TC
YEDITEPE UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

DEPARTMENT OF ORTHODONTICS

THE EFFECTS OF LIGHT AND VIBRATION APLICATION ON ALIGNER TREATMENT DURATION CASES WITH LOWER CROWDING OF MANDIBULAR INCISORS

DOCTOR OF PHILOSOPHY THESIS

Dt. MUSTAFA OZCAN

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Director of Institute of Health Sciences

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.

01.08.2022

Dt. Mustafa ÖZCAN

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TABLE of CONTENTS

LIST of TABLES

LIST of FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

cm	centimeter
cm2	square centimeter
DHCC	Dihydroxycholecalciferol
Min	Minutes
Ga-Al-As	Gallium-Aliminium-Arsenide
GF	Growth Factor
He/Ne	Helium Neodymium
HOT	Rapid Orthodontic Treatment Device
Hz	Hertz
ICC	Interclass Corelation Coefficient
IFN	Interferon
IL	Interleukin
J	Joule
LED	Light Emitting Diode
M-CSF	Macrophage Colony Stimulation Factor
mm	millimeter
N	Newton
n	Number of participants
Ni-Ti	Nickel-Titanium
nm	Nanometer
OPG	Osteoprotegerin
Average	Average
p	Significance
PETG	Polyethylene terephthalate glycol
PDL	Periodontal Ligament
PG	Prostaglandin
PGE2	Prostaglandin E2
RANK	Receptor Activator Nuclear Kappa B

RANKL	Receptor Activator Nuclear Kappa B Ligand
SS	Standard Deviation
TNF	Tumor Necrosis Factor
W	Watts
"	inch
<	Small
>	large
=	equal
+	Positive, Plus
-	Negative ± More or Less
%	Percentage

ABSTRACT

ÖZCAN, M. (2022) The Effects of Light and Vibration Aplication on Aligner Treatment Duration Cases with Lower Crowding of Mandibular Incisors Yeditepe University Institute Of Health Sciences Department Of Orthodontics, PhD Thesis. Istanbul

The aim of this study is to evaluate the effects of lights and vibration on aligner treatment duration cases with lower crowding of mandibular incisors. There are invasive and non-invasive methods for accelerating orthodontic tooth movement. There is a tendency for both clinicians and researchers to focus on accelerating methods for orthodontic tooth movement due to the huge demand for adults for a shorter orthodontic treatment time such as medicines, led light force, low level of laser theraphy, photo biomodulation, surgical methods, corticotomy, piezocisions, decortication or micro-osteoperforation, combination of led light and vibration, bracket systems or digital methods. With this study it was also desired to create a more conservative technique to accelerate tooth movement than those other methods, which would easily be accepted by the patients and have continuous effects throughout the desired period of the treatment.In this retrospective study, a total of 89 patients who applied to Yeditepe University Faculty of Dentistry Department of Orthodontics were included in the study. Patients were assigned to four groups. First group which included 19 (11 female, 8 male) patients was the control group. Second group with 26 (14 female, 12 male) patients received a 30 Hz 25 N vibration device, third group which had 21(12 female, 9 male) patients received a device which produced 850 nm LED light and the last group consisting of 23 (14 female,9 male) patients got a device which combined vibration and light features. All patients with devices were asked to use them 20 minutes daily. At the initial appointment (T0), at 28 days later (T1), at 48 days later (T2), and 62 days later(T3) impressions were taken to produce dental casts. The tooth movements of the patients were recorded measuring the differences in amounts of crowding. According to measuring on 62 nd day; there is no statistical differences between control group and neither photo biomodulation group nor vibration group. A significant increase in speed of tooth movement speed was observed in the HOT group ($p<0.05$). The treatment done with clear aligners and the combination of light and vibration might be an effective method in accelerated orthodontic tooth movements.

Key words: Clear Aligners, Vibration, Photo-biomodulation, Accelerated Tooth Movement

ÖZET

ÖZCAN, M. (2022) Işık ve Titreşim Uygulamasının Alt Keser Çapraşıklığı Olgularında Tedavi Süresi Üzeerindeki Etkisi Yeditepe Üniversitesi Sağlik Bilimleri Enstitüsü,, Ortodonti Departmanı Doktora Tezi, Istanbul

Bu çalışmanın amacı alt kesici diş çapraşıklığı olan bireylerde şeffaf plaklarla yapılan tedavide ışık ve titreşimin etkisini ortaya çıkarmaktır. Ortodontik diş hareketini hızlandırmak için girişimsel ve girişimsel olmayan methotlar vardır. Hem klinisyenlerde hem de araştırmacılar hastaların kısa ortodontik tedavi süresi isteğini karşılamak için hızlandırma metotlarından olan ilaçlar, led ışık kuvveti, düşük seviye lazer terapileri,fotobiyomodülasyon,cerrahi metotlar, kortikotomi,piezoinsizyon, dekortikasyon ya da mikroosteoperforasyonlar, ışık ve titreşim kombinasyonları, bracket sistemleri ya da dijital methotlara odaklanmışlardır.Bu çalışma cerrahi metotlara alternatif olabilecek hasta tarafından kolay kabul edilebilecek ve etkisinin uzun süreceği bir metot geliştirmeyi hedeflemektedir.Bu retrospektif çalışmada toplamda Yeditepe Üniversitesi Diş Hekimliği Fakültesi Ortodonti Anabilim Dalında tedavileri tamamlanmış 89 hasta dahil edilmiştir.Hastalar 4 gruba bölünmüştür. Birinci grup 19 (11E/8M) kişiden oluşan kontrol grubudur.İkinci grup 26(14K/12 E) kişiden oluşan 30 Hz 25 N kuvvetle titreşim uygulanan, üçüncü grup 21 (12K/9E) kişiden oluşan 850 nm LED ışık uygulanan, son grup ise 23(14K/9E)kişiden oluşan kombine olarak ışık ve titreşim uygulaması yapılan gruptur. Tüm gruplarda verilen aygıtların günlük 20 dk kullanılması istenmiş ve verilen çizerge ile takibi sağlanmıştır. İlk randevuda (T0), 28 gün sonra (T1), 48 gün sonra (T2), ve 62 gün sonra (T3) olacak şekilde hastalardan ölçüler alınmış ve ölçülerden elde edilen modeller üzerinden çapraşıklık miktarı değişim ölçümleri yapılmıştır. 62 gün sonra yapılan ölçümlerde kontrol grubunda değişime göre titreşim grubunda ve ışık grununda istatistiksel olarak fark bulunamamıştır. HOT grubunda anlamlı diş hareket hızı artışı gözlemlenmiştir. ($p<0,05$). HOT grubu olan ışık ve titreşim uygulamasının hızlandırılmış diş hareketinde şeffaf plaklarla yapılan ortodontik tedavide etkili bir yöntem olduğu görülmüştür.

Anahtar Kelimeler: Şeffaf Plaklar, Titreşim, Fotobiyomodülasyon, Hızlandırılmış Diş Hareketi

1. INTRODUCTION and PURPOSE

Orthodontic treatments are one of the factors that increase the quality of life of the patients. Therefore, the demand for orthodontic treatment is increasing day by day. In addition to an aesthetic smile, as a clinician; we can list the factors that increase the quality of life, correcting the functional occlusion, increasing self-confidence, and improving social and psychological health. However, in order to meet these expectations, the duration of fixed treatments takes 2-3 years on average. [1,2] Individuals seek either to shorten this period or to get the best results in orthodontic treatment with more invisible methods. Due to these aesthetic needs, today, individuals mostly prefer the lingual orthodontic treatment method that passes through the lingual surface of the teeth, or the orthodontic treatment methods with removable clear aligners with the option of insertion and removal, apart from plastic, composite or ceramic brackets, which are mostly fixed treatment methods. Although aesthetic brackets are preferred by the patient because they are less obvious, they complicate the treatment due to increased friction. [3]

Since composite brackets discolor over time, they caused negative feedback from the patients to the physician in a short time. Ceramic brackets, on the other hand, have disadvantages such as breakage of the bracket, more friction in the ceramic than metal in the slot, enamel damage during the removal of the bracket, and abrasion of the opposing teeth it comes into contact with. [4]

Lingual orthodontics is the most preferred option for patients who have high aesthetic concerns during orthodontic treatment, which are specially prepared in the laboratory for the models created from the measurements taken on the lingual surface of the teeth of the brackets. However, it is an expensive alternative because of the processes performed and the need for personalized production or sequencing. In lingual treatment, it can also irritate soft tissues such as gingiva or tongue since it is located on the back surface of the teeth. Again, since the biomechanical properties are different from the classical orthodontic treatment, the duration may be longer. [3]

Removable appliances are mostly used as a preventive or interceptive in [5]orthodontic treatments. Expansion appliances or appliances used to regulate the relationship of the jaws with each other in the initial period, as well as appliances used in the retantion period can be given as examples. The advantage and disadvantage of removable appliances is that they can be put on and taken off. While the patient with a good fit is more motivated by removing it in the social environment and wearing it at other moments, it may result in some patients not wearing it at all. Therefore, the patient’s adherence to treatment is extremely important. In addition to these appliances, small tooth movements with thermoforming clear aligners, which started to be used in orthodontic tooth movements, were first included in the literature by Kesling in 1945.This technique was later modified by many researchers and started to be used as a main treatment method rather than as an aid in orthodontic treatment. Raintree Essix put forward a new vision in the treatment of simple cases by replacing the teeth on the measurements taken in 1993 and used it as a treatment method. Afterwards, this system was digitized based on the studies carried out at the University of Chicago. Digitization has transformed this system from a 2 or 3 plate system to a structure that will allow more complicated treatments with much more plates. This is the result of Align Technology's serious investment in this issue, focusing on the work that will continuously improve the system with the innovations it has made and the patents it has received. Today, it is a treatment method that is frequently preferred by individuals with high aesthetic concerns. [6]

In addition to aesthetic expectations, individuals always seek to be shorter in [7] terms of duration. They want their clinicians to do their best in this regard as soon as possible. Long-term or very rapid fixed orthodontic treatments cause various disadvantages. These can be listed as the decrease in motivation of both the clinician and the patient due to the prolongation of the period, and accordingly the formation of caries on the tooth surfaces, the loss of health of the gums or the increase in the risk of root resorption. Many methods have been tried in the literature to accelerate tooth movement, and new methods are still being developed. These include injections that will accelerate the physiological response due to mechanical forces, electrical and electromagnetic field applications, surgical methods, gene stimulation, vibration, laser, and photo biomodulation applications. These applications are shorten the treatment period by showing effects on the physiological structure of tooth movement or on the mechanical methods used.

The aim of this study is to compare and evaluate the effects of vibration and photo biomodulation methods on the resolution time of crowding mandibular incisors during their treatment.

With our study, it is aimed to develop a conservative method that can be easily accepted by the patient, which can be used as an alternative to invasive or chemical-assisted methods that can affect patients, such as the surgical methods used today, and whose effect can be continued for the desired period during the treatment.

2. LITERATURE REVIEW

Orthodontic treatments have become a more acceptable treatment method by adults as their aesthetic features during treatment increase. These developments have brought advantages and disadvantages in terms of treatment duration and treatment quality. While patients previously refused the treatment due to the appearance during the treatment, today the treatment with ceramic brackets, lingual treatment or orthodontic treatments with clear aligners have come to meet the expectations of patients with high aesthetic expectations during treatment. But no matter which method individuals choose the thing that does not change is the basic principles of tooth movement. Although these principles are modified with different methods to shorten the treatment period, they must be at a certain limit in order not to harm biologically. To understand the biology of orthodontic tooth movement, it is necessary to know the surrounding tissues well, because the orthodontic tooth movement mechanism occurs according to the effects of the forces on the teeth to the surrounding tissues and the responses received from these tissues. The tooth and the surrounding tissues are called periodontium. Periodontium contains four different structures: gingiva, periodontal ligament, cementum and alveolar bone.

2.1. Periodontium

2.1.1. Gingiva

It is the structure that surrounds the area called the collar, which is the neck part where the enamel border of the teeth ends and covers the jawbone. The gingiva, which originates from connective tissue, contains collagen and reticular fibrils, as well as fibroblasts, mast cells, inflammatory cells, osteoblasts and osteoclasts that play a role in the bone formation and destruction mechanism, and the vascular nerve package that nourishes and stimulates this structure. [8]

2.1.2. Periodontal Ligament

The periodontal ligament (PDL) is the connective tissue that connects the teeth to the bone and surrounds the tooth roots. It is located between the cementum and the alveolar space and fills this space with a collagen-rich connective tissue content. In healthy patients, PDL wraps around the tooth roots with a 0.5mm gap and connects the teeth to the bone. PDL, which is a connective tissue, contains fibroblasts and mast cells as in the gingiva. In addition to these structures, it contains cementoblast, cementoclast, which is responsible for cement production and destruction. There are also odontoblast, macrophage and monocyte cells. PDL also contains epithelial remnants that proliferate during orthodontic tooth movement. The role of these cells in the PDL is not fully understood, but their proliferation raises the question of whether they are part of the remodeling activity. [9]

2.1.3. Cementum

Another sub-formation of the periodontium is a tissue that is anatomically composed of calcified, avascular and mesenchymal cells covering the root surface of the tooth, which is open to resorption or, on the contrary, to the repair of the resorbed structure. If the cement is resorbed, the PDL cement connection is disrupted and ankylosis, called fusion of the tooth to the bone, may occur. In this case, the tooth loses its ability to move. [8]

2.1.4. Alveolar Bone

It is the dynamic structure of the alveolar bone periodontium that is open to construction and destruction. Thanks to this dynamic structure, the alveolar bone around the tooth can be reshaped depending on the functional physiological or orthodontic forces. If we examine the tooth movement closely, it occurs depending on the mako or micro responses in the alveolar bone, according to the direction, severity, duration and frequency of application of the forces coming to all structures forming the periodontium. These histological changes that occur during orthodontic tooth movement are similar to migration that occurs during eruption of teeth. While tooth eruption occurs physiologically, this structure in orthodontic tooth movement is the sum of both physiological and pathological results shaped by the incoming forces. If we examine the tooth movement in 3 phases, the first of these is the response formed by the tissues formed by defensive tissue inflammation, as well as the stretching capacity of the periodontal ligaments against damage. This phase starts from the moment the force is applied and lasts for 1-2 days and ends with the start of the second phase, the chronic phase. The second phase, the chronic phase, lasts for 20-30 days. During this period, no movement is observed in the tooth, and it is a process that continues with the effect of the hyalinization layer formed due to the tissue response. The third phase is the progressive movement phase. In this phase, the hyalinization layer formed in the tissue dissolves and the tooth regains its mobility. The size of this layer increases with the magnitude of the applied force. Therefore, the application of large forces should be avoided.[10,11]

2.2 Orthodontic Theories of Tooth Movement

Orthodontic treatments are based on the reshaping of the teeth or jaws, depending on the mechanism of construction and destruction. There are three theories explaining this subject, which has been researched since the nineteenth century. These are the pressure tension theory, the bone bending theory and the piezoelectric theory.

2.2.1 Pressure -Tensure Theory

When histological studies of orthodontic tooth movement are examined, according to Oppenheim[12] and Schwarz[13], according to this theory, after the force on the teeth, the teeth move in the periodontal ligament as directed by the force.[13] The PDL, which is a part of the periodontium and allows the five teeth to be attached to the bone, is compressed in the direction the tooth moves and is subjected to tension in the other direction. Two zones associated with this movement are identified. The direction in which the PDL is compressed, that is, the direction in which the tooth moves, is defined as the “pressure zone” and the opposite of the direction of movement of the tooth is defined as the “tension zone” due to the resistance it creates against movement. As the PDL is compressed in the pressure region, the blood flow decreases, while in the tension region, the blood flow either stays the same or increases. In fact, if the tension is too high, the blood flow may stop temporarily. Both chemical structure and oxygenation change in direct proportion to this change in blood supply. Since this change within minutes changes the entire PDL metabolism, the rate of metabolites formed also changes. This situation stimulates tooth movement either directly or due to a chain of events that affect each other. [14]

Schwarz [13] also examined the capillary blood pressure relationship between the applied force and the response in the tissue. According to the results of this study, he reported that if the capillary pressure exceeds 20-25 g/cm2, necrosis will occur. However, Schwarz stated that if the force is also increased, there will be resorption in the tooth and bone tissues or hyalinization areas will be formed. In this theory, the irregularity that occurs in the PDL in the pressure region negatively affects fiber production and cell proliferation, and even causes it to decrease. Depending on the decrease in blood supply, regional necrosis in the tissue creates compensatory hyperemia, that is, additional blood supply areas in the adjacent ligaments. The first observed situation in this necrosis area or hyalinization areas is the appearance of pycnotic nucleides and the formation of dead areas without cells. The chemicals secreted due to necrosis cause the arrival of cells such as macrophages, foreign body giant cells and osteoclasts, which are in healthy tissues adjacent to this region and are responsible for destruction events. The arrival of these cells to the necrotic area provides healing in this tissue and resorption in bone and cement, which is called indirect or undermining resorption. While the events in the pressure region are summarized like this, in the tension region, the fiber bundles are stretched and cellular activity increases. This increase increases both fiber production and cell proliferation. While examining the histological changes that occur as a result of orthodontic force in his studies, Reitan[11] observed that the normal tissue structure in hyalinized tissues was disrupted, and the collagen structure changed and even lost its characteristic feature. In the same studies, Reitan[11] observed that hyalinization occurs in the tilting movement, less translation occurs in translation, and more hyalinization occurs in short-rooted teeth. Therefore, he stated that unit area is important in tissue changes for hyalinization and that these changes should be minimized as carefully as possible. Another researcher on this subject is Baumrind. Baumrind questioned this theory that PDL forces of different sizes provide tooth movement and that it is necessary to evaluate PDL as a hydrostatic system in this system, and conducted studies supporting the bone bending theory, which proposes that tooth movement distributes the pressure equally in the periodontium, except for the teeth and bones.

2.2.2 Bone Bending Theory

According to this theory, the bone structure can be bent and twisted because it is more elastic than other dental hard tissues. This theory was first put forward by Farrar [15] in 1888 and was supported by Baumrind's [16] studies on rats and Grimm et al. [17] studies on humans. All these authors think that the orthodontic forces coming to the teeth are transmitted to the roots of the teeth and all the tissues surrounding these roots, causing the hard parts of the bone and periodontal ligaments to bend. They argue that while this process is faster in regions where the bone is subjected to bending, these events progress more slowly in other regions. Remodeling occurs not only in the lamina dura of the alveolar bone, but also in the trabecular surfaces of the corpus of the alveolar bone. While the force coming to the tooth is distributed by the stress lines in the bone, a biological response occurs in the cells perpendicular to these stress lines. This response allows the bone to reshape and keeps the external forces in balance.

2.2.3. Piezoelectric Signals Theory

Basset and Becker [18] who suggested that orthodontic tooth movement is a response of tissues under stress during movement in the periodontium of teeth, suggested that this response is an electrical potential. They argued that this electrical potential is loaded on the stress energy of the macromolecules and stimulates certain regions in the cell membrane, and they move the ions in the cell membrane with the effect of these stimulated fields. Later, Zengo et al. [19] investigated this mechanically charged electrical potential in vivo and in vitro. They showed that there are different loadings in the convex and concave bone in the orthodontic force applied area. They argued that while this charge is electronegative for concave fields, it is electropositive or neutral in convex fields. They showed that due to this loading, osteoblastic activity increased in the electronegative area and there was destruction due to osteoclastic activity in the electropositive area. Davidovitch et al. [20,21] showed that there is a relationship between the mechanical and electrical loading of the bone and that this creates two electrical fields in the bending areas of the bone. At the same time, an increase in cellular activity was observed in the PDL and alveolar bone when an external electrical load was applied to the area where orthodontic tooth movement was planned, and the force was applied. This accelerated tooth movement. This electrical charge is a situation observed in the material that has a crystal structure and this crystal structure is deformed, and organic and inorganic contents are together. Borgens [22] suggested in 1984 that this structure takes place in bone cells, and that it is also in the matrix, but that the main event is under the influence of bone cells. Pollock et al [23] also contributed to science by supporting this view.

