate of canine movement only in term of folds, for this reason we could not compare the results that we achieved with theirs.

On both piezocision side and MOPs side, the amount of distal canine movement was greater during the first 3 weeks. Gradual declination in the rate tooth movement was observed during the second 3 weeks. This gradual decrease can be attributed to the fact of transient nature of RAP, and also to suggestion of Frost (139) that prove that the effects of RAP can diminish with a decrease in tooth movement velocity over time. Aboul-Ela *et al.*(41) observed that the higher changes in the anteroposterior position of canines were observed during the first 2 months, they found that 1.89 mm of distal canine movement was achieved in the first month and 1.83 mm achieved in the second month. Aksakalli *et al*.(190) obtained 1.53 mm of canine distalization in the piezocision group for the first month, the amount decreased to 1.37 mm for the second month. In the study of Gün (189), the results showed that the highest rate of tooth movement on the piezocision side was achieved after first 2 weeks with amount of 0.81 mm and decreased gradually toward the end of the study.

The obtained results in our study revealed that the piezocision side exhibited greater rate of canine movement than MOPs side. These differences can be attributed to the relatively extensive surgery required for the piezocision procedure, which may result in more profound RAP enhanced on the piezocision side. This explanation is compatible with the finding of Frost (139) and Wilcko et al (114) who suggested that the severity of bone injury is directly correlated with the intensity of bone healing and the rapidity of tooth movement.

In our study, after 6 weeks of canine distalization, the amounts of disto-palatinal canine rotations were not significant on both sides. On the piezocision side, the canines showed rotation of 0.816°, whereas, on MOPs side the rotation was 1.367°. The results were compatible with the results achieved in a study by Azimova (199) with non-significant amount of rotation observed in both study and control sides. Significant amounts of rotation were observed in a study of Gün (189), after 10 weeks of canine retraction, the piezocision side showed 8.94° rotation of canine, whereas, control side had 7.16°. The reason of these greater amounts of rotation can be attributed to the direct of application of distalization force from the miniscrews to the bracket of the canine. In our study, and in order to decrease these effects and in an attempt to achieve bodily movement, we applied the retraction force from the miniscrews to the specially designed power arm on the bracket of the canine.

No significant molar anchorage loss occurred during canine retraction on either the Piezocision side or the MOPs side. The achieved results showed that the loss of anchorage on the Piezocision side was 0.07 mm, whereas, anchorage loss on the MOPs side was 0.08. In this study, miniscrews implants were used as a skeletal anchorage during retraction of canine. The miniscrews were placed between the maxillary second premolar and the first molar buccally. The results agree with findings of Thiruvenkatachari *et al*. (49) who advocated the use of miniscrews as an effective alternative to conventional molar anchorage. Similar results were achieved by Gün (189), Azimova (199), and Aboul-Ela *et al*.(41), they all used miniscrews as an anchorage device during maxillary canine retraction

CONCLUSIONS

Based on the results that we obtained from this study, we can summarize the conclusions as the following:

1. The rate of canine retraction was significantly higher on the piezocision side compared to the MOPs side.

2. Piezocision can be used as an effective treatment adjunctive to reduce the time required for canine retraction.

3. Piezocision is a minimally invasive technique to achieve rapid tooth movement without the drawbacks of traumatic surgical approaches.

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7. APPENDICES

7.1. ETHIC APPROVAL

T.C. YEDİTEPE ÜNİVERSİTESİ

Sayı : 37068608-6100-15-1216
Konu: Klinik Araştırmalar
Etik kurul Başvurusu hk.

05/05/2016

İlgili Makama (Aiman Elmabruk)

Yeditepe Üniversitesi Diş Hekimliği Fakültesi Ortodonti Anabilim Dalı Aiman Elmabruk'un sorumlu olduğu **"Manuel Dril ve Piezosizyon ile Yapılan Transmukozal Dekortikasyon İşleminin Diş Hareketine Olan Etkilerinin Klinik Olarak İncelenmesi ve Karşılaştırılması"** isimli araştırma projesine ait Klinik Araştırmalar Etik Kurulu (KAEK) Başvuru Dosyası (**1195** kayıt Numaralı KAEK Başvuru Dosyası), Yeditepe Üniversitesi Klinik Araştırmalar Etik Kurulu tarafından **04.05.2016** tarihli toplantıda incelenmiştir.

