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Deleterious Effects of Orthodontic Tooth Movement

A Project Submitted to

The College of Dentistry, University of Baghdad, Department of Orthodontics

in Partial Fulfillment for the Bachelor of Dental Surgery

By

Ali Ibrahim Mohammad

Supervised by

Lecturer Dr. Sara Mohammad Jasim Al-Mashhadany

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Certification of the Supervisor

I certify that this project entitled "Deleterious Effects of Orthodontic Tooth Movement" was prepared by the fifth-year student Ali Ibrahim Mohammad under my supervision at the College of Dentistry/University of Baghdad in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry.

Supervisor’s name: Lecturer Dr. Sara M. Al-Mashhadany

Date:

Dedication

This graduation project is dedicated with gratitude To God who has been with me through my lifetime. To my parents who always motivate and support me to achieve success, you mean the world to me.

Acknowledgement

First of all I would like to present my thanks to "**Allah**" for inspiring me withenergy and strength to accomplish this work, and pray upon his great prophetMohammad (peace be upon him).

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- CBCT: cone-beam computed tomography
- CF: continuous force
- CGRP: calcitonin gene-related peptide
- CIF: continuous interrupted force
- CLMF: cyclical, low magnitude forces
- GCF: gingival crevicular fluid
- IF: intermittent force
- IL-1 β: interleukin 1-beta
- IL-6: interleukin 6
- NKA: neurokinin A
- OF: orthodontic force
- OTM: orthodontic tooth movement
- PDL: periodontal ligament
- RR: root resorption
- SP: substance P
- TMD: temporomandibular dysfunction
- TMJ: temporomandibular joint
- TNF-α: tumor necrosis factor alpha

Introduction

The specialty of orthodontics relates to facial and occlusal development and involves the supervision, interception, and correction of occlusal and dentofacial anomalies known as malocclusion. Malocclusion is a term which refers to malalignment of teeth and incorrect relationship between the upper and lower arches. Patients with malocclusion have no specific signs and symptoms, but may complain about esthetics, difficulty with speech, and mastication. The prevalence of malocclusion has been found to vary in different countries, ranging from 20 to 43% in India, from 20 to 35% in the United States, 62.4% in Saudi Arabia, and 88.1% in Colombia. **(Adegbite *et al.*, 2012)**

Orthodontic treatment is a discipline in dentistry, like many other disciplines in this field, it can have adverse effects associated with the execution of treatment. These effects can be related to the patient or practitioner. Some of these effects are not fully understood, such as root resorption, and others are associated with orthodontic treatment without supporting evidence. Consideration of risk factors prior to treatment is important. These adverse effects include root resorption, pain, pulpal changes, periodontal disease, decalcification, and temporomandibular dysfunction (TMD). **(Talic, 2011)**

OTM does not appear to possess unique signaling mechanisms. The challenge, therefore, for researchers interested in understanding the mechanisms of OTM should be on deciphering how all signals, ranging from mechanical strains to biological signals, are integrated, processed, and eventually manifested as movement through the alveolar bone. **(Brooks *et al.*, 2015)**

There is a high degree of uncertainty regarding the appropriate force level that should be applied during orthodontic tooth movement (OTM). As a result, orthodontic treatments may take longer than necessary, leading to unwanted side effects. **(Theodorou *et al.*, 2019)**

This review of literature will discuss the deleterious effects of orthodontic tooth movement as well as a clinical case of root resorption.

Aims of the Study

- This review of literature describes the cellular and molecular biology of orthodontic tooth movement, including various theories and effect of chemical mediators on tooth movement
- To present the different side effects of orthodontic tooth movement
- To suggest some methods of decreasing incidence of mentioned deleterious effects

1. Chapter One: Review of Literature

Orthodontic tooth movement (OTM) is characterized by remodeling changes in dental and paradental tissues, including dental pulp, periodontal ligament (PDL), alveolar bone, and gingiva. An orthodontic appliance transfers mechanical stresses through the tooth to the periodontium where they are translated into physical, chemical, and electrical signals to cells that activate tissue remodeling to allow tooth movement. OTM differs markedly from physiological dental drift or tooth eruption. The former is uniquely characterized by the abrupt creation of compression and tension regions in the PDL while physiological tooth movement is a slow process. Optimal orthodontic force (OF) was defined as "the force leading to a change in tissue pressure that approximated the capillary vessels' blood pressure, thus preventing their occlusion in the compressed periodontal ligament," (20-25 g/cm2 of root surface). If it exceeds this pressure, compression could cause tissue necrosis through "suffocation of the strangulated periodontium." The current concept of optimal force is based on the hypothesis that a force of a certain magnitude and temporal characteristics (continuous vs intermittent, constant vs declining) would be capable of producing a maximum rate of tooth movement without tissue damage and with maximum patient comfort. The force of an orthodontic appliance which is meant to deliver a continuous force can subside rapidly and thus be interrupted aftera limited period of time. **(Parajuli *et al.*, 2010)**

There are three types of force applied in orthodontics. The "continuous force (CF)" is produced by wires and springs with super elastic characteristics (high limits of elasticity and shape memory), with the goal of maintaining the initial strength over a long period between activations. The "continuous interrupted force (CIF)" is obtained when wires or springs with reduced limits of elasticity and shape memory are used; the force gradually decreases until it reaches a level at which it is incapable of producing tooth movement. In contrast, an “intermittent force (IF)” acts over a shorter period and is completely eliminated with the removal of the force-generating device. IFs are commonly seen with the use of removable extraoral devices and intermaxillary elastics. **(Cuoghi *et al.*, 2021)**