The biological mechanism of orthodontic tooth movement is still a controversial issue. To date, there is still no clear result. However, nowadays, these studies have passed into histological, histochemical and immunohistochemical dimensions and studies are continuing.

2.3 Biochemistry of Orthodontic Tooth Movement

Osteoblasts are cells that play an important role in the cellular structure and destruction changes that occur in the bone during orthodontic tooth movement. They are effective in this destruction that occurs in the bone, namely resorption and production, that is, apposition. [24] They are involved in the differentiation of prostaglandin, inositol phosphates and cyclic nucleotides during these events and may undergo a shape change depending on mechanical stimuli. This shape change can reach the cell nucleus without cell membrane or cytoplasm enzymes. At the same time, osteoblasts are also responsible for processes such as fracture, fracture healing, as they are responsible for the rebuilding destruction of bone. The working mechanism of osteoblasts is explained by the differentiation of mesenchymal stem cells, which migrate from the bone marrow after an average of 10 hours, in bone formation events that begin towards the end of the second day in PDL following the application of the force required for orthodontic tooth movement. [25]

Osteoclasts are another group of cells responsible for bone formation and destruction. Tissue damage caused by orthodontic force in PDL in the area where orthodontic tooth movement will take place and deformation in alveolar bone are giant multicellular structures that emerge during osteoclastogenesis event called deformation. Its origin is the stem cells of the blood lymph system or hematopoietic tissues (spleen, liver, bone marrow and peripheral blood cells). These cells differentiate into osteoclasts. They are found in the Howship lacuna and together with osteoblasts are responsible for bone remodeling. [25,26]

Fibroblasts, these cells responsible for collagen synthesis and destruction, are the basic cells of the connective tissue. These cells can exist in two different phases as active or inactive in the matrix. Inactive fibroblasts are also known as fibrocyte. They can differentiate into cells such as osteoblasts in osteogenesis. [8,27]

Osteocytes are cells that are formed since osteoblasts, which are responsible for the bone formation and destruction mechanism, are not embedded in the matrix they secrete. [26] In bone, their location is usually in the regions defined as lacunae between the lamellar structure of the bone. [28] Mature bone is rich in osteocytes since they are formed due to being buried. Osteocytes can survive as long as this organism can keep itself alive. These cells, which are extremely sensitive to orthodontic forces, create an acute response when there is tension in the PDL and provide the initiation of osteogenesis with bone apposition. [29]

Cytokines are signaling proteins or peptides responsible for autocrine and paracrine communication between immune cells. [28,30] Cytokines, which are extracellular proteins, are synthesized by bone marrow or bone cells. They are also involved in inflammation, cell growth, healing, and the systemic response to injury. These molecules usually appear with inflammation or immune cell activations. In orthodontic tooth movement, PDL creates vasodilation in blood vessels in the tooth region where orthodontic force is applied. [31] This vasodilation causes migration of inflammatory cells and increased cytokine production. In bone metabolism, interleukins (IL), tumor necrosis factors (TNF), RANKL (receptor activator of nuclear factor-kappa B ligand from the TNF group), interferons and growth factors are cytokines that affect bone remodeling, that is, bone formation destruction. IL-1β, IL-6 are known as early biomarkers in the initial period of tooth movement. [32] Inflammatory cytokines, mechanical forces and neurotransmitters trigger the release of IL-1β. These cytokines directly stimulate osteoclast function during the initial period of orthodontic tooth movement. This stimulation triggers IL-6 production. It reduces osteoprotegrin (OPG) production by osteoblasts, which are involved in the message to resorb bone against osteoclasts (SD45/31) and IL-6 provides the activation required for bone resorption.

Tuncer et al. showed an increase in IL-8 level in the tension region of the PDL during orthodontic force and emphasized that this is an important factor in triggering bone remodeling. Another cytokine is TNF-α. [33,34] TNF-α is involved in the formation of acute or chronic inflammation and plays an important role in osteoclastogenesis. TNF-α is also the cytokine that is released during periodontal disease and is responsible for bone resorption in periodontal destruction. TNF-α acts like growth factor on osteoclast progenitors on osteoclast formation. It has an inhibitory effect on osteoblasts. [35] TNFs are produced by monocytes, macrophages, osteoblasts and epithelial cells. [36,37] Lowney et al. [38] observed that the amount of TNF in the gingival pocket increased after orthodontic force application on 20 patients.

Prostaglandins (PG) are local hormone-like chemicals derived from arachidonic acid produced by osteoblasts when tissue damage occurs, depending on the amount of damage. [39] The increase in stress due to the application of orthodontic force in the extracellular matrix results in the deformation of the osteocytes formed by the embedding of osteoblasts in the alveolar bone. [40] After deformation of osteocytes, osteocytes secrete prostaglandin and initiate tooth movement. Prostaglandin E (E1 and E2) plays an important role in stimulation of bone remodeling. Membrane phospholipids gain mobility after prostaglandin secretion. This results in the formation of inositol phosphate. Prostaglandin E2 (PGE2) activates osteoclasts, which induces bone resorption. Shimizu et al. and Yamaguchi et al. In their in vitro studies, they showed that PGE2 production increased due to mechanical stimulation in PDL due to orthodontic strength. Therefore, PGE2, like IL-1 and IL-6, is accepted as one of the early biomarkers of orthodontic tooth movement in bone resorption. [41,42]

RANK/RANKL/OPG System; RANKL, which is one of the TNF group cytokines, and its pseudo-receptor RANK (receptor activator of nuclear factor-kappa B) and osteoprotegrin (OPG) play important roles in the regulation of bone metabolism, that is, formation and destruction. When the force is removed from the orthodontic force applied area or in the absence of force, there is no force that compresses the PDL cells. PDL cells secrete OPG, which inhibits differentiation into osteoclasts. [42] OPG secretion prevents bone resorption in alveolar bone. RANKL is responsible for the cascade of osteoclast formation and activation. Many hormones and cytokines are responsible for bone resorbing effects in this chain. [43,44] Osteoclast precursors contain receptors called RANK. RANKL tries to bind to these receptors. If this binding occurs, osteoclast precursors transform into active osteoclasts. The pseudo-receptor OPG produced by the osteoblast competes with RANK. So, both RANK and OPG are racing to connect to RANKL. If RANK cells bind to OPG, the last step in osteoclast differentiation is inhibited and osteoclast matrix activation is suppressed, along with inducing apoptosis. In this competition, if the binding to OPG is more, resorption will not be seen. If RANK predominates, resorption and tooth movement are observed. Therefore, the balance of RANK-RANKL binding and RANK-OPG binding is important in the bone remodeling process. In gene transfer studies, it was observed that osteoclastogenesis activation increased and tooth movement accelerated in RANKL injection. On the contrary, it was observed that osteoclastogenesis was inhibited as a result of OPG application, and as a result, tooth movement slowed down.[45,46] Nishijama et al.[47] found in their study that the amount of RANKL in the gingival groove fluid increased and OPG decreased as a result of compression in the PDL due to orthodontic force.

2.4 Chronological Pattern in Orthodontic Tooth Movement

Normally, PDL and alveolar bone cells in our body work against the forces of chewing and physiological tooth movement.[46]If an orthodontic force is applied, they rearrange their number according to the functions of the cells in their content at the cellular level. Depending on the incoming orthodontic force, the PDL is compressed in the direction of movement and stretched in the opposite direction of the movement. In line with the macro and micro events that occur due to this change, the PDL expands in the stretched region, its vascular structure increases, and macrophage and leukocyte migration occurs in this region due to inflammation. In the compression region, the PDL narrows or becomes compressed, and deformation of the alveolar bone begins. Depending on the severity of the orthodontic force applied, areas that we call necrotized hyalinization occur in areas that are compressed under pressure. This hyalinization tissue is dispersed by resorption agents that reach the periodontium from the bone marrow through the osteoclasts. This condition, called indirect bone resorption, lasts for 3-4 weeks. If the applied force is more optimal or less, then this system gives more physiological responses. On the side exposed to pressure or compression, there is an increase in the number of periodontal cells, immature mesenchymal cells, and prevascular major cells. 2-3 days after the application of force, osteoclasts appear in the pressure area and direct bone resorption begins, which takes a minimum of 10 days. [40,48]

2.5 Optimum Orthodontic Strength

The ideal situation in orthodontic tooth movement is the formation and destruction of the alveolar bone, if it is directly related to the harmony that takes place on the PDL surface. In the direction in which orthodontic forces are applied, stress is also observed in the PDL opposite to the compression force direction. This situation around the PDL completely changes the blood supply and then the homeostasis electrochemically. This electrochemical change also regulates the bone formation and destruction mechanism. This reshapes the alveolar bone contour. Optimum orthodontic strength is defined in the literature as the force that causes as little tissue damage as possible and least disturbs the patient during the movement of the teeth in the desired direction. [49]

According to this definition, we can divide the force into two as light or heavy. Working with light forces gives more physiological results, as heavy forces both negatively affect bone formation and damage the PDL. Since discomfort to the patient is also a part of the optimum strength, it varies from person to person relatively. Researchers have also expressed different opinions on this issue. Burstone [50] suggested that the orthodontic force never spreads evenly across the PDL. Storey, on the other hand, argued that even if the orthodontic force is mild, there is a small amount of trauma possibility. Schwarz (1932) defined the optimum force as "the force that exerts pressure on tissue equal to that of a capillary blood vessel". Schwarz [13] also suggested that suboptimal forces do not cause tissue damage, but strong forces produce areas of necrosis. Oppenheim [12], on the other hand, observed that there were no cells in the compression region of the PDL under optimum force applied conditions. Storey and Smith showed that they joined Oppenheim and Reitan in 1952 with similar studies. The forces, generally called light and heavy, move the teeth with direct and indirect bone resorption. If light force is applied, direct resorption is observed, while indirect bone resorption is observed due to hyalinization at heavy forces. Since the surfaces of the teeth and surrounding tissues and the individual's feeling will be different for each individual, the optimum force to be applied differs according to each tooth and individual. [14,51]

2.6 Methods to Accelerate Tooth Movement

Like the other medical branches, oral and dental health practices are one of the factors that increase the quality of life of the individual. The role of orthodontic treatments in these applications is also high. Orthodontic treatments not only meet the aesthetic expectations of the individual and increase their functional functions, but also contribute to the increase of the individual's social and psychological self-confidence. With the increase in this awareness, the interest of adults in orthodontic treatment has also increased. The most important factor in adults making this decision is the visibility of the treatment and the duration of the treatment. Although these concerns are mostly aesthetic, a comprehensive orthodontic treatment takes 2-3 years on average. [52,53] The long duration of orthodontic treatments causes loss of motivation in individuals and often results in lack of hygiene. Depending on this situation, the risk of gingival diseases and caries formation increases. [54,55] Another important factor in this preference of individuals is the occurrence of pain. Therefore, the basic expectation consists of three main elements. These can be grouped as aesthetically pleasing, fast and pain-free treatment. For this reason, the number of scientific studies on these subjects, especially on accelerating tooth movement, is increasing day by day and maintains its currency. Studies have mostly been on methods that will slow down or partially stop tooth movement, prevent the formation of the hyalinization layer, or methods that will shorten the lag phase. At the same time, it appears in the literature as studies aiming to accelerate tooth movement by creating the structure and destruction mechanism called remodeling earlier. If we prioritize in detail, these can be grouped under two main headings as surgical and non-surgical methods. Surgical methods are invasive methods and are divided into subgroups as dental and alveolar distraction osteogenesis, periodontally accelerated osteogenic orthodontics, corticotomy, cortission and piezoscision. Injection of mediators such as PGE2, corticosteroid, nitric oxide with the help of physiological mediators that enable the transformation of mechanical forces into a cellular response, and electrical and magnetic field, gene stimulation, laser applications, photo biomodulation and vibration applications of these methods constitute non-surgical interventions.

2.6.1 Surgical Applications Used to Accelerate Orthodontic Tooth Movement

2.6.1.1 Distraction Osteogenesis

Distraction osteogenesis is a method that enables the stress caused by the effect of mechanical forces applied to the bone to activate the formation of new bone tissue. [56] The mechanism of formation of new bone depends on the stress on the repair callus between the fragments formed by the dividing bone tissue. In distraction osteogenesis, approximately 1 mm of bone can be formed per day, depending on the force applied to the bone and the production and washing that occurs as a result of tension and compression. [57] The distraction screw reduces the resistance of the alveolar and gingival tissues, thereby accelerating tooth movement and providing a dentoalveolar distraction. [58] İşeri et al. performed osteotomies around the canine tooth and achieved rapid canine distalization in the dentoalveolar segment with a tooth-supported distraction device. While canines retract an average of 0.20-0.25 mm with traditional methods, 1.2 mm per week can be achieved with this method. Liou and Huang [57] introduced PDL distraction, also known as interseptal bone thinning, to the literature. It has been suggested that distraction can also be applied to the PDL, as seen in the mid palatal suture during rapid maxillary expansion. The acceleration of this movement has been associated with the weakening of the bone distal to the canine and the ability of the teeth to move easily in this fibrous tissue. [57,59] Compared with the technical classical method , it has advantages such as parallel movement of teeth, absence of root resection and minimum loss of anchorage in molar teeth. However, additional surgical procedures and the use of a distractor for the technique, adversely affecting the design if the canine is in the infra position and reducing its effect, and not being able to apply the interseptal bone thinning procedure in patients with sagging maxillary sinus can be described as disadvantages of this technique.

The difference between dentoalveolar distraction and PDL distraction, i.e. thinning of the interseptal bone, is that the osteotomized areas are different. For dentoalveolar distraction, the bone around the canine is cut as a block, that is, incision lines are made from the mesial, distal and apical. In PDL distraction, it is the process of thinning the interseptal region with a bone bur after the extraction of the first premolar. In the literature, it has been stated that in cases of using tooth-supported distraction devices, the extraction gaps are completed between 10-16 days and there is no negative effect on the surrounding tissues. In the literature, in which PDL distraction was applied with tooth-assisted distraction, it was stated that the canine distalization, which took 6-8 months with classical methods, was completed in 3-3.5 weeks. In the literature, it has been shown that tooth movement is accelerated by the use of Ni-Ti close coil and elastic chain, which are used after PDL distraction in orthodontic treatments planned with maxillary first premolar extraction.

2.6.1.2 Corticotomy

The first definition for corticotomy was made at the end of the 1800s, as it would involve making linear incisions in the cortical bone layer surrounding the tooth roots in order to enable the teeth to move immediately.

Today, corticotomy is defined as osteotomy to the cortical bone. This application is only in the form of an incision, perforation in the cortical layer of the bone, or minimally invasive surgery that reaches the medullary part of the bone.

Corticotomy is a method that provides thinning of the cortical layer of the bone due to the incisions made to the cortical bone and accelerates the orthodontic tooth movements locally depending on the bone formation and destruction mechanism depending on the traumatic stimulus in the bone.

“Regional Accelatory Phenomenon (RAP) [60] in the literature, may vary depending on the structure of the tissue. Bone healing mechanism is thought to be performed 10-50 times faster compared to the normal bone formation and resorption cycle.

With the idea of eliminating the continuity of the cortical layers in the bone, the first application was made by Slave in 1959 by making interdental incisions. [61] He claimed that root resorption would not occur in this application, since the teeth were still moving within the bone blocks. During tooth movement, constitutive destruction in medullary bone was faster than in cortical bone. In this direction, he suggested that deformations in the cortical would accelerate the orthodontic treatment.

With corticotomy applications, Düker, Yaffe et al., Sebaoun et al. [62–64]Many studies have been carried out, especially in the field, and have tried to optimize this technique with minor modifications.

In his study, Dükker [62] suggested that there is no problem in PDL and pulp vitality, but the incision line should be terminated at least 2 mm apical to the alveolar crest in order to ensure vitality.

Yaffe et al. [63] reported that RAP was observed only by removing the mucoperiosteal flap in their study on the rat mandible.

Sebaoun et al. [64], on the other hand, showed that selective alveolar decortication process accelerated the alveolar cancellous bone formation and resorption cycle.

But the main modification is Wilcko et al. [65–67] and today this Technique is called "wilcodontics". This modification includes labial and lingual grafting of the teeth that will move by lifting full thickness flaps during fixed orthodontic treatment.

Germec et al. [68] In the case report published that it was aimed to shorten the treatment time with the modified technique by eliminating the lingual corticotomy in an adult patient who required lower incisor retraction with the extraction of the first premolars. In the technique, the mucoperiosteal flap was lifted and interradicular vertical incisions were made with a 0.5 mm diameter bur in each region between the mesial teeth of 33 and 43. These incisions were followed by cortical bone incisions extending from labial to lingual. It has been reported that with the retraction mechanics applied directly after the surgery, the extraction gaps were almost closed in 3 weeks and the lower incisor retraction was completed in 6 weeks. They suggested that this new approach significantly shortened the surgical time and the total treatment time.

When the literature for recent years is examined, Kim et al. [69] Dibart et al. [70,71] and Casetta et al. [72] introduced a minimally invasive technique that does not require any flap lifting. The piezoscision technique is a much more minimally invasive method compared to these procedures. In this technique, the interproximal areas of the teeth are opened with a scalpel and a corticotomy is applied to the buccal cortex of the bone with piezosurgical instruments. The thesis study on this subject by Azimova [73] includes the application of decortication, also called microosteoperforation, transmucosal without lifting the flap by using a manual drill bur during the distalization of the canine. The purpose of these applications is to evaluate the effects of these microosteoperforations on tooth movement. As a result of the study, Azimova [73] showed that tooth movement increased significantly with 3 microosteoperforations . Similar studies were also conducted by Gün [74]as a thesis study and by Aboul-Ela et al. and its effect on the acceleration of tooth movement has been shown.

In another study conducted to develop the minimally invasive method, Alikhani et al.[75] investigated the effects of transmucosal micro-osteoperforations with a disposable Propel device on tooth movement during canine distalization, as well as on the amount of chemokines and cytokines.

The effect of corticotomy in accelerating tooth movement has been proven in many studies, but the difficulties and negativities of surgical interventions have also been shown. At the same time, it has the disadvantage that it needs to be repeated in case of need during treatment. Therefore, minimally invasive applications are more easily accepted by patients in corticotomy applications.

2.6.2 Non-Surgical Applications Used to Accelerate Orthodontic Tooth Movement

2.6.2.1 Chemical Applications

Prostaglandins (PG) are local hormone-like chemicals or lipid components, derived from arachidonic acid, which are found in almost every tissue in humans, are derived enzymatically from fatty acids, and are immediately synthesized in proportion to the amount of damage when tissue damage occurs. [35,39,76] They can be synthesized rapidly due to cell damage caused by inflammation in the body. Its release is regulated by the enzyme's phospholipase A2 and cyclooxygenase. PGE2 plays an important role in bone metabolism due to mechanical stimulus. With the mechanical stimulation created by orthodontic forces, an increase in the amount of prostaglandin in the tissues has been observed, and it has been proven by many studies that this increase plays an important role in bone formation. [77,78]
Yamasaki et al. [79,80] injected PGE1 locally into the gums of moving teeth in their study on monkeys and determined that tooth movement accelerated significantly at the end of the 5th day. Sekhavat et al. [81] similarly observed an increase in tooth movement speed when they applied misoprostol, a PGE1 analog, to rats systemically.