Kurul tarafından yapılan inceleme sonucu, yukarıdaki isimi belirtilen çalışmanın yapılmasının etik ve bilimsel açıdan uygun olduğuna karar verilmiştir (**KAEK Karar No: 614**).

Prof. Dr. Turgay ÇELİK
Yeditepe Üniversitesi
Klinik Araştırmalar Etik Kurulu Başkanı

Yeditepe Üniversitesi 26 Ağustos Yerleşimi, İnönü Mahallesi Kayışdağı Caddesi 34755 Ataşehir / İstanbul
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7.2. CURRICULUM VITAE

Personal Information

Name	Aiman	**Surname**	Elmabruk
Place of Birth	Tajoura-Libya	**Date of Birth**	**22.04.1981**
Nationality	Libya	**National Number**	**99838281828**
E-mail	**aymen.elhadi@yahoo.com**	**Tel**	**00905435431083**

Educational Status

Degree	**Field**	**Institue**	**Year of Graduation**
Phd			
Master of Science			
Bachelor of Dental Surgery	Dentsitry	Tripoli University-Libya	2006
Secondary School		Alasma High School	1999

Languages	**Yabancı Dil Sınav Notu (☐)**
English	TOEFL:82
Turkish	

Work Experiences

Work	**Place**	**Period**
General Dentist	**Alnajah Dental Center**	**2007-2011**
Clinical Instructor	**Tripoli University**	**2008-2011**

Computer Skills

Program	**Skill**
Microsoft Powerpoint	**Good**
Microsoft word	**Good**

7.3. INFROMED CONSENT

Sayın Hastamız,

- Bu belge bilgilendirilme ve aydınlatılmış onam haklarınızdan yararlanabilmenizi amaçlamaktadır.
- Size gerçekleştirilebilecek klinik araştırmalar amaçlı girişimler konusunda, tüm seçenekler ile bu girişimlerin yarar ve muhtemel zararları konusunda anlayabileceğiniz şekilde **bilgi alma hakkınız ve bir kopyasını isteme hakkınız** vardır.
- Yasal ve tıbbi zorunluluk taşıyan durumlar dışında **bilgilendirmeyi reddedebilirsiniz**. Yazılı bildirmek koşulu ile bilgi almama veya yerinize güvendiğiniz bir kimsenin bilgilendirilmesini talep etme hakkına sahipsiniz.
- Klinik araştırmalara katılım konusunda bilgilendirildikten sonra bunu kabul edebilirsiniz. Ya da k**arar verebilmek için uygun zaman talep edebilirsiniz.**
- Hayatınız veya hayati organlarınız tehlikede olmadığı sürece onamınızı (yazılı talep etme koşulu ile) **dilediğiniz zaman geri alabilir** ya da önceden kabul etmediğiniz herhangi bir tanı/tedavi amaçlı girişimi **tekrar talep edebilirsiniz**.
- Hastanemizde verilen hizmetleri **Hastane Tanıtım Broşürü**nden edinebilirsiniz. Ayrıca Hastanemiz personeli hakkında http://www.yeditepehastanesi.com.tr/ web sayfamızdan daha detaylı bilgilere ulaşabilirsiniz.
- Burada belirtilenlerden başka sorularınız varsa bunları yanıtlamak görevimizdir.

Araştırmanın Adı / Protokol numarası

Manuel Dril ve Piezosizyon ile Yapılan Transmukozal Dekortikasyon İşleminin Diş Hareketine Olan Etkilerinin Klinik Olarak İncelenmesi ve Karşılaştırılması

Araştırma Konusu

Diş hareketini hızlandırmak amacı ile 2 farklı methodu değerlendirerek karşılaştırdığımız bir çalışma yapıyoruz. İlk yöntemde ultrasonik cihaz kullanılarak kemikte 2 adet çizgi şeklinde çentik oluşturulmaktadır. İkinci yöntemde ise manuel vida cihazı kullanılarak kemiğe 3 adet delik açılmaktadır.