Kale et al. [82] showed a significant acceleration of tooth movement due to PGE2 injection on Sprague-Dawley type rat. In the same study, in the histomorphometric examinations, it was found that the number of howship lacunae and the number of capillaries per mm ^{2} were significantly higher in rats injected with PGE2. He suggested that this was due to the increase in pressure in the alveolar bone adjacent to the PDL. PGE2 increases the number of osteoclasts present and makes its resorbing effects evident. [83,84]

Rifkin et al. [84] showed that PGE2 increases the number of osteoclasts on the bone and accordingly gives it a more serrated surface structure.

The biggest side effect or disadvantage of these PG injections is the hyperallergenic state that develops due to the release of noxious agents. [83]

Corticosteroids are steroid hormones produced in the cortex and formed in the immune system's response to inflammation in the stress response. It takes part in carbohydrate control, fat and protein metabolism, bone formation and destruction cycle. [35]

Ashchraftt et al. [85] In their study on rabbits, they achieved 4 times faster tooth movement in the experimental group given 'cortisone acetate', a type of steroids. In another study in rats, they gave 'prednisolone', a derivative of steroids. While prednisolone was given 1 mg/day for 12 days before tooth movement started, saline solution was applied to the control group. Immediately after the administration of saline and prednisolone, mesialization of the 1st molar tooth was started with a force of 30 g. On the 24th day of the experiment, the animals were sacrificed, and the amount of tooth movement and root resorption were evaluated. While no significant difference was found between the tooth movement speed in the groups, less root resorption was observed in the saline group. Thus, they concluded that steroid treatment had a suppressive effect on clastic activity.

Kalia et al. [86] investigated the effects of corticosteroids on orthodontic tooth movement in their "split mouth" study on rats. They showed that corticosteroids increase the speed of orthodontic tooth movement but decrease the rate of new bone formation. In addition, they revealed that corticosteroid application decreased the stabilization after treatment and accordingly the effect of prolonging the consolidation period.

If we summarize the effect of corticosteroids, while corticosteroids accelerate tooth movement, the main side effect of long-term use is osteoporosis, which increases the risk of recurrence at the end of the treatment. [87]

Parathyroid hormone is a hormone secreted by the parathyroid glands and regulates the calcium balance in the blood. The secretion of parathyroid hormone increases the calcium concentration in the blood and stimulates bone resorption. This hormone causes differentiation of osteoclasts on mesenchymal cells, which stimulates the effects of both osteoclasts and osteoblasts. [88,89]

Potts and Gardella [90] stated that if the amount of parathyroid hormone increases continuously, there will be bone loss and when it increases in short intervals, it creates an anabolic effect in the bone, but they revealed that it increases bone volume, density and strength when given at short intervals daily.

In rats, severe bone destruction in the alveolar bone around the incisors due to mild orthodontic forces in the hyperparotid middle, and an increase in the amount of hyalinized bone with increased vascularity in the adjacent regions were observed. [91]

Soma et al. [92] They revealed that systemic and continuously administered parathyroid hormone increased osteoclastic activity in the areas compressed in the PDL. In addition, in the same study, it was found that bone resorption did not increase in other regions and generally increased tooth movement, but in the group given intermittently.

In his thesis study, Canikli̇oğlu [93] showed that tooth movement accelerated in the group injected with parathyroid hormone.

In the literature, there are also studies that argue that locally injected parathyroid hormone is more effective in bone resorption instead of systemic applications.

Thyroid gland: It affects many cell activities and metabolism with the thyroxine and calcitonin it produces. It is also a gland involved in bone formation indirectly by affecting calcium absorption. Thyroxine increases bone resorptive activity in bone metabolism and causes a decrease in bone density. [94] Since thyroid hormone increases interleukin production, it indirectly increases osteoclastic bone resorption. [95] In the literature, a significant acceleration in tooth movement was observed in rats in which exogenous thyroxine hormone was administered systemically, there are studies showing that it also increases the speed of tooth movement in local application. [96,97] While thyroxine accelerates tooth movement, calcitonin secreted by the thyroid gland has the opposite effect. Calcitonin stimulates the bone-forming activity of osteoblasts and reduces osteoclastic activity. [94]

The most active metabolite of vitamin D is known as 1,25 dihydroxycholecalciferol (1,25DHCC). In other words, vitamin D and its active metabolite 1,25DHCC are effective in bone formation and destruction metabolism. At the same time, it has been revealed that there are vitamin D receptors in osteoblasts, osteoclast precursors and active osteoclasts. [98]

Collins and Sinclair [99] evaluated the change in osteoclast number by injecting 1,25-DHCC into the ligaments. In their study, they revealed that the number of osteoclasts increased, and tooth movement with low forces accelerated by 60%. In the histological evaluation made from the same study, an increase in the amount of osteoclasts and an increase in alveolar bone resorption on the pressure side of PDL were observed. Similarly, Kale et al. [82] concluded that the speed of tooth movement increased in Sprague-Dawley rats with a locally applied injection of 1,25-DHCC.

Takano-Yamamoto et al. [100] evaluated the speed of orthodontic tooth movement by injecting 1.25DHCC into the bifurcation region of the molars in their study on rats. Histological examinations under the light microscope showed that the number of osteoclasts and, accordingly, bone resorption increased. They also argued that it would strengthen the regeneration of the alveolar bone surrounding the tooth.

Shetty et al. In their preliminary study, the effects of Vitamin D3 injected after the extraction of the first premolars in humans with the split-mouth technique on the orthodontic tooth movement speed were investigated. Vitamin D3 in the experimental group and local anesthesia solution in the control group were injected on the 7th, 21st and 47th days of the individuals to be distalized. In the examination, a significant decrease was observed in the orthodontic tooth movement speed in the experimental group compared to the control group. Based on these studies, it has been shown that local injection of Vitamin D3 significantly slows down tooth movement in humans.

Nitric oxide (NO) is a short-lived free radical and plays a role in the regulation of pulpal blood flow, bone formation and destruction mechanism and bone cell function. Nitric oxide synthase is responsible for NO synthesis and is synthesized from oxygen and amino acid L-arginine.

Akin et al. [101] in rats, an increase in orthodontic tooth movement was observed due to NO injection. In histological evaluations, a significant increase was observed in the capillary vasculature, the number of osteoclasts and the number of howship lacunae.

Hayashi et al. [102] on the other hand, observed orthodontic tooth movement by injecting nitric oxide synthesis inhibitors on rats. They observed a significant decrease in tooth movement as a result of nitric oxide inhibition.

Shiraz et al. [96]While investigating the effect of NO on orthodontic tooth movement in rats, the groups were injected with saline solution, NO precursor L-arginine, NO synthase inhibitor (L-NAME (N(G)-nitro-L-arginine methyl ester). They observed a significant increase in tooth movement.

Non-steroidal anti-inflammatories (NSAI), fluorides, bisphosphonates, estrogen relaxin, calcitonin, interleukin antagonists, TNF α antagonists, integrin inhibitors, immunomodulatory drugs, immunosuppressant drugs, anticonvulsants, leukotrienes, osteocalcin, diazepam, different dental factors such as nicotine and caffeine. There are also studies on its effects on.

2.6.2.2 Gene Transfer

The mechanism of osteoclastogenesis is controlled by 2 cytokines, RANKL and macrophage colony-stimulation factor (M-SCF). The mechanism is based on the fact that osteoblasts secrete RANKL and have a positive effect on osteoclastic activity, and the release of OPG has a negative effect on RANKL. In other words, while RANKL release increases osteoclastic activity, OPG release decreases osteoclastic activity, which slows down bone turnover. The main balance depends on the balance of RANK, RANKL and OPG. This balance is important for the regulation of bone resorption. RANK is important in the conversion of osteoclast precursors to osteoclasts. When the amount of RANK, which is the RANKL receptor, increases, osteoclastic activity increases. [45,103,104] The binding between RANK and RANKL depends on the amount of OPG. OPG and RANKL are in the race. The result of this race directly affects the bone formation mechanism. Studies have shown that it changes the speed of orthodontic treatment with pharmacological injection [103–105] However, since the effects are not continuous in this method, daily systemic administration or local injection is required.

Kanzaki et al. [45] in their study on rats, they transferred the RANKL gene locally to the PDL during the movement of the maxillary first molar. They observed a significant difference in tooth movement at the end of the 3rd day between the experimental group and the control group. While this speed difference was higher at the beginning, at the end of the 21st day, the difference was found to be between 30-70% faster. In histological examinations, it was observed that osteoclastogenesis was activated in the periodontium without any systemic effect, and tooth movement increased accordingly.

In addition, it was concluded that due to this mechanism, it may be effective in moving ankylosis teeth.

2.6.2.3 Mechanical Stimulation - Vibration

Bone tissue, like other tissues in our body, adapts itself by being reshaped according to the action-reaction principle in the facial muscles and applied forces. It has been shown in the literature that the anabolic potential of mechanical stress in bone remodeling is strongly correlated with frequency. [106] Based on this action-reaction principle, it has been suggested that appropriate mechanical pressures can accelerate bone remodeling and the anabolic response to occur. [26] The origin of the idea of applying mechanical stimulation to the bone tissue is the emergence of a significant decrease in bone density, such as 1.6%, in 1 month due to the exposure of astronauts to high pressure in the low-gravity area. [107]

Vibration is defined in the literature as a mechanical stimulus characterized by an oscillating motion, which is stimulation at high frequency and low magnitude. The 3 main components of vibration are frequency, magnitude of motion, and direction of motion. The unit of frequency is Hertz (Hz) and the unit of magnitude is considered to be amplitude, which can be evaluated in mm. These 3 main components allow vibration to decompose mechanical stimulation in the applied area.

Rubin et al. [108] observed that vibration applied at low magnitude and high frequency for 28 days on rats accelerated bone formation in the control group.

Bautsman et al. [109] applied vibration as a medical therapeutic technique to patients with limited mobility and paralysis. The aim of the study was to maintain and improve bone density, and they had promising results.

Gilsanz et al. [110] investigated the change in bone density by applying low-level high-oscillation frequency to 48 female patients with low bone mineral density. When the application of high-oscillation low-level vibration applied for 12 months for 10 minutes every day was evaluated, a significant increase was observed not only in bone but also in muscle tissue compared to the control group. The result of this study supports that this practice can be a preventive practice in individuals at risk of osteoporosis.

Gusi et al. [111] followed 28 postmenopausal female patients in their planned study for 8 months to examine the effect of vibration. They showed that the results obtained were supportive of other studies in the 8-month follow-up evaluations and that the vibration application was significantly effective in protecting and strengthening the bone structure.

Goodship AE et al. and Omar H et al. evaluated the effects of vibration on healing in the postoperative period and showed that low magnitude and high frequency mechanical signals accelerate cranial bone healing and endochondral bone healing. [112,113]

In another study Rauch et al. [114] work on rabbits to examine the effects of vibration on sutural bone formation and development, he grouped planning as control group, static force group and oscillating force group. After 12 days of applications, significant increases were observed in sutural bone width and sutural osteogenesis in the vibration group. They also showed that vibration application is a powerful tool and increases anabolic sutural growth due to the mechanical effect of vibration. Vibration has become a method used in sports and health centers today as it can be applied to the whole body as a minimally invasive application, has no pharmacological side effects, is easy to apply and does not require a surgical procedure. Many devices that reach 50 Hz in frequency and a few mm in amplitude are widely used in sports centers.

The developments of vibration applications in other fields of medicine have triggered applications in dentistry and orthodontics. Based on the subject that mechanical stimuli increase sutural development, Meikle et al. [115] prompted a new study to plan a model of cranial sutures that mimic PDL and other sutures under orthodontic treatment in individuals undergoing orthodontic treatment. Mao [116] stimulated the periodontal area with high-frequency and low-magnitude mechanical stimuli, increasing osseous remodeling, thereby increasing orthodontic treatment. He thought it would speed up the treatment. [117]

Darendeliler et al. [118] planned a study examining the change in tooth movement of high frequency and low amplitude vibrations on 44 wistar rats for 12 days. In the setup created in the experimental group, the molar teeth of wistar rats were vibrated in the mesio-distal direction at a frequency of 30 Hz for 8 hours a day, and they started movement in the molar teeth by means of NiTi coil springs that applied 0.25 N force. They observed a significant difference in tooth movement due to the vibration applied in the experimental group compared to the control group. In the light of these data, they concluded that vibration can be used as a method to accelerate tooth movement.

Nishimura et al. . [119] investigated the effect of vibration on orthodontic tooth movement on 42 wistar rats. The rats were divided into 2 groups as control and experimental groups, and for 21 days, according to the predetermined protocol, the molar teeth would move in the buccal direction with a mechanic that will move in the buccal direction once in 7 days for 8 minutes at 60 Hz. frequency vibration was applied. After the experiment, the rats were sacrificed and the RANKL receptor, fibroblast and osteoclast ratios were evaluated by immunohistological analysis. A proportionally significant increase in the number of fibroblasts and osteoclasts was observed in the vibration group. It was also noted that there was activation in the RANK-RANKL signaling pathway, which is responsible for osteoclast formation in the same group.

After all these studies, Kau [120] suggested that the vibration applied to the patients shortened the treatment rate in his case report of 14 patients whose orthodontic treatment was ongoing. In another study, Kau observed that vibration had no effect on resorption and did not damage the roots of the teeth. [120] reported that the vibration applied to the patients at 113 Hz frequency for 10 minutes a day caused significantly less root resorption in the roots. [121] Kau et al. [120] followed the 20-minute use of vibration applied at a frequency of 30 Hz with a force of 0.2 N in 14 patients who were planned to be treated with premolar extraction in a clinical study they conducted, for 6 months. In the study, measurements were made with a digital caliper directly from the mouth according to the amount of tooth movement, changes in the crowding in the lower and upper jaws, and the occlusion of the extraction spaces. In the light of these parameters, they concluded that the application of vibration increases the speed of tooth movement in extraction cases.

Leethankul et al. [122] investigated the effect of vibration on IL-1β in their study in individuals between the ages of 19 and 25 who will undergo canine distalization with the split mouth technique in vivo. Mechanically, 60 g of force was applied to 15 patients and the amount of canine distalization was also evaluated. In the study planned in split mouth, patients applied vibration with a motorized toothbrush for 15 minutes a day to the determined side for 2 months. As a result of the study, they revealed that vibration increases the level of IL-1β and that the vibration applied on tooth movement has an accelerating effect.

Pavlin et al. [123] evaluated the effects of 'Acceledent' vibrating at 30 Hz frequency with 0.25 N force in 45 patients aged 12-40 years in their clinical study. The researcher, who gave non-working acceledent devices to the experimental group and the control group, evaluated the effect of vibration on the distalization of the canine after the first premolar extraction. given. In the session in which distalization was performed with 0.018 steel wire, only the canine teeth were distalized and en masse retraction was performed with 0.19 x 0.025 wire in the anterior region. Measurements from the patients were made directly with a digital caliper and recorded. After the evaluation of the measurements, it was revealed that the vibration application significantly increased the orthodontic tooth movement.

Woodhouse et al. [124] Similarly, they evaluated the effectiveness of the device called Acceledent in a clinical study conducted in 2015. A total of 81 individuals, 41 females and 40 males, were included in the study, which was planned as a multicenter, in permanent dentition under the age of 20. NiTi wires with a thickness of 0.014, 0.018, 0.017x0.025 and then stainless-steel wires with a thickness of 0.019 x 0.025 were tied to the patients with elastomeric ligatures, in accordance with the protocol determined, respectively. The wire change reference is determined as the wires becoming easy to fit. The patients were divided into 3 groups and vibration device was given to the first group, non-working devices to the second group, and no device was given to the control group. The devices were applied to the patients for 20 minutes a day and the appointments were given at 6-week intervals. After the leveling phase was completed, crowding index measurements were made during the leveling phase in patients who followed the premolar extraction treatment protocol. When the findings of the study were evaluated, no acceleration in tooth movement was observed between the groups.

Yadav et al. [125] investigated the effect of mechanical vibrational stimulation at low intervals on tooth movement in an animal study they planned. By reporting that no significant difference was observed in the tooth movement of the experimental group compared to the control group, it was concluded that vibration applications did not accelerate orthodontic tooth movement.

In a study conducted on 26 rats in 2014, the rats were divided into 4 groups, and only vibration was applied to the first group, only orthodontic force was applied to the second group, and both vibration and orthodontic force was applied to the third group, and no force was applied to the last group. A force of 25 g was applied to the groups with orthodontic effect with Ni-Ti springs for 14 days. Vibration at 0.4 N and 30Hz frequency was applied to the vibration groups for 10 minutes, twice a week. As a result of this study, it was concluded that the vibration application significantly reduced the tooth movement speed, contrary to the findings in other studies. [126]

When all these studies are examined, it is seen that vibrational mechanical stimuli have an increasing, decreasing, or stabilizing effect on bone metabolism and therefore tooth movement speed. Since the effect of vibration on orthodontic tooth movement is a subject that has not been fully clarified, it is necessary to study and carry out detailed research in order to obtain more comprehensive information on this subject.

2.6.2.4 Photo biomodulation Light or Laser

It is a structure created so that laser light is in the form of coherent and single color and can become very intense. As a word, it is an abbreviated form of the first letters of the definition of "Light amplification by stimulated emission of radiation".

Lasers, which were first produced by Maiman [127] in 1960 as an optical source, which is a harmonious beam form of photons, create different effects on tissues according to their application time and energy density. The local temperature increases of lasers in the tissue less than 1°C is called bio stimulant effect. This irradiation bio stimulant effect of the laser is utilized in low-dose laser therapies. Lasers have bio stimulant effects due to low-dose applications, as well as effects on bone formation and destruction. These effects stimulate the proliferation of cells such as osteoclast, osteoblast, and fibroblast.

Cruz et al. [128] In a study evaluating bone healing in extraction cavities, they showed that healing was faster in laser-treated groups and fibroblast proliferation was more dominant.

Saito et al. [129] In their study to examine the effect of low-level laser application at different intervals for 7 days on bone regeneration in mid palatal suture expansion, they showed that laser application depends not only on the timing of application but also on its frequency. They also revealed that it has effects that will shorten the retention time and accelerate bone healing.

In a culture study conducted by Ozawa et al, [130] it was revealed that laser influences cell proliferation and differentiation, and with this effect, it increases osteoblastic and osteoclastic activity.

Kawasaki and Shimizu [131] examined tooth movement in laser-applied rats in their study. As a result of their clinical and immunohistochemical evaluations, they observed 30% faster movement in the laser-treated group compared to the control group.

Cruz et al. [128] investigated the effectiveness of split mouth laser application for 2 months following premolar extraction in 11 patients aged 12-18 years. In the study, which was started after the leveling of the teeth was completed, the amount of distalization of the maxillary canines was measured with the activation made every 30 days. In their study, they reported that there was 34% faster tooth movement on the laser applied side. Cruz et al. [128] like this study, Genç et al., Doshi-Mehta and Bhad-Patil and Yousef et al. [132–134] In the studies carried out, they showed in the literature that low-level laser lights accelerated tooth movement and created a significant difference compared to the control group.

Maiya et al. [135] evaluated the effects of laser on wound healing in diabetic rats. While laser application was not applied to the rats in the other group, which was determined as the control group, laser was applied 5 days a week in the other group until the wound healing was completed. Wound healing was completed in an average of 18 days in the laser applied group, while it was reported to be 59 days in the control group. According to these results, they concluded that laser photo stimulation provides a significant acceleration in diabetic wound healing.

Limpanichkul et al. [136] in a study examining the effects of laser on tooth movement, divided 12 patients into control and experimental groups using the split mouth technique. In the experimental group, they applied 25 J/cm2 low-level laser to the 3 surfaces of the teeth whose movement was desired. When they evaluated the results, they could not find a significant difference in the experimental and control groups. They concluded that the 25 J/cm2 laser dose is not sufficient to accelerate orthodontic tooth movement.

Yamaguchi et al. [137] evaluated the effects of low-level laser application on matrix metalloprotein-9, cathepsin K alpha and beta 3 integrin levels in rats. According to the results of this evaluation, they revealed that Matrix metalloprotein-9, cathepsin K alpha and beta 3 integrin levels significantly increased tooth movement.

Sousa et al. [138] evaluated tooth movement on three-dimensional model analyzes of retracted teeth of low-level laser applications. As a result of the study, they reported that it increased significantly in the laser applied group.

Demidova-Rice et al. [139] planned a study comparing the effects of lasers with a wavelength of 635 nanometers (nm) and different power dispersions on excisional wound healing. They reported that the most effective result in wound healing was 2j/cm2 power. They reported that there was no difference between coherent He/Ne laser with the same wavelength and non-coherent LED (Light Emitting Diode) light sources. Again, in the same study, it was reported that the best result was at the wavelength of 820 nanometers.

Light accelerated orthodontics applications started to come to the fore when similar results were achieved in LED light after the clinical effects of laser. After establishing the balance between power intensity and duration in LED light, the idea that these effects can be obtained with a device given to the patients has emerged. These devices have been transformed into a more acceptable device by the patients as they are controlled, harmless and user-friendly.

In 2013, Kau et al. [140] divided the patients into 4 groups in his study examining the effects of photo biomodulation, that is, low-level radiation, in 90 patients undergoing orthodontic treatment. While conventional orthodontic treatment was applied in the Control group, which is the 4th group, LED light with a wavelength of 850 nm was applied for 20 minutes a day in the 1st group, 30 minutes a day in the 2nd group, and once a week for 60 minutes in the third group. In this study, in which the efficiency of photo biomodulation at the leveling level was investigated, the crowding level was determined as Little's crowding index. During the leveling period, the follow-up protocol was determined to be every 2 weeks for the first 6 weeks, and then every 4 weeks until the leveling was completed. In order to measure the amount of change on crowding, the Little’s Crowding Index was measured in the anterior teeth between the canine-canine teeth in each session. In this study, in which devices emitting infrared light at a wavelength of 850 nm were used, when the cheek surface was irradiated with a power density of 60 mW/cm2, a weekly total energy density of 72, 108 and 216 J/cm2 was reached in the groups, respectively. After leveling was completed, the rate of decluttering was compared between groups. While tooth movement was recorded as 1.12 mm per week in photo biomodulation groups, this value was recorded as 0.49 mm in the control group. Based on these results of the study, it has been argued that photo biomodulation applications in the leveling phase significantly shorten the treatment period.

While it was argued that it accelerated tooth movement in a group of studies in which low-level laser applications were tried, studies advocating the opposite were reported by Nimeri et al. and Long et al. [141,142] has been included in the literature.

Our null hypothesis in our study is that vibration and light applications will not have a significant effect on accelerating tooth movement.

2.7. Definition and History of Thermoformed (Thermoplastic) Clear Aligner

Thermoplastic materials, meaning 'the group of plastics that soften when heated and harden again when cooled', take their origin from the Greek words 'thermos' to form hot and 'plasso'. They were first produced in 1986. [143]

They were used for the first time in tooth movement by Kesling [6] in 1945. Small tooth movements were achieved with thermoformed transparent-looking appliances without bands, brackets or wires. Kesling used this application to obtain small tooth movements with the flexible positioner device at the end of orthodontic treatment and reported that its effect can only be achieved in small movements. [6]

Marshall and Howay continued their transparent appliance applications with the introduction of the 'vacuum former' device in 1959. A year later, Nahoum produced this first aligner and applied it on a patient and published the treatment results. [144]After Nahoum published this study, many researchers tried this application on their patients and published the results. [144–148]

The use of clear aligners in this phase in orthodontics has become more common with the development of pressure molding devices and the easier production of aligners. Later, it was realized that it was a device that could make tooth movement with the changes made on the plaster models. Since they can provide the realignment of the teeth, these plates have been started to be used gradually to correct mild crowding called 'aligners'. [149]

Due to the nature of the thermoplastic material, tooth movement with the clear aligner is limited, so either the platter must be modified by reheating, or a new aligner must be made. The modification can be made with the help of special forceps heated to a certain temperature, or it can be done with temporary attachments on the tooth. If a heat treatment is to be done, it has been observed that a stretch of about 3 mm can be achieved, and more of it thins the plate. This method is frequently preferred by physicians because it does not require a new plate production cost, can be done directly at the patient's bedside, and does not require laboratory work and time. However, it should be noted that if this shaping is not done correctly, it will provide uncontrolled tooth movement. Therefore, when more tooth movement or more controlled tooth movement is planned, techniques have been developed that will be more effective in producing more than one aligner gradually. [149]

A student from the Faculty of Business Administration, whose treatment process continues at the University of Connecticut, goes to a friend in computer engineering with the idea of digitizing these processes, which are done manually at every stage. These applications, which were carried to the digital world under the leadership of these two students, are now being made with the help of software. Nowadays, in-office production applications have started by purchasing these software’s through many companies and making plans in the office.

2.7.1. Essix System

After all the developments with clear aligners, Sheridan [150] (Raintree Essix, Inc., 4001 Division St, Metairie, LA-USA) presented the essix system to his patients as an inexpensive, aesthetic, comfortable and easy-to-build treatment alternative in 1993. Due to all the features offered, it has become a treatment system that is quickly accepted by the patients.

In this technique, the position of the tooth whose movement is desired in the plaster model is changed and fixed in the desired position. Afterwards, the appliances obtained from clear aligner shaped under heat and/or pressure are delivered to the patient as a therapeutic device. While the patient is using the plates, a change in position is obtained in the teeth while the teeth are trying to reach the position of the prepared plates. Different thicknesses and forms of Essix plates are also shaped under heat and/or pressure, and many uses such as joint splint or occlusion riser due to TMJ disorders, habit breaker to prevent existing habits, placeholder to protect the place of prematurely lost teeth, and whitening plate for home bleaching. are also available. Although the Essix system was mostly used as a reinforcing appliance in the first period, it is also used as active therapeutic plaques that create tooth movement today as well as this use. [151]

Sheridan advocated that 3conditions must come together in order to create ideal tooth movement with the essix system. These are defined as first sufficient force for the teeth to move, secondly enough space for the teeth to be moved, and finally enough time for the force to be effective to complete the movement. In the movements planned with this system, in areas where the plaque alone is not sufficient for tooth movement, the protrusions created by Hilliard Thermoplier (Dr. Keith Hilliard, Lakeland, Florida) with the help of special forceps in certain parts of the plaque, pressure areas or protrusions created by placing composite on the tooth surface in layers, the force can be increased. is optimized.

In this system, the tooth or teeth that are planned to be moved are brought to their position at the end of the movement and the plaque is prepared with the help of heat and pressure. After this stage, the plastic, which is the plaque material, is able to return to its original state, that is, the strength is obtained by the effect of the forces arising from its resilience. Clear Aligner can be shaped up to a maximum of 3mm under heat and pressure. If they are forced more, the appliance becomes thinner, and the desired effect cannot be achieved. Corrections made in the model to ensure the movement of the teeth, such as reductions or additions to the tooth surface, are also made in the mouth, and the patient is asked to use it continuously except for meals. [151]

If we evaluate the Essix system biomechanics, with the correction made, the clinician has the freedom to apply the orthodontic force within the biological limits where it will have the best effect on the crown surface. The force obtained by these corrections determines the type and direction of tooth movement. For example, if the force is applied close to the incisal edge while correcting the model, more tipping motion in the target tooth; If it is applied close to the gingival edge, more body movement occurs. With the Essix system, it is possible to obtain movements such as tipping, rotation, torque, extrusion, intrusion according to the correction made in the model. [152]

In the Essix System, a single appliance can provide an average of 2-3mm of movement. With the help of appliances, 1 mm tooth movement per month can be targeted. If the targeted amount of movement is more than these limits, the measurement can be taken and repeated until this process is completed, or a large number of plates can be prepared by obtaining more than one model from the taken measurement. Therefore, it is generally recommended to apply the essix system to cases that can be solved with 1 or 2 aligners, and it has low production cost. [153]

2.7.2. Invisalign System

The idea of Invisalign, which was put forward by Stanford University Computer Engineering students Zia Christi and Kelsey Wirth in 19997, is based on the clear aligners that Christi underwent orthodontic treatment using traditional brackets during her high school years and then given for reinforcement. The basis of this idea is the observation that when Christi wears the aligner regularly, her teeth do not deteriorate, but when it starts to fail, her teeth deteriorate, and then when she wears it regularly, her teeth improve. Based on this observation, Christi and Wirth founded Align Technology, Inc. (Santa Clara, Calif) with the help of 3D imaging techniques. Align Technology firm has started to produce the clear aligner in series within a system that includes the previous works of co-workers such as Kesling, Sheridan, Nahoum [6,144,151] and the principles of the essix system, but not manually, but in a system where coordinated 3D planning is made with CAD-CAM technology. After these developments, Align Technology introduced the Invisalign system in 1998 and started to use it on patients as of May 2000. The produced plaques were used sequentially, and they realized the idea they had put forward by correcting the teeth. [154]

In order to complete the data in the Invisalign system, measurements from the lower and upper tooth rows and occlusion records are taken from the patient. In addition, intraoral and extraoral photographs, panoramic and preferably cephalometric x-rays, if any, are added and sent to the Invisalign laboratory. The plaster models obtained with the help of the measurement and occlusion record are scanned with 100-micron precision computer tomography. After removing the artifacts in the image, 3D digital models are obtained. [155]

In order to plan tooth movements, a patient-specific virtual treatment plan is made by using the software called 'Treat Software'. In this personalized planning, the final position of the teeth is determined, and the order of tooth movement is defined. In the Invisalign system, dimensional measurements on teeth and jaws can also be made with the program called 'Tooth Measure'. Type, torque, rotation, crowding, and overjet, overbite and occlusal relationships between the teeth can be measured. At the same time, pre- and post-treatment changes and progress can be evaluated by superimposing on palatal rugae or untreated teeth or dental implants. [156,157]

In this system, auxiliary elements such as 'attachment' made of composite material can be added to the treatment plan for rotation, extrusion or intrusion movements that the plates cannot do alone or that will be forced. [158]

This personalized planning is submitted for the approval of the doctor and the patient with the help of the program called 'ClinCheck'. This program is on an online structure that allows the doctor to send additional requests and make corrections regarding tooth movements. Even today, treatment planning can be completed faster by making live updates.

Following the completion of the treatment planning, the planned tooth movement is divided into sections in line with the approval given. Stereolithographic models showing each stage of the treatment are produced with the help of 3D printers and clear aligner series are produced on these models and sent to the clinician.

The plates produced by Invisalign are in polyurethane structure with methylene diphenyl diisocyanate and 1.6 hexanediol added and are 0.8 mm thick. The diphenyl structure in these plates provides the necessary durability. 0.25-0.33 mm of movement is planned for each plate, and it is requested that the plates be used between 18-22 hours a day for 2 weeks. [155]

The Invisalign method has been a preferred method especially among adults due to its advantages such as being aesthetic, easier cleaning of the teeth and not affecting the daily life of the patient [159] Since Invisalign appliances are removable appliances, patient cooperation, treatment It is of great importance in terms of reaching the desired result at the end, even the most important parameter. Appliances are effective patients should use their appliances for at least 22 hours a day. This treatment the method is intended for adults who are willing to use clear orthodontic appliances and for growth. it could be applied to young people who would not be guided. However, the wings are used to guide growth and development in Align Technology's Mandibular Advancement protocol have changed this.

Joffe, in his study in 2003, reported that the Invisalign system gave successful results in moderate crowding such as 1.5 mm, in cases of excess space such as 1-5 mm, in cases requiring deep bite and dental expansion. However, in the same study, it was reported that it was insufficient in cases with space narrowing of more than 5 mm, skeletal anterior-posterior incompatibilities, rotations of more than 20 degrees, anterior open bite, tipping movements of more than 45 degrees, multiple missing teeth, and teeth with short clinical crowns.

In the same study, the researcher showed that it provides ideal aesthetics, ease of use, and ease of oral hygiene procedures as an advantage. [160]

2.7.3. Clear Correct System

It was established in Texas in 2006 by one of the practitioners using OrthoClear in Texas.It continued its activities with the support of a group of technicians working with plaster models. In 2008 they digitized the process. The company was purchased by Strauman in 2008 and continues its activities within this body.[161]

2.7.4. Orthero System

The company, which was established in 2014 as a clear aligner in Istanbul Technical University Arı Teknokent, provides services in many countries, especially in Turkey, under the name Orthero, with the investments it later received.[162]

2.7.5. In House Aligner Production Techniques

It is possible to plan orthodontic tooth movement by clinicians who do not want to work with companies or technicians who want to provide individual service to physicians through software they can obtain from many companies. These softwares can be obtained from many companies such as orchestrate, 3shape, nemo ceph or maestro, or very simple movements can be planned via mesh mixer. In the planning phase, the teeth are first segmented. After segmentation, the teeth are planned within the motion hierarchy. The software is automatically staged within the limits determined in the program according to the most advanced movement in the planned movements. At the end of the staging, the total number of clear aligner to be used is revealed. Prepared models are prepared with 3D printers. These used printers are adapted to the models with PET G, which is a plate material under heat and pressure, after this process. The PET G material removed from the model is cut from the edges and polished and delivered to the patients for use in order.

2.7.6. Programs Used in In House Aligner Production

2.7.6.1. Orchestrate Software

Orchestrate Orthodontic Technologies is a ground-breaking 3D digital firm. Orchestrate 3D has created the world's most advanced "in office" 3D digital orthodontic system which has ten years background. NASA, the Department of Defense, Northrop Grumman, the United States Air Force, the United States Army, General Electric, Nike, Oakley, Procter & Gamble, and many other Fortune 500 companies and universities rely on this technology.[163]

2.7.6.2. 3Shape Studio Software

Tais and Nikolaj, two graduate students in 200, have a passion for 3D technology. They join forces to win an entrepreneurial prize. They develop a scanner and software that revolutionizes the hearing aid market. Simultaneously, the digital world begins to take 3shape. In 2005, 3shape launched dental model scanner. Then in 2009, 3Shape releases its first orthodontic software, allowing laboratories and practices to use digital technology for orthodontic treatment planning and appliance creation. Now in 3shape studio module includes; Trios Design Studio, Implant Studio, Clear Aligner Studio and Splint Studio. [164]

2.7.6.3. Nemo Studio Software

Nemotec, a leading Spanish technology company for the dental industry. 3D Smile Guide: In all suite applications, including visualization of the patient's photo in all. Modules: face prediction in planning. Virtual articulator is accessible in all suite components. Prostheses have been redesigned: Preview of the many prosthesis galleries when designing a smile, as well as real-time evolution on the patient's photo. To generate treatment plans, a new intuitive and easy micro odontogram has been developed.

Cephalometric Software - NemoCeph Automatic facial recognition, automatic recognition and placement of cephalometric points, new relevant cephalometric analyzes such as Jefferson's, and the ability to customize.

NemoCast – Orthodontic diagnosis and planning software. For orthodontists, lowering orthodontic case preparation time by 70% to complete a setup for aligners or indirect bonding.

The CBCT allows for automated segmentation of teeth (crowns and roots) in three clicks while visualizing root movement during setup. Attachment-based indirect bonding A large collection of brackets and jigs.

NemoSmile Design is a digital smile design software. Manipulation of the prosthesis is more intuitive for grin design, allowing you to make a mock up in minutes. Smile guides in 3D.

NemoScan – Implantology diagnosis and planning software. A large implant library with over 60 available brands and a comprehensive library of attachments. Implantology planning with prosthesis in mind.

NemoFAB - Orthognathic surgery software developed in partnership with Dr. Arnett. The new edition provides the ability to define personalized osteotomies as desired by the user, as well as additional forms.[165]

2.7.6.4. Maestro3d Software

AGE Solutions was founded in 2007 by two ex-CNR (National Research Council) experts from Pisa, Italy, who specialized in the creation of three-dimensional acquisition systems and the elaboration, presentation, comparison, and processing of three-dimensional data. The roots of AGE Solutions may be traced back to the shared love of two founding members for computer graphics and the technical-scientific basis that was developed through the years of permanence inside the VCL (Visual Computer Lab) of ISTI-CNR of Pisa, Italy. The company includes different packages for clinicians or dental technicians. Maestro Dental Studio includes, Ortho Studio, Dental Restoration, Smile Creator. In Ortho Studio, the clinician can work on study models, can do virtual set up, also can do clear aligner treatment and indirect bonding tray. It has also integration of CBCT. [166]

3.MATERIALS AND METHODS

3.1. Sample

Patients who were treated at Yeditepe University Faculty of Dentistry, Department of Orthodontics between January 2018-June 2020 and whose archive records fully comply with the following criteria Patients included:

- In permanent dentition,
- Between the ages of 18-30,
- Except for wisdom teeth, there is no congenital or acquired tooth deficiency for any reason,
- Lower arch crowding index is moderate (between 5 and 9 mm) according to Little's crowding index,
- In the anamnesis, he/she had not used any orthodontic device before and had orthodontic treatment. who have not seen
- There was no systemic disease in the anamnesis, and no medication was taken during the study
- Having used a device for light or vibration or the application of light and vibration except control group.

In this period, in the examination carried out in the Archives of Yeditepe Faculty of Dentistry, Department of Orthodontics Assistant Clinic, 186 patients with lower incisors were treated with fixed treatments and 158 patients with clear aligners. It was determined that 93 patients treated with clear aligners were also treated using one or more of the acceleration methods. Of 93 patients, 32 patients were treated with vibration, 26 with light, 29 with a combination of light and vibration, and the remaining 6 patients were accelerated by surgical methods. When the records of the patients were examined in accordance with the protocol, those with complete records were found to be vibration (n=26), light (n=21), light and vibration (n=23), respectively. The control group will consist of people (n=19) who did not apply any method.

In accordance with the archive rules of Yeditepe Faculty of Dentistry, Department of Orthodontics, Assistant Clinic, the clinical protocol stages are for clear aligner treatments,

- Taking the diagnostic model size conventionally or by scanning intraoral scanner,
- Taking initial photos both intraoral and extraoral,
- Panoramic and cephalometric x-rays,
- Preparation of presentation of each case for consideration in case discussion,
- In line with the decision of the case meeting, the written presentation of the treatment alternatives, the explanation of the possible risks, and the signature of the consent form,
- Planning the digital planning with the consultant professors,
- If attachment is required before the aligners are delivered to the patient, application and intraoral photography,

- Taking photographs of the mouth in every 2 aligner replacements and comparing them with digital planning to ensure the course of treatment and follow-up
- If necessary, taking the improvement measure and continuing the treatment with the same procedures in additional plaques.
- At the end of the treatment, it is the end of the treatment with fixed retainers, taking the measurements and photographs of the end, explaining the possible risks of the end consent and ending the treatment after the signature.
- It is the interface arrangement of the treatment follow-up details on the HIS program (Patient monitoring system) for each appointment of the patients or digitally recording and tracking the amount of abrasion, which aligners are delivered.

In the patients in the archive of these patients, it is planned to divide the intermediate impression models into subgroups according to the Little crowding index, to compare the models to evaluate the treatment speed and the need for rearrangement and the success rates in tooth movements. The relationship between the changes achieved will be compared statistically. A total of 89 patients will be studied.