Araştırmaya Katılımcı Sayısı

12 Hasta

Bu Araştırmanın Amacı

Bu çalışmanın amacı diş hareketini hızlandıran yöntemlerin etkinliklerini karşılaştırmaktır.

Süresi 6 Hafta

İzlenecek Yöntem / Yöntemler

İlk yöntemde ultrasonik cihaz kullanılarak kemikte 2 adet çizgi şeklinde çentik oluşturulmaktadır. İkinci yöntemde ise manuel vida cihazı kullanılarak kemiğe 3 adet delik açılmaktadır.

Araştırma Sonunda Beklenen Fayda

Ortodontik tedavilerin süresini kısaltmaya yarayan yöntemler hakkında ayrıntılı bilgi edinmek ve bunları hastaların tedavilerinde kullanarak daha etkili tedaviler yapmak beklenmektedir.

Araştırma Sırasında Karşılaşılabilecek;

Riskleri	***Rahatsızlıklar***
a)	a)
b)	b)
c)	c)
d)	d)
e)	e)
f)	f)
g)	g)

Risk / rahatsızlık durumlarında yapılması gerekenler
Oluşabilecek ağrı durumunda ağrı kesicinin kullanımı.

Aşağıdaki özel durumlara ait katılımcı var mı?

	EVET*	HAYIR
Çocuk	x	
Mahkum		x
Gebe		x
Mental yetersizlik		x
Sosyoekonomik eğitim olarak yetersiz		x

*Ancak çocuklarda, hamilelik, lohusalık ve emzirme dönemlerinde ve kısıtlılık durumunda; gönüllüler yönünden araştırmadan doğrudan fayda sağlanacağı umuluyor ve araştırma gönüllü sağlığı açısından öngörülebilir ciddi bir risk taşımıyor ise, usulüne uygun bir şekilde alınmış bilgilendirilmiş gönüllü olur formu ile birlikte ilgili etik kurulun onayı ve Bakanlık izni alınmak suretiyle araştırmaya izin verilebilir.

ONAM (RIZA)

Bilgilendirilmiş Gönüllü Olur Formundaki tüm açıklamaları okudum. Bana, yukarıda konusu ve amacı belirtilen araştırma ile ilgili yazılı ve sözlü açıklama aşağıda adı belirtilen hekim tarafından yapıldı. Araştırmaya gönüllü olarak katıldığımı, istediğim zaman gerekçeli veya gerekçesiz olarak araştırmadan ayrılabileceğimi ve kendi isteğime bakılmaksızın araştırmacı tarafından araştırma dışı bırakılabileceğimi biliyorum. Bu durumda hastanenin çalışma düzeni ve hastalara verilen bakımda aksaklık olmayacağı konusunda bilgilendirildim. Bu araştırmaya katılırken zorlama, maddi çıkar ve ast üst ilişkisine dayalı herhangi bir baskı olmaksızın bu çalışmaya katıldığımı beyan ederim. Bu bilimsel çalışmanın devamı esnasındaki süreçle ilgili olarak ayrıca eklenen çalışma protokolü ile bilgilendirildim.

Söz konusu araştırmaya, hiçbir baskı ve zorlama olmaksızın kendi rızamla katılmayı kabul ediyorum.

Gönüllünün Adı / Soyadı / İmzası / Tarih

Açıklamaları Yapan Kişinin Adı / Soyadı / İmzası / Tarih

Gerekiyorsa Olur İşlemine Tanık Olan Kişinin Adı / Soyadı / İmzası / Tarih

Gerekiyorsa Yasal Temsilcinin Adı / Soyadı / İmzası / Tarih

24 Saat ulaşılabilir iletişim bilgiler:

Araştırma nedeniyle ve süresince herhangi bir problem ile karşılaşıldığında Dt. Aiman Elmabruk ’a Yeditepe Üniversitesi Diş Hekimliği Fakültesi Ortodonti Anabilim Dalı, Bağdat Cad. No:238-Göztepe adresinden (Tel: 0216 363 6044, dahili No: 6255) veya 0543 543 10 83 numaralı telefon ile ulaşılabilir.

Bilgilendirilmiş Gönüllü Onam Formu asgari olarak yukarıda belirtilen başlıkları içermelidir.