38 of the included individuals were male, it varies between the ages of 18-30, 51 of which are females, and the mean age is 23.16±3.55. The first group, the control group, consisted of 19 individuals (11 females, 8 males) and were selected from patients who were treated only with clear aligners. No acceleration method was used in these patients in the control group. The second group is the vibration group consisting of 26 people (14 females and 12 males). The third group, that is, the group in which the LED light was applied, consisted of 21 people (12 females, 9 males). There are 23 people (14 females, 9 males) in the fourth group in which LED light and vibration were applied, which has not been applied in the treatment with clear aligner before.

Marmara University Faculty of Dentistry Dean's Local Ethics Committee that the planned study complied with the World Medical Association Declaration of Helsinki “Good Clinical Practices and Good Laboratory Practices Rules”.

3.2 Devices and Materials Used in the Study

- Vibration device applying 30 Hz frequency, 0.25 Newton force (Yeditepe University Faculty of Engineering and Architecture Biomedical Engineering)
- Photo biomodulation device that applies light at a wavelength of 850 nm (Yeditepe University, Faculty of Engineering and Architecture, Biomedical Engineering)
- Vibration and photobiomodulation device that combines 30 Hz frequency, 0.25 Newton vibration and 850 nm wavelength light application.
- Usb Cable and Powerbank 2000 mAh.
- 0.01 mm precision digital caliper (Worldforce tools)
- Orchestrate 3D Aligner Planning Program
- Uzaras Dreammaker 3D Printer
- Esun 1.75mm Filament
- Biostar ® Scheu (Scheu Dental GmbH Iserlohn Germany)

- Durable 0.75 mm Clear Aligner Material
- Condensation silicone (Speedex, Colten, Switzerland)
- Hard plaster (Amberok, Luoyang, China)
- Sirona Cerec Omnicam Orthodontic Module

3.3 Method

3.3.1. Informing Patients

Patients since the patients were taken from the Archive of Yeditepe University Faculty of Dentistry, Department of Orthodontics and it was a retrospective study, no additional information was given to the patients. Evaluation was made on the recorded values based on the patient's statement.

3.3.2 Preparation of Appliances and Working Principle

Three different types of appliances were developed by Yeditepe University Faculty of Engineering and Architecture Biomedical Engineering in our planned study. The first appliance is a vibration appliance and is 30 Hertz. frequency and 0.25 Newton (25 grams) power vibration. Second appliance photo biomodulation It emits light at a wavelength of 850 nm. The third device is vibration and the device that simultaneously applies photo biomodulation is the combination of the other two appliances with 30 Hz 0.25 N and 850nm.The appliances developed for the study are fully equivalent in function to the products on the commercial market. However, it is a prototype. Vibration in appliances motors Shaftless Vibration Motor 10x3 (10mm Cable Lenght It has been tested with an optical tachometer that the appliances apply the desired type of vibration. For the photo biomodulation application, PHOEBE Teeth Whitening Light contains 16-LED lights Red 5mm LEDs at 850nm wavelength with 60° angle of view were used. There is an on/off button on the area where the usb cable extending from the appliances enters. The appliance starts to work with the activation of this button, depending on the appliance's feature. The appliance is closed when it is brought in the opposite direction. The part that is put on the mouth of the appliances can be cleaned by the antiseptic wet towels.

Figure 3.1: Views of the prepared photo biomodulation device

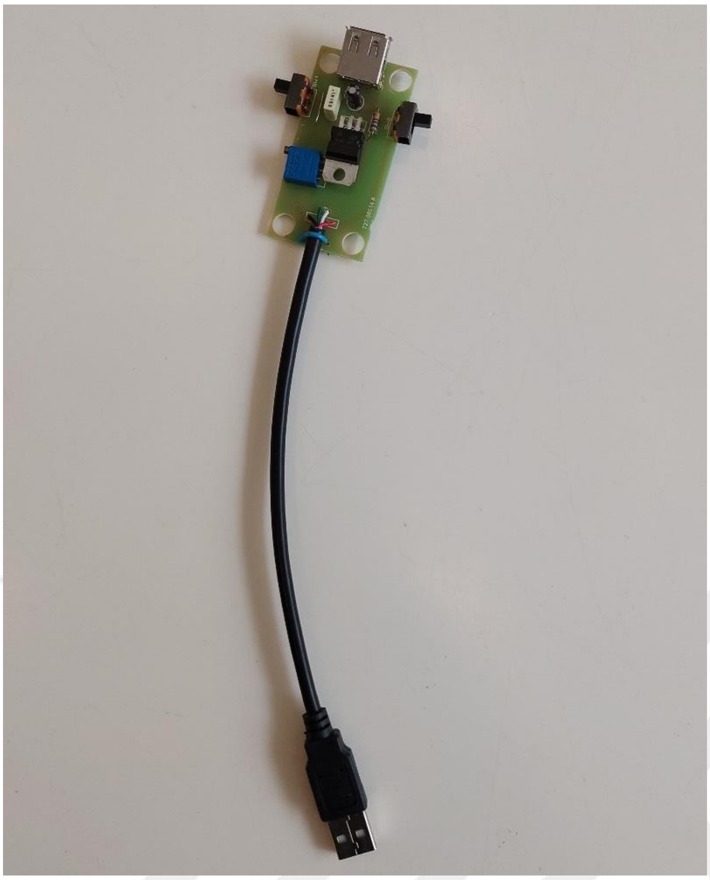

Figure 3.2: Internal parts prepared for the operation of the prepared Photo biomodulation and Vibration device.

Figure 3.3. Mouthpiece of the prepared Photo biomodulation and Vibration device to be applied to the patient.

Figure 3.4. View of the prepared key on and off system in a closed box.

Figure. 3.5. A sample of the device prepared to be delivered to patients.

Working with usb and powerbank.

Figure 3.6: A front view of the mouthpiece of the vibrating-only device.

Figure 3.7: Application of the Appliance

After the appliance is placed in the mouth, it does not need to be supported by hand. The buttons on the appliance allow it to be opened and closed easily. Thanks to its ease of use, the appliance It does not interfere with the daily work during the day.

Figure 3.8: Digital caliper

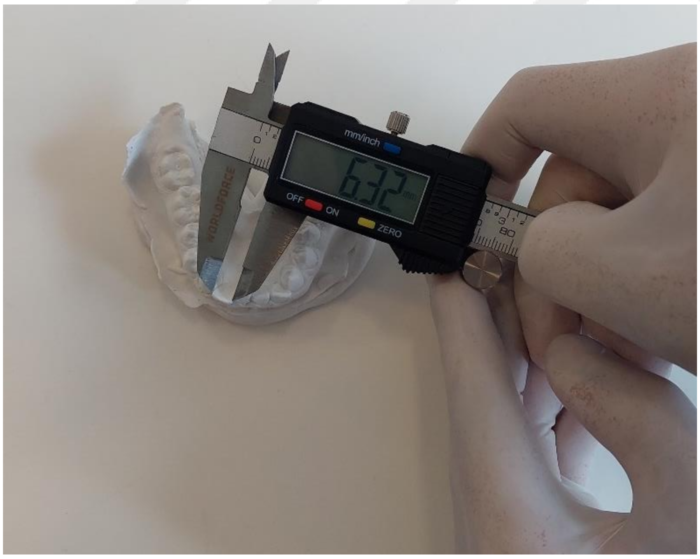

Figure 3.9: Measurement of Little's crowding index with a digital caliper.

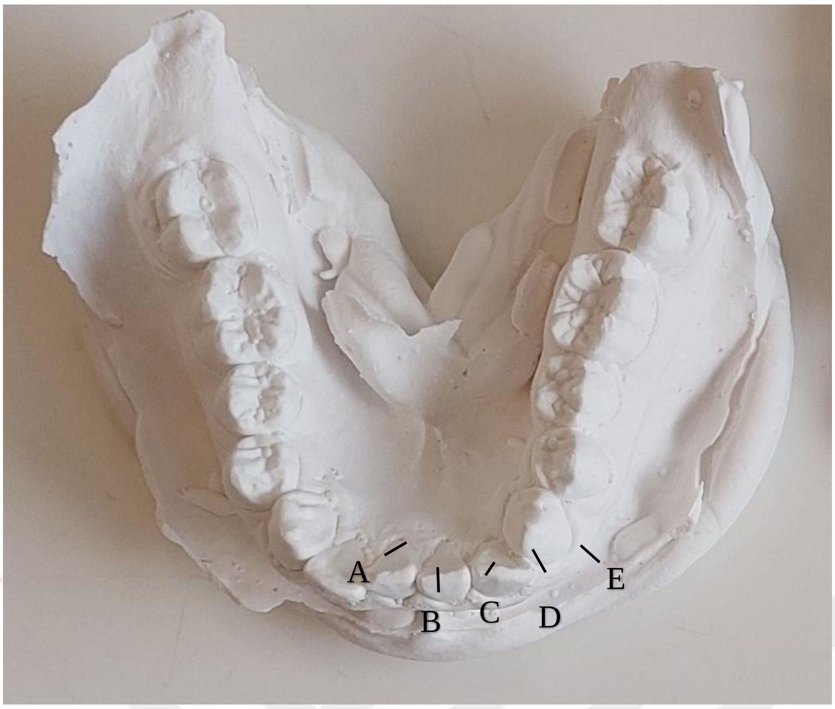

Figure 3.10: Schematic view of Little's crowd index measurement: A: The distance between the mesial contact point of the canine tooth and the distal point of the lateral tooth

B: The distance between the mesial contact point of the lateral tooth and the distal point of the central tooth

C: The mesial contact point of the central tooth and the mesial contact point of the other central tooth C Distance between the distal contact point of the central tooth and the mesial point of the lateral tooth

D: Distance between the distal contact point of the lateral tooth and the mesial point of the canine:

E Little's Crowding index : A+B+C+D+E

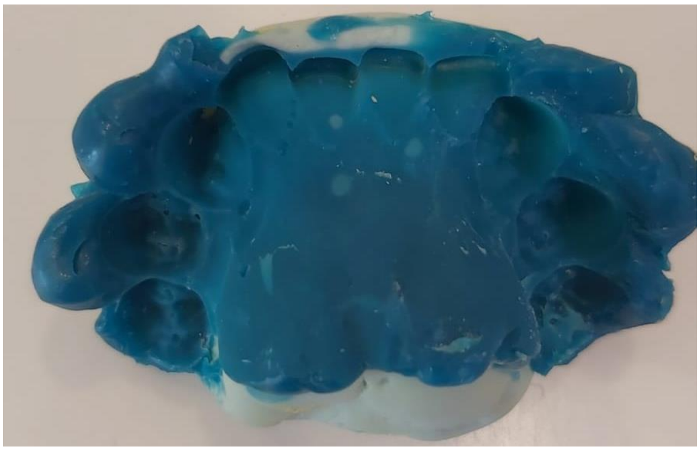

Figure3.11. Impression taken with silicon for intermediate measurements

Figure 3.12. Plaster model prepared from intermediate measurements

3.3.3 Treatment protocols

All individuals included in our study were digitally planned with the Orchestrate 3D Aligner Program. After the digital planning, the models were produced with Uzaras Dreamliner 3D Printer using Uzaras 1.75 mm filaments.

The patient treatments were completed with the clear aligners prepared using the Biostar (Scheu Dental GmbH Iserlohn Germany) device with a plate thickness of 0.75mm (Scheu Dental GmbH Iserlohn Germany) that is durable for the produced models.

After the attachment applications required for the treatment were made, the plates were delivered to the patients in order, to be changed every 15 days at the first appointment, then two plates to be replaced every 15 days at the first appointment, then again for 10 days, and once a week at the third appointment.

At that time, the patients were delivered with devices such as light, vibration and combination. They were asked to use the devices for 20 minutes and a follow-up chart was given to the patients. They were asked to note the hours they used in this follow-up chart, in minutes.

After the device was delivered, information was given about the use of the appliance and the cleaning of the appliance. The patients who provided the use of two clear plates were called for a control appointment. The first measurements were made with a digital caliper on the models obtained from the measurements taken with silicone from the patients using the first 2 clear aligners. In the following periods, the same controls and measurements were made.

3.3.4 Crowding Resolving Measurements

Session T0, 28. necessary measurements were made from the intraoral measurements taken 4 times in total, on day T1, day 42 T2 and day 56 T3. The researcher took measurements without seeing patient names and without knowing which group the patients belonged to on plaster models. The numbers were changed after one week, all measurements were taken one week apart by the same researcher which made twice.

3.4 Statistical Analysis

While evaluating the findings obtained in the study, IBM SPSS Statistics 22 program was used for statistical analysis. The suitability of the parameters to the normal distribution was evaluated by Kolmogorov-Smirnov and Shapiro Wilks tests. While evaluating the study data, in addition to descriptive statistical methods (mean, standard deviation, frequency), the Oneway Anova test was used for the comparison of the normally distributed parameters in the comparison of the quantitative data, and the Tukey HDS test was used to determine the group that caused the difference. Kruskal-Wallis test was used for the comparison of the parameters that did not show normal distribution, and Dunn's test was used to determine the group that caused the difference. Analysis of Variance in Repeated Measures test and post hoc Bonferroni test were used for within-group comparisons of normally distributed parameters. Chi-square test was used to compare qualitative data. Spearman's rho correlation analysis was used to examine the relationships between parameters that did not conform to the normal distribution. Significance was evaluated at the $p<0.05$ level.

4. RESULTS

4.1 Evaluation of Method Error

The method error calculated for the amount of crowding in the lower incisors are shown in Table 4.1. The table shows the method error and the lower and upper limits of the 95% confidence interval for the measurements. The intra-class correlation coefficient (ICC) determined in the measurements was found to be close to 1.00, and this value revealed that the measurements were repeatable with a non-significant error that would not affect the results.

Table1.: Methodological error evaluation regarding the amount of crowding measurements at T0, T1, T2 and T3 times

Deviousness	Intra-Class Correlation Coefficient (ICC)	95% Confidence Interval		p
		Lower Boundary	Upper Limit	
T0	0.999	0.999	1,000	0,000*
T1	0.998	0.997	0.999	0,000*
T2	0.998	0.997	0.999	0,000*
T3	0.999	0.999	1,000	0,000*

ICC: Interclass Correlation Coefficient

The results for the method error calculated for the amount of crowding between teeth are shown in Table 1. The method error and the lower and upper limits of the 95% confidence interval for each measurement are given in the table. As seen in the table, the intraclass correlation coefficient (ICC) determined in all measurements was found to be close to 1.00. The results of the within-class correlation coefficient analysis for method error showed that crowding out measurements could be repeated with a non-significant error that would not affect the results.

4.2 Evaluation of Age and Gender Distribution of the Groups Statistical Reviews

The study was conducted with a total of 89 cases, 51 (57.3%) female and 38 (42.7%) males, aged between 18 and 30. The mean age is 23.45±3.62 years. The cases were evaluated under four groups as “Control” (n=19), “Vibration” (n=26), “Light” (n=21) and “HOT” (n=23).

Table 2: Evaluation of the groups in terms of age and gender

	Control	Vibration	Light	HOT	p
Age Mean±SD	23.16±3.55	24.31±2.51	22.57±5.06	23.52±3.19	[1] 0.426
Gender n (%)					
Woman	11 (57.9%)	14 (53.8%)	12 (57.1%)	14 (60.9%)	[2] 0.969
Male	8 (42.1%)	12 (46.2%)	9 (42.9%)	9 (39.1%)	

[1] *Oneway ANOVA Test* [2] *Chi-square test*

There was no statistically significant difference between the groups in terms of mean age and gender distribution ($p>0.05$).

4.3 Between-Group Comparison of Initial Crowding Values

Table 3: Evaluations of crowding amount measurements

	Control	Vibration	Light	HOT	
	Mean±SD	**Mean±SD**	**Mean±SD**	**Mean±SD**	**1p**
T0	5.66±0.47 ^{A,a}	5.56±0.39 ^{A,a}	5.75±0.41 ^{A,a}	5.65±0.43 ^{A,a}	0.476
T1	5.49±0.46 ^{A,b}	5.39±0.39 ^{A,b}	5.34±0.41 ^{A,b}	5.16±0.42 ^{A,b}	0.074
T2	5.31±0.48 ^{A,c}	5.22±0.41 ^{AB,c}	4.95±0.41 ^{BC,c}	4.68±0.42 ^{C,c}	0,000*
T3	5.14±0.48 ^{A,d}	5.06±0.39 ^{A,d}	4.55±0.41 ^{B,d}	4.19±0.42 ^{C,d}	0,000*
2p	0,000*	0,000*	0,000*	0,000*	

[1] *Oneway ANOVA Test* [2] *Analysis of Variance in Repeated Measurements*

**p<0.05*

NOTE: Uppercase letters in rows indicate intergroup variation, and lowercase letters in columns indicate intertemporal variation.

4.4. Evaluation of Crowding Amounts

The amount of crowding was measured at the beginning of the experiment (T0), T1 and T2 times in each group and statistically evaluated (Table 5.6). The relationship between the time changes and the amount of crowding for each group was examined with the Repeated Measure ANOVA test. ANOVA test was used to assess whether there was a difference in the amount of crowding between different groups at the same time.

1 ANOVA Test 2RepeatedMeasure ANOVA Test

Capital letters are vertical, lowercase letters are horizontal. Same letters represent no significant difference, different letters represent significant difference.

Amount of crowding measurements made at T0, T1 and T2 times for each group created for the study setup were analyzed statistically by performing variance analysis The change over time was significant in the control group, vibration group, light group and HOT group ($p=0.000$ $p<0.001$). In other words, there is a statistically significant difference between the amount of crowding at T0, T1 and T2 times (Figure 4.1).

There was no statistically significant difference in the amount of crowding between the control and experimental groups ($p>0.05$) (Figure 4.2).

A statistically significant difference was found in the amount of crowding between the groups at T1 time ($p<0.05$). Similarly, a statistically significant difference was observed in the amount of crowding between the groups at T2 time ($p<0.05$). Pairwise comparisons were made for these variables with difference in order to determine from which groups the difference originated (Table 4.6). A significant difference was found in the amount of crowding between the control and HOT groups at T1 time ($p<0.05$). At T2 time, the difference between the control and light groups and between the control and HOT groups was significant ($p<0.05$).

Table 4: Post hoc analysis table

		T2	**T3**
		p	**p**
Control	Vibration	0.888	0.905
	Light	0.040*	0,000*
	HOT	0,000*	0,000*
Vibration	Light	0.138	0.001*
	HOT	0,000*	0,000*
Light	HOT	0.164	0.030*

Tukey HSD Test **p<0.05*

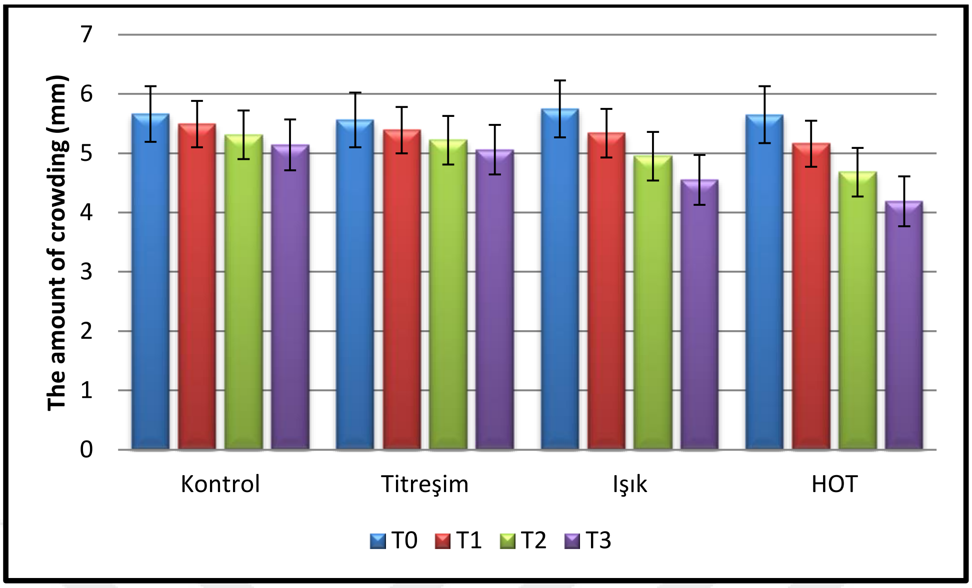

Figure 4.1: Amount of Confusion Between Groups

There was no statistically significant difference between the groups in terms of average crowding at T0 and T1 times (p>0.05) (Table 3).

There was a statistically significant difference between the groups in terms of crowding averages at T2 time (p:0.000; p<0.05) (Table 3). As a result of post hoc analyzes to determine which groups the significance originates from; The crowding mean of the HOT group was significantly lower than the Control (p:0.000) and Vibration (p:0.000) groups (p<0.05). The mean crowding of the light group was found to be significantly lower than the control (p:0.040) group (p<0.05). There was no statistically significant difference between the other groups in terms of T2 time crowding measurements (p>0.05) (Table 3).

There was a statistically significant difference between the groups in terms of crowding mean at T3 time (p:0.000; p<0.05) (Table 3). As a result of post hoc analyzes to determine which groups the significance originates from; The mean T3 crowding of the HOT group was significantly lower than the Control (p:0.000), Vibration (p:0.000) and Light (p:0.030) groups (p<0.05). The mean crowding of the Light group was significantly lower than the Control (p:0.000) and Vibration (p:0.001) groups (p<0.05). There was no statistically significant difference between the control and vibration groups in terms of T3 time crowding measurements (p>0.05) (Table 3).

Table 5: Post hoc analysis table of changes over time

		Control	Vibration	Light	HOT
		p	**p**	**p**	**p**
T1	T2	0,000*	0,000*	0,000*	0,000*
	T3	0,000*	0,000*	0,000*	0,000*
	T4	0,000*	0,000*	0,000*	0,000*
T2	T3	0,000*	0,000*	0,000*	0,000*
	T4	0,000*	0,000*	0,000*	0,000*
T3	T4	0,000*	0,000*	0,000*	0,000*

Bonferroni Test **p<0.05*

In the control group, There is a statistically significant difference between the mean crowding measurements at T0, T1, T2 and T3 measurement times (p:0.000; $p<0.05$) (Table 3). The decreases observed in T1, T2 and T3 times compared to T0 time are statistically significant (p:0.000; $p<0.05$). The decreases in T2 and T3 times compared to T1 time were statistically significant (p:0.000; $p<0.05$). The decreases observed in T3 time compared to T2 time are statistically significant (p:0.000; $p<0.05$) (Table 5).

Vibration group: There is a statistically significant difference between the mean crowding measurements at T0, T1, T2 and T3 measurement times (p:0.000; $p<0.05$) (Table 3). The decreases observed in T1, T2 and T3 times compared to T0 time are statistically significant (p:0.000; $p<0.05$). The decreases in T2 and T3 times compared to T1 time were statistically significant (p:0.000; $p<0.05$). The decreases observed in T3 time compared to T2 time are statistically significant (p:0.000; $p<0.05$) (Table 5).

Light group: There is a statistically significant difference between the mean crowding measurements at T0, T1, T2 and T3 measurement times (p:0.000; $p<0.05$) (Table 3). The decreases observed in T1, T2 and T3 times compared to T0 time are statistically significant (p:0.000; $p<0.05$). The decreases in T2 and T3 times compared to T1 time were statistically significant (p:0.000; $p<0.05$). The decreases observed in T3 time compared to T2 time are statistically significant (p:0.000; $p<0.05$) (Table 5).

HOT group: There is a statistically significant difference between the mean crowding measurements at T0, T1, T2 and T3 measurement times (p:0.000; $p<0.05$) (Table 3). The decreases observed in T1, T2 and T3 times compared to T0 time are statistically significant (p:0.000; p<0.05). The decreases in T2 and T3 times compared to T1 time were statistically significant (p:0.000; p<0.05). The decreases observed in T3 time compared to T2 time are statistically significant (p:0.000; p<0.05) (Table 5).

Table 6: Evaluations regarding the amount of crowding changes

	Control	**Vibration**	**Light**	**HOT**	
	Mean±SD (median)	**Mean±SD (median)**	**Mean±SD (median)**	**Mean±SD (median)**	**1p**
T0-T1	0.17±0.06 (0.2) ^{A}	0.16±0.05 (0.2) ^{A}	0.41±0.03 (0.4) ^{B}	0.49±0.03 (0.5) ^{C}	0,000 *
T0-T2	0.35±0.11 (*.4) ^{A}	0.34±0.11 (0.4) ^{A}	0.81±0.03 (0.8) ^{B}	0.97±0.07 (1) ^{C}	0,000 *
T0-T3	0.52±0.15 (0.6) ^{A}	0.50±0.15 (0.6) ^{A}	1.20±0.04 (1.2) ^{B}	1.46±0.10 (1.5) ^{C}	0,000 *
T1-T2	0.18±0.07 (0.2) ^{A}	0.17±0.07 (0.2) ^{A}	0.40±0.02 (0.4) ^{B}	0.48±0.04 (0.5) ^{C}	0,000 *
T1-T3	0.35±0.10 (0.4) ^{A}	0.34±0.11 (0.4) ^{A}	0.79±0.03 (0.8) ^{B}	0.97±0.07 (1) ^{C}	0,000 *
T2-T3	0.17±0.06 (0.2) ^{A}	0.16±0.05 (0.2) ^{A}	0.39±0.02 (0.4) ^{B}	0.48±0.04 (0.5) ^{C}	0,000 *

[1] *Kruskal Wallis Test* **p<0.05*

Table 7: Post hoc analysis chart of changes

		T0-T1	**T0-T2**	**T0-T3**	**T1-T2**	**T1-T3**	**T2-T3**
		p	**p**	**p**	**p**	**p**	**p**
Control	Vibration	0.938	0.886	0.821	0.898	0.872	0.867
	Light	0,000*	0,000*	0,000*	0,000*	0,000*	0,000*
	HOT	0,000*	0,000*	0,000*	0,000*	0,000*	0,000*
Vibration	Light	0,000*	0,000*	0,000*	0,000*	0,000*	0,000*
	HOT	0,000*	0,000*	0,000*	0,000*	0,000*	0,000*
Light	HOT	0.011*	0.010*	0.007*	0.010*	0.008*	0.010*

Dunn's Test **p<0.05*

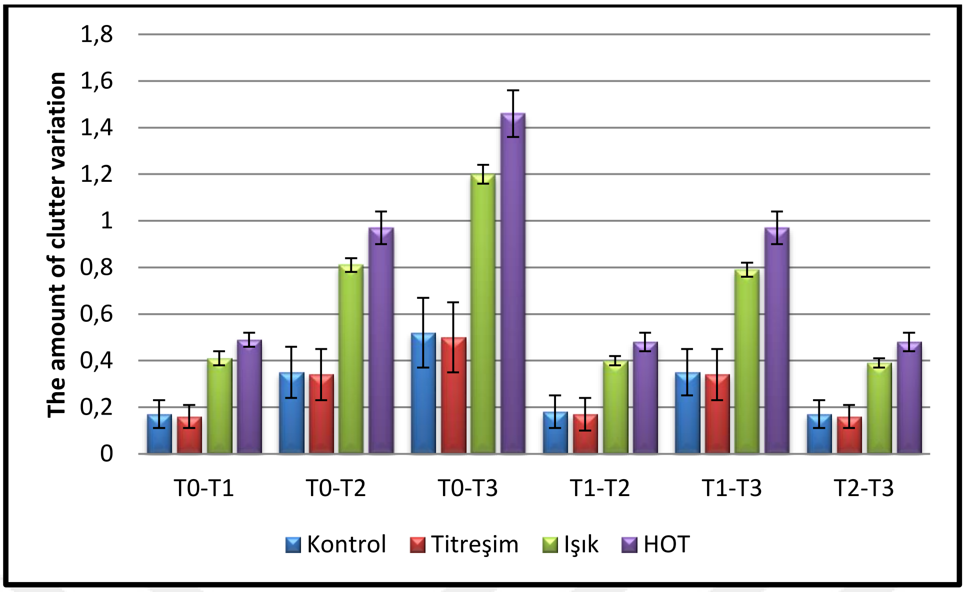

Figure 4.2. Change in crowding in T0, T1, T2 and T3 periods

There was a statistically significant difference between the groups in terms of the amount of crowding at T1 time compared to T0 (p:0.000; $p<0.05$) (Table 6). As a result of post hoc analyzes to determine which groups the significance originates from; T0- T1 crowding change amount of HOT group was found to be significantly higher than Control (p:0.000), Vibration (p:0.000) and Light (p:0.011) groups ($p<0.05$). The amount of crowding change in the Light group was found to be significantly higher than the Control (p:0.000) and Vibration (p:0.000) groups ($p<0.05$). There was no statistically significant difference between the control and vibration groups in terms of the amount of T0-T1 crowding change ($p>0.05$) (Table 7).

There was a statistically significant difference between the groups in terms of the amount of crowding at T2 time compared to T0 (p:0.000; $p<0.05$) (Table 6). As a result of post hoc analyzes to determine which groups the significance originates from; The amount of T0-T2 crowding change in the HOT group was significantly higher than the Control (p:0.000), Vibration (p:0.000) and Light (p:0.010) groups ($p<0.05$). The amount of crowding change in the Light group was found to be significantly higher than the Control (p:0.000) and Vibration (p:0.000) groups ($p<0.05$). There was no statistically significant difference between the control and vibration groups in terms of the amount of change in T0-T2 crowding ($p>0.05$) (Table 7).

There was a statistically significant difference between the groups in terms of the amount of crowding at T3 time compared to T0 (p:0.000; $p<0.05$) (Table 6). As a result of post hoc analyzes to determine which groups the significance originates from; The amount of T0-T3 crowding change in the HOT group was significantly higher than the Control (p:0.000), Vibration (p:0.000) and Light (p:0.007) groups ($p<0.05$). The amount of crowding change in the Light group was found to be significantly higher than the Control (p:0.000) and Vibration (p:0.000) groups ($p<0.05$). There was no statistically significant difference between the control and vibration groups in terms of the amount of change in T0-T3 crowding ($p>0.05$) (Table 7).

There was a statistically significant difference between the groups in terms of the amount of crowding at T2 time compared to T1 (p:0.000; $p<0.05$) (Table 6). As a result of post hoc analyzes to determine which groups the significance originates from; The amount of T1-T2 crowding change in the HOT group was significantly higher than the Control (p:0.000), Vibration (p:0.000) and Light (p:0.010) groups ($p<0.05$). The amount of crowding change in the Light group was found to be significantly higher than the Control (p:0.000) and Vibration (p:0.000) groups ($p<0.05$). There was no statistically significant difference between the control and vibration groups in terms of the amount of change in T1-T2 crowding ($p>0.05$) (Table 7).

There was a statistically significant difference between the groups in terms of the amount of crowding at T3 time compared to T1 (p:0.000; $p<0.05$) (Table 6). As a result of post hoc analyzes to determine which groups the significance originates from; The amount of T1-T3 crowding change in the HOT group was significantly higher than the Control (p:0.000), Vibration (p:0.000) and Light (p:0.008) groups ($p<0.05$). The amount of crowding change in the Light group was found to be significantly higher than the Control (p:0.000) and Vibration (p:0.000) groups ($p<0.05$). There was no statistically significant difference between the control and vibration groups in terms of the amount of change in T1-T3 crowding ($p>0.05$) (Table 7).

There was a statistically significant difference between the groups in terms of the amount of crowding at T3 time compared to T2 (p:0.000; $p<0.05$) (Table 6). As a result of post hoc analyzes to determine which groups the significance originates from; The amount of T2-T3 crowding change in the HOT group was significantly higher than the Control (p:0.000), Vibration (p:0.000) and Light (p:0.010) groups ($p<0.05$). The amount of crowding change in the Light group was found to be significantly higher than the Control (p:0.000) and Vibration (p:0.000) groups (p<0.05). There was no statistically significant difference between the control and vibration groups in terms of the amount of T2-T3 crowding change (p>0.05) (Table 7).

4.5. Evaluation of Accelerator Device and Clear Aligner Usage

Table 8: Evaluations of device usage times

Device Usage time (min)	Vibration Mean±SD (median)	Light Mean±SD (median)	HOT Mean±SD (median)	p
First term	18.77±1.48 (19.5)	19.1±1.09 (20)	18.83±1.34 (19)	0.780
Second term	18.46±1.36 (19)	18.67±1.62 (19)	19±1.17 (19)	0.338
Third term	18.5±1.39 (19)	18.86±1.35 (19)	19.09±1.12 (19)	0.283

Kruskal Wallis Test

There was no statistically significant difference between the groups in terms of first, second and third period device usage times (p>0.05).

Table 9: Correlation of device usage times and crowding changes

Group			First period of use	Second term usage period	Third period of use
Vibratin	T0-T1	r	0.150	0.003	-0.012
		p	0.465	0.989	0.953
	T0-T2	r	0.180	0.043	0.027
		p	0.380	0.835	0.896
	T0-T3	r	0.180	0.043	0.027
		p	0.380	0.835	0.896
	T1-T2	r	0.258	0.167	0.137
		p	0.202	0.414	0.506
	T1-T3	r	0.225	0.108	0.084
		p	0.269	0.599	0.683

	T2-T3	r	0.101	0.023	0.105
		p	0.624	0.912	0.610
Light	T0-T1	r	-0.072	-0.031	-0.057
		p	0.757	0.893	0.806
	T0-T2	r	0.033	0.154	0.158
		p	0.886	0.504	0.495
	T0-T3	r	0.029	0.013	0.019
		p	0.900	0.954	0.935
	T1-T2	r	0.172	0.265	0.301
		p	0.455	0.245	0.186
	T1-T3	r	0.141	0.082	0.114
		p	0.542	0.723	0.623
	T2-T3	r	0.159	-0.059	-0.047
		p	0.490	0.799	0.839
HOT	T0-T1	r	-0.192	0.247	0.269
		p	0.381	0.255	0.215
	T0-T2	r	-0.191	0.252	0.273
		p	0.382	0.246	0.208
	T0-T3	r	-0.217	0.257	0.277
		p	0.321	0.237	0.201
	T1-T2	r	-0.204	0.262	0.281
		p	0.350	0.227	0.193
	T1-T3	r	-0.242	0.267	0.285
		p	0.266	0.219	0.187
	T2-T3	r	-0.255	0.262	0.281
		p	0.241	0.227	0.193

Spearman's rho correlation test

In the vibration group, the relationship between the device usage times stated by the patients and the amount of tooth movement was examined and it was seen that there was no statistically significant relationship between them ($p>0.05$).

In the light group, the relationship between the device usage times stated by the patients and the amount of tooth movement was examined and it was seen that there was no statistically significant relationship between them ($p>0.05$).

In the HOT group, the relationship between the device usage times stated by the patients and the amount of tooth movement was examined and it was seen that there was no statistically significant relationship between them ($p>0.05$).

Table 10: Evaluations of plaque usage times

Clear Aligner usage time (hours)	Control Mean±SD (median)	Vibration Mean±SD (median)	Light Mean±SD (median)	HOT Mean±SD (median)	p
First term	20.42±1.17 (20)	20.95±0.85 (21)	20.89±0.74 (21)	20.42±1.17 (20)	0.220
Second term	20.42±0.7 (20)	21.04±0.77 (21)	20.88±0.71 (21)	20.42±0.7 (20)	0.751
Third term	20.67±0.58 (21)	20.95±0.86 (21)	20.76±0.7 (21)	20.67±0.58 (21)	0.437

Kruskal Wallis Test

There was no statistically significant difference between the groups in terms of first, second and third period clear aligner use ($p>0.05$).

Table 11: Correlation of plate usage times with the amount of crowding change

			First term usage time (hours)	Second term usage time (Hours)	Third term usage time (Hours)
Control	T0-T1	r	-0.211	-0.060	-0.426
		p	0.386	0.806	0.069
	T0-T2	r	-0.111	-0.063	-0.323
		p	0.651	0.799	0.177
	T0-T3	r	-0.098	-0.147	-0.337
		p	0.689	0.549	0.159
	T1-T2	r	0.050	-0.060	-0.112
		p	0.839	0.806	0.647
	T1-T3	r	-0.079	-0.160	-0.320
		p	0.749	0.513	0.182
	T2-T3	r	-0.034	-0.226	-0.323
		p	0.891	0.353	0.177
Vibrati on	T0-T1	r	-0.036	-0.127	-0.063
		p	0.861	0.536	0.759
	T0-T2	r	-0.061	-0.130	-0.058
		p	0.769	0.525	0.779
	T0-T3	r	-0.061	-0.130	-0.058
		p	0.769	0.525	0.779
	T1-T2	r	-0.113	-0.140	-0.053
		p	0.583	0.496	0.796
	T1-T3	r	-0.089	-0.139	-0.057
		p	0.665	0.499	0.782
	T2-T3	r	-0.166	-0.001	0.088
		p	0.417	0.995	0.668
Light	T0-T1	r	0.089	0.278	0.171
		p	0.702	0.223	0.459
	T0-T2	r	0.144	-0.003	-0.195
		p	0.534	0.991	0.397
	T0-T3	r	0.057	0.014	-0.253
		p	0.807	0.951	0.268
	T1-T2	r	0.126	-0.305	-0.423
		p	0.585	0.179	0.056
	T1-T3	r	0.026	-0.231	-0.415
		p	0.910	0.314	0.062
	T2-T3	r	-0.013	0.038	-0,156
		p	0.956	0.871	0.500
HOT	T0-T1	r	0.410	0.241	-0.082
		p	0.052	0.269	0.711
	T0-T2	r	0.410	0.241	-0.082

	p	0.052	0.269	0.711
T0-T3	r	0.402	0.241	-0.090
	p	0.057	0.269	0.685
T1-T2	r	0.419	0.241	-0.074
	p	0.047*	0.268	0.737
T1-T3	r	0.410	0.241	-0.082
	p	0.052	0.269	0.711
T2-T3	r	0.419	0.241	-0.074
	p	0.047*	0.268	0.737

Spearman's rho correlation test **p<0.05*

Control group: The relationship between the duration of clear aligner use by the patients and the amount of tooth movement was examined and it was seen that there was no statistically significant relationship between them (p>0.05).

In the vibration group, the relationship between the duration of clear aligner use by the patients and the amount of tooth movement was examined and it was seen that there was no statistically significant relationship between them (p>0.05).

In the light group, the relationship between the duration of clear aligner use by the patients and the amount of tooth movement was examined and it was seen that there was no statistically significant relationship between them (p>0.05).

In the HOT group, there was a positive, moderate (41.9%) and statistically significant relationship between the first period of plaque use and the amount of T1-T2 crowding changes (p:0.047; p<0.05). There was a positive, moderate (41.9%) and statistically significant relationship between the first period of clear aligner use and the amount of T2-T3 crowding change (p:0.047; p<0.05).

Relationship between the duration of device use by the patients and the amount of tooth movement at other times was examined and it was seen that there was no statistically significant relationship between them (p>0.05).

Table 12: Correlation of plaque usage times and device usage times

	Device usage time (min)		First period record usage time (hours)	Second period record usage time (Hours)	Third period record usage time (Hours)
Vibration	First semester	r	0.329	-0.025	-0.285
		p	0.101	0.904	0.159
	Second term	r	0.244	-0,150	0.073
		p	0.229	0.465	0.723
	Third term	r	0.091	-0.082	0.297
		p	0.657	0.690	0.141
Light	First semester	r	0.110	-0.255	0,000
		p	0.636	0.266	1,000
	Second term	r	0.233	-0.426	0.038
		p	0.310	0.054	0.871
	Third term	r	0.179	-0.349	0.045
		p	0.437	0.121	0.846
HOT	First semester	r	-0.112	-0.117	-0.001
		p	0.612	0.596	0.996
	Second term	r	-0.076	-0.119	0.030
		p	0.731	0.590	0.893
	Tthird term	r	-0.062	-0.009	0.026
		p	0.779	0.969	0.908

Spearman's rho correlation test

In the vibration group, There was no statistically significant relationship between the duration of plaque usage and device usage time stated by the patients ($p>0.05$).

In the light group, There was no statistically significant relationship between the duration of plaque usage and device usage time stated by the patients ($p>0.05$).

In the HOT group, There was no statistically significant relationship between the duration of plaque usage and device usage time stated by the patients ($p>0.05$).

5. DISCUSSION AND CONCLUSIONS

5.1 Discussion of Purpose, Samples and Methods

The aim of our study was to investigate the accelerated tooth movement of crowded mandibular incisors in patients treated with clear aligners by using vibration and photo biomodulation methods and the combined use of these methods retrospectively. In addition, in our study, invasive or systemic conservative, non-invasive and patient alternatives to methods that can affect patients It can be easily accepted by the patient, its effect for the desired period of time during the treatment. It is aimed to develop a sustainable method and incorporate it into clinical practice.

Fink et al. and Fisher et al. If we examine the studies on the duration of orthodontic treatment, comprehensive orthodontic treatments take about 2-3 years[52]. Treatment time length is challenging for both patients and clinician, it is a factor that negatively affects the motivation of the patient both at the start of the treatment and during the treatment[54,55]. Therefore, clinical researchers working in orthodontics They focus on studies on methods that will shorten the treatment period. [52]

If we evaluate the factors affecting the speed of orthodontic tooth movement; applied orthodontic mechanics and used in addition to the materials used in the treatment, the speed of the biological response is one of the main factors affecting the duration of treatment. The biological response, studies conducted to increase the speed of orthodontic tooth movement observed during by shortening or eliminating the lag phase characterized by hyalinization, it aims to create the cycle of production and destruction in tissues, or in other words, osteoblastic and osteoclastic activity earlier. When bone resorption, which is thought to be mainly due to osteoclastic activity, accelerates tooth movement also increases. It is accepted that it accelerates this activity, and studies are carried out to accelerate this activity [40]. At the same time, this field of study still maintains its popularity because it is very important in terms of patient expectation.

Since bone tissue responds with the action-reaction principle like all other biological tissues, it adapts again by being shaped as it is exposed to forces. Clinton et al [167]. It was revealed in their study in 2001[167]. Appropriate It has been suggested that mechanical pressures applied in large amounts can accelerate bone remodeling and anabolic response [26]. Tooth movement speed of mechanical stimulation It has been studied extensively by various researchers until today in order to examine its effect on A lot of work has been done [117,121,122,124,125]. In fact, meta-analyses and systematic reviews have also been made specifically in this area [168]. The first research on lasers was produced by Maiman [127] in 1960, very intense, A beam of coherent photons developed to produce coherent and monochromatic light. form optical devices [43]. In the laser application, the intensity of the energy applied on the tissues and depending on the application time, various effects occur in the tissue. The effects observed with a regional temperature increase of less than 1°C in the tissues are called biological stimulants, that is, bio stimulant effects. This bio stimulant effects are low-dose laser therapies [169]. Laser In addition to the bio stimulant effects of its applications, osteoclast, osteoblast and The properties of stimulating the proliferation of cells such as fibroblasts were also determined [129,170]. By researchers working in this field, laser applications Many studies have been conducted examining the effects on tissues and tooth movement speed [129,131,135,141]. Apart from laser, vibration is also used in clinical applications that are claimed to shorten the treatment time. The devices generate vibrations with a frequency of 30Hz and a force of 0.25 Newtons, and it is recommended to use them for 20 minutes a day. This vibration value is approximately eight times smaller than the vibration values of an electric toothbrush.

Similarly, the devices on the market with the same claim emit 9.5J/cm2 LED light at a wavelength of 850 nm, and it is recommended to use them for 10 minutes a day. Based on this information, in our study, the effects of using devices that vibrate at a frequency of 30 Hz with a force of 0.25 Newton, LED light devices that emit 9.5 J/cm2 of energy at a wavelength of 850 nm, and HOT devices that combine the two applications for 20 minutes a day were evaluated.

In our study, patients with moderate crowding were included according to Little's crowding level, and while the non-extraction orthodontic treatment protocol was followed, the changes in the amount of crowding were followed during the treatment of lower incisors with clear aligners. The treatment was taken to ensure that there were no missing and/or excess teeth in the dental arch. Tooth In case of deficiencies, the movement of existing teeth to the edentulous area may be easier or in the upper jaw. If there is a deficiency, the lower teeth that are not in occlusion can move more easily. At the same time, if a long time has passed since the extraction, there may be difficulty in tooth movement because there will be an hourglass defect. Since difficulties may occur due to this lack of movement area in patients with excess teeth, and patients with missing and/or excess teeth to strengthen standardization were not included in our study.

Since patients with moderate crowding were included in our study, there was no need for an extraction treatment protocol in patients. At the same time, patients requiring extraction treatment were not included in our study, as the rate of destruction in the extraction region may be different due to extraction, and this would adversely affect the standardization of the treatment rate parameter. In extraction treatments, full measurements are usually required for the evaluation of parameters such as inclination and rotation due to canine distalization. These evaluations can usually be measured with overlaps in teeth where movements such as rugae and molars are not planned.

Inclination and rotations do not affect the measurements when measuring the amount of crowding during the leveling phase in non-extraction cases. Therefore, another reason why our study was studied with patients whose non-extraction treatment protocol was followed is that our study was not suitable to be designed as a split-mouth. Devices that provide vibration and light applications A separate study group was formed for each different application, since it is thought that when applied to one half of it, the other side may be affected, and this may affect the results.

In addition, another reason for working with patients with non-extraction treatment protocol was our prediction that patients who would meet these criteria would be more numerous than those who would receive extraction treatment. In our study, patients with moderate crowding were observed in the aligner change phase in their treatment with clear aligners while it was investigated. The reason for selecting patients with moderate complexity is such as extraction therapy or stripping for the treatment of patients with crowding the need for applications that will affect the results of our study, low In patients with a high level of crowding, the crowding resolves before the end of the study. the continuity of the work will be hindered.

The reason for working on the lower incisors in this study is that due to the lower incisors being smaller than the upper incisors, they will show more significant changes in the leveling phase [171]. But for aligner treatments, it is difficult to move them because they are too small by covered with aligners. The reason why we used Little's crowding index in our study is that it is a simple and proven method, and measurements can be made easily with this method. Pandis et al. [172] in the study they conducted in 2007, the amount of leveling of the crowded lower incisors

Kau et al. [140] was measured using Little's crowding index and this method was evaluated by comparing the clinical efficacy of different bracket types on tooth leveling. In their study conducted in 2013, they examined the effect of the photo biomodulation method on the speed of tooth movement. Like our study, the differences between the amount of leveling of the incisors were compared using Little's crowding index [140].

In our study, the changes in the first 6 aligners were evaluated in the treatment of crowding changes in the lower incisors in individuals treated with clear plaques. The first 2 plaques were delivered to the patients with the placement of the necessary attachments in the treatment planning prepared after digital planning on the lower jaw teeth of the patients.

In the follow-up, the devices to be used for acceleration were delivered to the patients together with the aligners, with the next 2 plates to be changed every 10 days and finally once a week. Our study was included in the study since the beginning of the study, and our study was evaluated with detailed records based on a total of 62 days of follow-up, including the 28th day, the 48th day and the 62nd day. The reason why our study continued for 62 days is to ensure that there are interim recording stages that allow observing the differences that may occur during leveling, and to ensure that the study is completed while all patients are still in the leveling phase. In the literature, until the leveling ends with fixed treatments, patients There are also studies that continue to be followed [173]. In these studies, the end of the leveling is either reported to the clinician by the patients or determined and evaluated by the clinician in the next sessions of the patients. There may be differences between the evaluations of the crowding index in the studies that he informs, and in studies where the leveling is controlled by the clinician, the time elapsed between sessions causes errors in the determination of speed tooth movement. For this reason, our study was limited to the use of clear aligners by patients for 62 days. Our patient group included in our study consisted of a total of 89 patients, 51 female and 38 males, between the ages of 18-30. The mean age of the patients was determined as 23.16±3.55. In the criteria for including individuals in the study; may affect orthodontic tooth movement. absence of any systemic disease, no medication during the study no treatment was taken not to use it, to not have received orthodontic treatment before, and to have good oral hygiene.

The patient inclusion criteria of our study were similar to those in studies in which the speed of tooth movement was measured in the other leveling stage with fixed mechanics. complies with the criteria [140,172,173]. In our study, 3 different types of appliances were used on the patients. appliance they started to apply the appliances every day during the delivery, and They were given a scoreboard on which they would write down the hours they finished. They were asked to note the times they put the records in and the hours they took out in the same scoreboard. Delivery of appliances to patients the reason for this is the ease of use for the patients and to eliminate the problems that will be created for clinician and the patients by calling the patients to the clinic for 20 minutes of practice every day. It is aimed to observe the amount of use and to motivate regular use with the scoreboard delivered to the patients.

Kau et al[140] in a clinical study in which they examined the effect of photo biomodulation on tooth movement speed, they had patients use an extraoral device in different amounts

During this application, 2 of the patient groups came to their clinics every day and 1 of them came to their clinics once a week. However, since the use of clear aligners also requires cooperation, in our study, it would be very difficult to find patients who would agree to come to our clinic every day for 62 days, and it would be difficult for the clinician. For this purpose, clear aligners, two of each, were delivered to the patients with an acceleration device, except for the control group, and the scoreboard system was applied.

Grove et al.[121174] orthodontic forces together with vibration application. In their study, in which they examined the effect on resorption, the patients were given vibration-providing mobile devices and they were asked to use them regularly every day. has been requested. In order to encourage patients to use the appliances, patients should study. informed by the attending clinician.

A similar study conducted by Tan[174] in the study, the appliances that apply vibration were delivered to the patients, and the patients in order to control and motivate patients, the patients were called by phone every day. In our study how regularly, the appliances used by the patients are used by the patients, it is not known whether they use the appliances in the amounts stated in the scoreboard. In this regard, the patient statement included in the scoreboard in the archive records is taken as basis. This is a limitation of such studies. Vibration device used in our study to accelerate orthodontic treatment is 0.25 Newton at a frequency of 30 Hertz. It creates a vibration with a magnitude of force. In our study, these values the effect of using the vibrating device for 20 minutes a day was evaluated.

Investigating the effects of vibration on bone formation-resorption cycle, tooth, and tooth movement speed. Experiments with different Hertz and forces in different application times in studies has been made. Rubin et al. [108] evaluated the effect of 90 Hz

0.25 g vibration in 10 minutes a day in their study on rats in 2001 . in 2003 by Kopher and Mao [117]. In the study carried out on rabbits, 10 vibrations with a force of 5N at a frequency of 1 Hz Mao and Nah[116] examined the difference between the effect created by vibration in 20 minutes at a force of 2 N and the static force at the same force.

Gilsanz et al. by[110] In the clinical study carried out, the patients were treated with 30 Hz, 0.3 gr vibration for 10 minutes a day. has applied. Omar et al. [113] mechanical stimuli carried out by the bone In an animal study examining its effect on healing, vibration at a frequency of 30 Hz per day for 20 minutes; Goodship et al [112]. in another animal study, 0,25 N vibration at 30 Hz frequency was applied for 17 minutes a day.

Grove et al. [121] The vibration applied at 113 Hz frequency for 10 minutes a day, Kau et al. [120] and Tan [174] vibration with a force varying between 0.2 and 0.3 Newtons at a frequency of 30 Hz for 20 minutes a day; Woodhouse et al. [124] examined the effects of applying the same vibration for 20 minutes a day on the teeth.

Kalajzic et al. [126] at 30 Hz and 0.4 N force vibration with an animal experiment in which they applied the vibration twice a week for 10 minutes. investigated its effect on bone remodeling.

Pavlin et al. In 2005, they performed a randomized clinical trial using Acceledent with 30 Hz 25 N force during canine retraction in 45 patients aged 12-40 years, for 20 minutes a day [123.]

Woodhouse et al. 2015 [124]For arch alignment on 81 patients, Miles et al. 2016 [175] In their study for arch alignment on 40 patients in the same year, they applied 30 Hz 25 N force for 20 minutes. Lombardo et al applied 30 Hz 25 N force in the aligner treatment in 45 patients in 2019. [176] Similarly, DiBiase et al. used a device containing 30 Hz and 25 N force in the treatment of aligners in 81 patients in 2018. [177]

LED light with a wavelength of 850 nm and an energy of 9.5 J/cm 2 was used. Like the studies conducted with different vibration values when examining the effect of mechanical stimulation, different wavelengths of rays were used for different durations in studies examining the effect of low-level laser therapy on tooth movement speed in the literature

Trelles and Mayayo [178] investigated the effect of light with a wavelength of 632nm and an energy of 2.4 J on bone healing. Ozawa et al. [130] at a wavelength of 830 nm. In their studies on the effects of 500mW light on the calvarial bones of rats. they examined.

Altan et al. 820 nm 100mW in histological evaluation of rats in 2012 (psoriasis 160) They carried out a study comparing the effects of using different amounts of Ga-Al-As diode laser light of power.

Cruz et al reported orthodontics of low-level laser and its effect on human teeth for the first time in 2004 [128]. examined; 780 nm wavelength of 20mW beam in different amounts to create 5 J energy. they have applied.

Demidova-Rice et al [139] conducted on rats in the study, the powers of the rays at 635nm, 670nm, 720nm and 820 nm wavelengths were compared. In the study, the wavelength of 820 nm was the most effective in wound healing and bone turnover. It was concluded that it was an effective amount. Coherent at the same wavelength in the same study Light-emitting laser source and non-coherent LED sources are compared with each other. As a result of the study, there is no significant difference between the laser beam source with the same wavelength and the LED source in terms of efficiency found to be absent.

Kau et al. [140] at 850nm wavelength in 2013 for orthodontic alignment Different types of LED light are 20 minutes a day, 30 minutes a day, and 60 minutes a week. The effects of its use on orthodontic tooth movement were compared with the control group of their work As a result of the study, the effects of use at different times were not compared with each other. In general, there were no significant teeth in the experimental group, divided into control and experimental groups. acceleration of movement has been reported.

In our study, two clear aligners were used, respectively, once in 14 days in T0-T1 period, once in 10 days in T1-T2 periods, and once in 7 days in T2-T3 periods. In our study, movements were planned as 0.25 mm in the anterior-posterior direction, 2 degrees of rotation, and extrusion and intrusion 0.1 mm in the clear aligners, respectively. The amount of movement in the teeth during orthodontic treatment, anchorage losses, Angulation and inclination changes can be measured by different methods. First of all, radiographic methods can be used, but this method was not used because radiological interventions would not be ethical in the patient so recently. Second clinical measurements can be made, but this method was not preferred because of its high margin of error. In our study, all measurements were made on the obtained plaster models. measurements can be made, easily archived and at the same time the margin of error can be reduced [179].

Limpanichkul et al. [136] low level laser Sebastiana [180] in the study in which they examined the effect of orthodontic tooth movement on orthodontic tooth movement. In a clinical study examining the effect of different wires on tooth leveling speed, Pandis et al. [172]. The effects of different brackets on the leveling of lower incisors crowding. in the study they examined; measurement on plaster models similar to our study they have done.

In her thesis study, Hepdarcan conducted in 2016, LED light at 850 nm wavelength was used for Photo biomodulation, a device that applies 30 Hz 25 N vibration for vibration, and a HOT device containing a combination of both values. These values match exactly with our parameters[181]

5.2. Discussion of Findings

Light and vibration by itself did not make a significant difference in accelerating the movement on the tooth movement speed application does not make a difference in increasing the speed of tooth movement; This is because the HOT application, in which light and vibration are combined, increases the speed of tooth movement.

There are many studies in the literature examining the effects of vibration application on bone metabolism and orthodontic tooth movement speed [108,115,117,124]. Some of these studies on orthodontic tooth movement are studies on animals, especially on rats [117–119,125], and some of them are cases with no control group and only vibration. Reports [120,182], some of them affect tooth movement biochemically and histologically. There are major differences from our study, since they are studies examining psoriasis [121,122]. they show. Pavlin et al. [123] and Woodhouse et al. by [124] The studies carried out are not related to our study in terms of being clinical studies. they show similarity. Pavlin et al. [123] in the study in which they examined tooth movement during canine distalization on first premolar extraction treatment mechanics, the tooth movement rate of vibration application. showed a significant increase. In our thesis, control the difference between the amount of change obtained in 62 days in the vibration group and the vibration group is not statistically significant. However, it is clinically significant. This study differs from our study in terms of the age range of the patients, the treatment protocol applied, the stage in which the treatment was followed, and the measurement methods. In our study, the age range was 18-30, and in the study, it was between 12-40. While our study observed the first stages in patients who received non-extraction orthodontic treatment in individuals without missing teeth, the amount of distalization performed with mini screw anchorage after initial leveling in patients with premolar extractions. Finally, the difference between the measurement methods can be shown as the reason for the different findings. In our study, plaster models were created with the intraoral measurements taken from the patients, and measurements were made on these models. Pavlin et al. [123] the measurements were made directly in the patient's mouth during the sessions. Woodhouse et al.[124] similar to our study, it was concluded that there was no significant difference in the vibration application on tooth movement speed. The groups, which were found to have no significant difference in the amount of crowding at the beginning according to Little's crowding index, were followed up until the end of the leveling. Like our study, models were obtained from the measurements taken and measurements were made. The crowding values were compared with the measurements taken at the end of the 6th week and the measurements taken at the beginning of the treatment. Moreover time comparison by looking at how many days the leveling was completed in total has been made. There was no difference between the groups in the correction of confusion and in the leveling period. Similar to our study, no significant difference was found.

Lombardo et al. similar to our study, they applied vibration applied with 30 Hz 25 N force for 20 minutes a day in their studies on 45 patients aged 14-45 years, performed in 2019, with clear aligners similar to our study. As a result of the study, they could not find a statistical difference between the control group and the vibration group, similar to our study. This similarity is due to the fact that we have the exchange protocol at similar times.[176]

Dibiase et al. [124] In 2018, in their studies on 81 individuals under the age of 20, in which 20 minutes of 30 Hz 0,25 N force vibration application was evaluated in the distalization of the canine with fixed mechanics, they could not find a statistical difference between the control group and the vibration group, similar to our study. They also stated that there was no effect on the total treatment time. This similarity is due to the use of vibration application at the same value and duration.

Katchooi et al.[183] 30 Hz and 0,25 N vibrations were applied to the patients for 20 minutes in their study conducted with clear aligner on 27 individuals in 2018. As a result of the study, there was no statistically significant difference between the control group and the vibration group, similar to our study. This similarity is due to the fact that plaques change rapidly, and teeth adapt quickly to plaques. [176].

In our study, when the effects of light application on tooth movement speed were compared with the control group, clinical acceleration was observed in tooth movement. Although there are many studies in the literature observing the effect of light application on bone metabolism and speed of tooth movement, some of these studies are biochemical and histological studies [129,137,170]some are animal experiments [131,135,170] and some are culture studies at the cellular level. [130] differ from our study.

Cruz et al. executed on clinical trial similar to our study [128], In this study, the effects of light application as a *split mouth* on 11 patients for 4 days at 20 mW 5 J/cm2 energy level for 10 seconds with 780 nm laser were investigated over the amount of distalization of the canine. In this study, which was planned with a two-month follow-up, at the end of 60 days, 4.39±0.27 mm tooth movement was observed on the low-level laser application side, similar to our study, while a lower tooth movement of 3.30±0.24 mm on the control side has been recorded. As a result, there was a 34% faster tooth movement on the light-treated side. The values recorded in this study are the teeth in our study. is higher than the amount of movement in both control and light groups. The reason for this may be that the tipping movement that may occur during the distalization of the canine creates the impression of more tooth movement. However, although the values differ , the results of the study are similar and parallel to our study.

Youssef et al. [134] They applied laser light at 809 nm, 100 mW energy level in their study with 15 patients on the 0th, 3rd, 7th and 14th days. In their study, in which they also evaluated the pain level simultaneously, more tooth movement was observed on the side where the laser application was made. This aspect is similar to our study [134]. Genc et al. Gallium-aluminum-arsenide (Ga-Al-As) diode laser application at 20 mW 0.71 J/cm2 energy level was performed on the 0th, 3rd, 7th, 14th, 21st and 28th days. Similar to our study, more tooth movement was observed on the light application side compared to the control group [132]. Sousa et al. In their study with 10 patients in 2011, they observed faster tooth movement on the light-applied side, similar to our biizm study, in the application of 780 nm, 20 mW, 10 sec, 5 J/cm2 laser in cases where the gap was closed with NiTİ spring. Doshi-Mehta and Bhad-Patil [133] conducted with 20 patients. In *split mouth studies* by researchers, low-level laser studied the effects of radiation. In both studies, there was a significant difference in tooth movement speed with laser applications, similar to our study. increase has been noted. Canine distalization carried out as a *split mouth* Although there are methodological differences due to the fact that they are studies, these studies and our There is a similarity between our study in terms of findings. Since the device we applied was not suitable for the split mouth design, the study was planned by increasing the number of samples.

Kau et al. [140] similar to our study, in their study including 90 patients, which they planned as a multicenter clinical trial in 2013. The effects of LED light at a wavelength of 850 nm on the orthodontic tooth movement speed were investigated. in hand According to their results, 0.49 mm tooth movement was observed in 7 days in the control group, In the study group, this value was reported as 1.12 mm. As a result of these values, light can be used to accelerate orthodontic tooth movement. They concluded that the application had more than 100% effect. These results are in agreement with our study. The reason for the high amount of acceleration used [140]. In the study, there was no significant difference in the amount of crowding between the groups at the beginning. may not find a difference. This high difference observed at the beginning of the tooth movement between groups The amount may be a factor affecting the difference.

Farhadian et al [184] used 40 mW/cm2 LED light at 640 nm wavelength for 5 minutes a day in their study on 60 patients. In the other group, 100 Mw/cm2 Laser light with a wavelength of 810 nm was applied. While an increase of 60.8% was observed in the laser group in the laser group, an increase of 26% was observed in the LED group compared to the control group. These findings are in parallel with our study. We think that the reason why the LED group is lower than the laser group is due to the lower wavelength of light used.

Goymen et al. [185] In their study in 2019, the first group 810-nm GaAlAs laser was applied at [8] J/cm2 at 0, 3, 7, 14, 21, and 28 days. In the second group, 20 mW/cm2 LED light with a wavelength of 850 nm was applied. The third group was the placebo-administered control group. As a result of the study, it was stated that both laser and LED light increased orthodontic tooth movement, and there was no difference in terms of root resorption. The findings of this study are similar to our study.

Rapid Orthodontic Treatment in our study devices that we refer to as HOT devices using the initials of in orthodontic treatments performed with the aid of tooth movement, there was no significant difference in tooth movement compared to the control group. showed a difference and tooth movement occurred faster. This finding indicates that HOT devices an alternative method among the methods that will accelerate orthodontic treatments in the future It can be included among the non-invasive methods. Corticotomy, which is frequently applied and very popular today, and when the studies examining the effectiveness of piezocision applications are evaluated tooth movement speed between light application and HOT application and surgical applications It is seen that there is a similarity in terms of effects on

Hepdarcan in her thesis study compared with the control group, the average tooth movement with light was 66%, She stated that there was an average increase of 105% in tooth movement with HOT application. In our study, a clinically significant difference was observed in the HOT group. [181]

Corticotomy and some of the studies examining the effectiveness of piezossion applications canine distalization in the thesis study by Gün [74] In the evaluation, a total of 3.11 mm in the piezoscision group, which was applied surgically in 10 weeks, It is seen that 2.11 mm tooth movement was reported in the control group. This is of serious clinical importance.

Azimova (103) In the thesis study conducted by, 3 transmucosal decortication procedures with a depth of 3 mm were performed on the working side with a manual drill bur in the experimental setup created as a split mouth. Again, this is clinically important.

Alikhani et al. [79] examined tooth movement speed with micro-osteoperforation procedure in 20 adult individuals with class II division 1 malocclusion. As a result of the study, they showed that their application accelerated the movement speed by 2.3 times. Light and HOT applications and surgical methods are quite different from each other in terms of application and effect. Corticotomy, piezoscision, while methods such as decortication are surgical methods that require anesthesia, light and HOT applications There is no surgical intervention, it only requires cooperation. Regional acceleration phenomenon in surgical methods It continues for a certain period of time after the procedure and then takes effect. may lose. These methods, which are similar in terms of effectiveness but quite different in terms of application, can be selected by recommending them according to the patient. Both methods are suitable It can be used as an alternative to each other by being preferred according to the patients. In our study, the use of appliances declared by the patients in all groups When the durations of the appliances are evaluated, between the groups no significant difference was observed. Usage times for both appliances and acceleration devices. There is no difference between the three times intervals in terms of usage. not reached. With this information, the duration of use stated by the patients and the dental amount of movement was also compared and there was no significant relationship between the declared period of use and the amount of tooth movement. This may be due to the fact that the differences between the specified periods of use are too small to cause a change in the amount of tooth movement, or that the patient makes an incorrect statement because it is based on the statements of the patients.

Pauls et al. [186] in the study they conducted in 2013, with the help of a microsensor in which the patients included the time they used the appliances delivered to them and the time they declared that they used it. they compared. In the study, patients were asked to use their appliances for 15 hours a day. has been said. Patients who do not know that this device is in the appliance Significantly higher than actual usage amounts when asked about usage times declared use. This situation will not make much difference in accelerators with a short usage time, but it can make a serious difference for clear aligner that require 22 hours of use. However, the data in this study were included in the evaluation based on patient statements. Similar studies have been done for headgear use or other removable appliances.

In a study examining the increase in the use of headgears from devices delivered to patients by conscious hypnosis,30 patients received headgears with a sensor that monitors their usage time given [187]. Patients to note the duration of use during the study requested; As a result of the study, the declared periods and the actual usage amounts are also determined. have been compared. A low correlation was observed between the two values. However, these sensors were not added because they are large and would have a biased effect on the addition to the clear plates. Both Pauls et al. and Trakyalı et al. The mean age in their studies is very low compared to our study. We think that this difference has arisen in other patients for this reason age in their work averages are lower than in our study. With the increase in age, the cooperation of the patients an increase can be expected [188].

In 2009 Daniels et al. [189] In a study among parents and children, it was reported that parents were more motivated than their children for the treatment of their children. This does not support our suggestion regarding the motivational relationship with age.

When there is more crowding in our study, more teeth It was not evaluated whether movement was seen in clear plates, because the movements were as planned and limited per plate. Clinically significant accelerating effect on tooth movement with future studies. The effects of photo biomodulation and HOT applications on bone metabolism can be investigated with biochemical markers. In addition, three effects on bone density More detailed information on the subject can be obtained by examining it in detail with CT. Similarly, These applications can also be examined on pain. The value of the vibration application can be increased, or the light used in the light application can be used in different times and with a wave of 850nm. different wavelengths to compare the effects of different wavelengths than Their use in different sizes and durations can be investigated. It can also be clinically evaluated whether similar results can be achieved with accelerator devices by reducing plaque usage times. In addition, by measuring how long both the plates and the appliances are used, which are placed inside the appliances and supported by a software, the studies to be carried out on the subject can be supported by supporting them with more concrete data.

5.3 Conclusion

- In this study, the vibration application at the time and frequency applied in the orthodontic teeth made with clear aligner. It is not effective in accelerating tooth movement.
- In this study, the duration and wavelength of light applied to the orthodontic teeth made with clear aligners It is an effective method of accelerating tooth movement.
- The HOT application, in which vibration and light are used together, is an effective method in accelerating tooth movement with clear aligners.

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7. APPENDICES

7.1 Ethical Comittee Approval

T.C.
MARMARA ÜNİVERSİTESİ
Diş Hekimliği Fakültesi
Klinik Araştırmalar Etik Kurulu

Projenin Adı: Alt Keser Çapraşıklığı Olgularında Şeffaf Plaklarla Yapılan Ortodontik Tedavilerde Işık ve Titreşimin Tedavi Süresi Üzerine Etkisinin Geriye Dönük İncelenmesi

Proje yürütücüsü: Prof. Dr. Didem Nalbantgil

Projedeki Araştırıcılar: Dt. Mustafa Özcan

Onay tarihi ve sayısı:30.06.2020, 2020/50

Sayın: Prof. Dr. Didem Nalbantgil

2020-425 Protokol nolu "Alt Keser Çapraşıklığı Olgularında Şeffaf Plaklarla Yapılan Ortodontik Tedavilerde Işık ve Titreşimin Tedavi Süresi Üzerine Etkisinin Geriye Dönük İncelenmesi" isimli retrospektif çalışmanız Marmara Üniversitesi Klinik Araştırmalar Etik kurulu tarafından incelenmiş ve etik yönden uygunluğuna karar verilmiştir.

Adı Soyadı
Prof. Dr. Nimet Gençoğlu
Prof. Dr. İlknur Tanboğa
Prof. Dr. Ali Recai Menteş
Prof. Dr. Yaşar Özkan
Prof. Dr. Ahu Acar
Prof. Dr. Zühre Hale Cimilli
Doç. Dr. Buket Evren
Prof. Dr. Şebnem Erçalık Yalçınkaya
Prof. Dr. Filiz Onat
Dr. Zerrin Kurşun
Prof. Dr. Afife Binnaz Hazar Yoruç
Dr. Öğr. Üyesi G. Hale Özcömert Coşkun
Dr. Öğr. Üyesi Gediz Kocabaş
Dr. Öğr. Üyesi H. Selin Yıldırım
Nuri Sertaç Sırma (sivil üye)

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7.2 CURRİCULUM VITAE

Personal Information

Name	Mustafa	**Surname**	Özcan
Place of Birth		**Date of Birth**	
Nationality	TUR	**TR ID Number**	
E-mail		**Phone number**	

Education

Degree	Department	The name of the Institution Graduated From	Graduation year
Doctorate			
Master	Digital Orthodontics	**Messina University**	2022
University	Dentistry	**Yeditepe University**	2014

Scientific works

Ozdemir D, **Ozcan M**, Bektaş D, Işıker M, Atmaca T. Factors That Effected Oral Hygiene in kids: A fields study. 3rd.National 1st International YUDBAT Congress, Istanbul, Turkey (Oral Presentation)
Fişekcioğlu E, **Ozcan M**, Eroğlu O, Uzrek B,Uzuner S, Öztürk A, Saatçioğlu Ş. The evaluation effects of Antidepresan and Antihipertansive drugs on patients saliva and primary caries. 3th National 1st International YUDBAT Congress, Istanbul, Turkey (Oral Presentation)
Oktay İ, **Ozcan M**,Sara B, Eroglu O, Uzuner S, Cansızoğlu M, Turan B, Bektaş D. The Evaluation of the OHIP Before and After Treatment in University Students in Different Branches of Dentistry,3th National 1st International YUDBAT Congress, Istanbul, Turkey (Oral Presentation)
Ülkür F, Ozdemir F, **Ozcan M**, Uzrek B, Uzuner S. The Evaluation of the relationship between the measurements taken from initial and final orthodontic models and duration of treatment among orthodontic patients at Yeditepe University Faculty of Dentistry. 3th YUDBAT National 1st International Congress, Istanbul, Turkey (Oral Presentation)
Ozcan M, Ulkur F, Kaspar C. Comparison of measurements on plaster and digital models used in orthodontic model analysis. 9th International Medical Students' Congress in Novi Sad (IMSCNS). 2014, Novi Sad, Serbia (Oral Presentation)

Küçük B, Güler N, Efeoğlu F, **Ozcan M.** Stress and Bruxism Relationship among Dental Students, 4th National 2nd International YUDBAT Congress, Istanbul, Turkey (Oral Presentation)
Ozcan M, Dikmetaş B, Dogan H,Germec D, Ozdemir F. The comparision of case based and lecture-based learning efficacy in undergraduate dental students with different personality traits. XVth International Congress of Turkish Orthodontic Society 2016 Antalya Turkey (Poster Presentation)
Ozcan M, Ulkur F, Kaspar C. Comparison of measurements on plaster and digital models used in orthodontic model analysis. XVth International Congress of Turkish Orthodontic Society 2016 Antalya Turkey (Poster Presentation)
Ozcan M,Uzuner S, Tozlu M. Evaluation of the preference of patients for rapid orthodontic tooth movement,XV. International Symposium of Turkish Orthodontic Society 2017 , Ankara, Turkey. (Poster Presentation)
Ozcan M, Uzuner S, Tozlu M. Comparision of Linear Measurements on Facial Morphologies of 3dMD and Cerec Smile Design Pictures. XV. International Symposium of Turkish Orthodontic Society 2017 , Ankara, Turkey. (Oral Presentation)
Nalbantgil D, Sirman S, **Ozcan M**, Akın E. Assessment of the Effects of Facemask Theraphy from Parents' Perspective.XV. International Symposium of Turkish Orthodontic Society 2017 , Ankara, Turkey. (Poster Presentation)
Ozcan M, Uzuner S, Tozlu M. Evaluation of Patients Preference for Aligner Therapy, 2nd European Aligner Society Meeting 2017, Venice, Italy. (Oral Presentation)
Nalbantgil D, Sirman S, **Ozcan M**, Akın E. Assessment of the Effects of Facemask Theraphy from Parents' Perspective. 94th EOS Meeting 2018,Edinbrugh, UK. (Poster Presentation)
Ozcan M, Uzuner S, Erten O,Tozlu M. Evaluation of the Preference of Patients for Custom Digital Orthodontics or Conventional Orthodontics. 94th EOS Meeting 2018,Edinburgh, UK. (Poster Presentation)
Ozcan M, Uzuner S, Tozlu M. Comparision of Linear Measurements on Facial Morphologies of 3dMD and Cerec Smile Design Pictures. 94th EOS Meeting 2018, Edinburgh, UK. (Poster Presentation)
Ozcan M, Uzuner S, Erten O, Tozlu M. Retrospective Analysis of Functional Treatment Needs of Orthognathic Surgery Patients. 94th EOS Meeting 2018, Edinburgh, UK. (Poster Presentation)
Ozcan M, Uzuner S, Erten O, Tozlu M. Patients' Perspectives of Digital Orthognathic Surgery Planning and Patient Spesific Implants, 94th EOS Meeting 2018, Edinburgh, UK. (Poster Presentation)

Ozcan M, Uzuner S, Erten O, Tozlu M, Nalbantgil D. Evaluation of the Lingual Surface Topography of the Anterior Teeth in order to Produce Custom Made Lingual Brackets for Impacted Anterior Teeth, 94th EOS Meeting 2018, Edinburgh, UK. (Poster Presentation)
Ozcan M, Sirman S,Uzuner S, Tozlu M. Evaluation of Efficacy of Tooth Movement for Clear Aligner Theraphy with Orchestrate 3D. 16th. International Congress of Turkish Orthodontic Society 2018 , Izmir,Turkey. (Oral Presentation)
Ozcan M, Sirman S,Uzuner S, Tozlu M. Evaluation of Patients Perspective for Conventional and Digital Impression Techniques. 16th. International Congress of Turkish Orthodontic Society 2018, Izmir, Turkey. (Poster Presentation)
Ozcan M, Uzuner S, Erten O, Tozlu M. Evaluation of the Preference of Patients for Custom Digital Orthodontics or Conventional Orthodontics. 16th. International Congress of Turkish Orthodontic Society 2018 , Izmir,Turkey. (Poster Presentation)
Ozcan M, Uzuner S, Erten O, Tozlu M. Retrospective Analysis of Functional Treatment Needs of Orthognathic Surgery Patients.16th. International Congress of Turkish Orthodontic Society 2018, Izmir,Turkey. (Poster Presentation)
Ozcan M, Uzuner S, Erten O, Tozlu M. Patients' Perspectives of Digital Orthognathic Surgery Planning and Patient Spesific Implants, 16th. International Congress of Turkish Orthodontic Society 2018, Izmir,Turkey. (Poster Presentation)
Tozlu M, **Ozcan M,** Biçici H. Evaluation of Refinement Needs in Aligner Orthodontics. 16th. Turkish Orthodontic Society Symposium 2019, Bodrum, Turkey. 16th. Turkish Orthodontic Society Symposium 2019, Bodrum, Turkey. (Oral Presentation)
Ozcan M, Tozlu M, Biçici H, Al Nasiri Z. Comparisions of Conventional and Digital Impression for Refinement in Aligner Treatment.16th. Turkish Orthodontic Society Symposium 2019, Bodrum, Turkey. (Oral Presentation)
Ozcan M, Biçici H, Elghady R, Al Nasiri Z. Evaluation of Root Resorption in Mandibular Incisors During Orthodontic Aligner Treatment with Different Acceleration Methods. 16th. Turkish Orthodontic Society Symposium 2019, Bodrum, Turkey.(Oral Presentation)
Ozcan M,Tozlu M, Biçici H. Evaluation of Root Resorption in Mandibular Incisors During Orthodontic Treatment with Aligner Theraphy.16th. Turkish Orthodontic Society Symposium 2019, Bodrum, Turkey.(Poster Presentation)
Ozcan M, Uzuner S, Tozlu M. Evaluation of Patients Preference for Aligner Therapy. 16th Turkish Orthodontic Society Symposium 2019, Bodrum, Turkey. (Poster Presentation)

Others (Projects / Certificates / Rewards)

Ozcan M, Ulkur F, Kaspar C. Comparison of measurements on plaster and digital models used in orthodontic model analysis. 9th International Medical Students' Congress in Novi Sad (IMSCNS). 2014, Novi Sad, Serbia (Best Oral Presentation)
Nalbantgil D, Sirman S, **Ozcan M**, Akın E. Assessment of the Effects of Facemask Theraphy from Parents' Perspective.XV. International Symposium of Turkish Orthodontic Society 2017 , Ankara, Turkey. (2nd Prize of the Poster Presentation)

eCligner Certification (2016)
Harmony Lingual Systems Certification (2017)
3M Incognito Lingual Systems Certification (2017)
Myofunctional Treatments (2017)
Alias L.S.W" Lingual Orthodontics Certification (2019)
Insignia Digital Orthodontics (2019)
K Line Clear Aligner System Certification (2020)
Airnivol Clear Aligner System Certification (2020)
Invisalign Certification (2020)
Flexiligner Clear Aligner System Certification (2020)
Spark Clear Aligner Certification (2021)
Win Lingual System Certification (2022)