1.1. Heavy Orthodontic forces

Heavy forces (which exceed capillary blood pressure of 20-25 gm/cm2 of root surface) produce the classic 3-phase reaction–initial strain, lag phase, and progressive tooth movement. Greater force levels will result in physical contact between teeth and bone, yielding resorption in areas of pressure and undermining resorption or hyalinization in adjacent marrow spaces. The first sign of hyalinization is the presence of pyknotic nuclei in cells, followed by areas of a-cellularity, or cell-free zones. Then, cellular elements such as macrophages, foreign body giant cells, and osteoclasts from adjacent undamaged areas invade the necrotic tissue. These cells also resorb the underside of bone immediately adjacent to the necrotic PDL areaand remove it together with the necrotic tissue. This process is known as undermining resorption. **(Parajuli *et al.*, 2010)**

1.2. Fixed vs Removable Appliances

In fixed appliances, hyalinized zones might develop in sites of compressed PDL, but, as soon as this necrotic tissue is eliminated and the tooth moves, the force decreases quickly. Finally, the arch-wire retains its passivity for a while, during which time (rest period) there will be an opportunity for calcification of the newly formed osteoid layer. Removable appliances deliver intermittent force which result in small compression zones in the PDL, short hyalinization periods, and lengthy rest periods when the appliance is removed intermittently. During this time, the tooth moves back to the tension side and remains in normal function. This condition is known as “semi-hyalinization,” meaning that in the compressed PDL not all fibers become compressed, and only some cells undergo necrosis. Consequently, osteoclasts might be formed directly along the bone surface subjacent to hyalinized tissue, and bone resorption is less disturbed by hyalinization. **(Parajuli *et al.*, 2010)**

1.3. Theories of tooth movement

1.3.1. Pressure-tension theory

This theory states that tooth moves in the periodontal space by generating a “pressure side” and a “tension side”. (figure 1.1) The pressure side will be disorganization of PDL and diminution of fiber production. The cell replication decreases seemingly due to vascular constriction. On the tension side, stimulation produced by stretching of PDL fiber bundles results in an increase in cell replication.

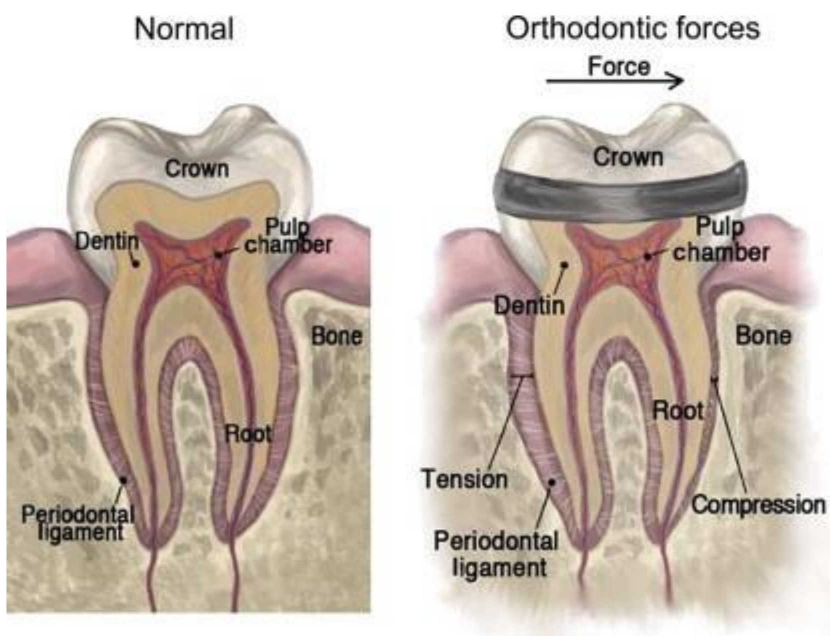

Figure 1.1 Mechanical force on the tooth causes compression of the periodontal ligament on one side and tension on the other side. The compression side is associated with aseptic injury and bone resorption and the tension side with bone formation. **(Graves *et al.*, 2011)**

This enhanced proliferative activity leads eventually to an increase in fiber production. The resorption of bone on the pressure side and apposition of bone on the tension side leads to tooth movement. **(Parajuli *et al.*, 2010)**

1.3.2. The bone-bending theory

When an orthodontic appliance is activated, forces delivered to the tooth are transmitted to all tissues near force application which will bend bone, tooth, and the solid structures of the PDL. As bone is more elastic than the other tissues, it bends far more readily in response to force application. The active biologic processes that follow bone bending involve bone turnover and renewal of cellular and inorganic fractions. In response to applied mechanical forces, there is generation of electric potentials in the stressed tissues. These electric potentials might charge macromolecules that interact with specific sites in cell membranes or mobilize ions across cell membranes. The concave side of orthodontically treated bone is electronegative and favors osteoblastic activity, whereas the areas of positivity or electrical neutrality– convex surfaces–showed elevated osteoclastic activity. Piezoelectricity is production of electric current when a crystalline structure is deformed as electrons in a lattice are displaced from one part to other. The role of piezoelectricity in OTM is controversial because of the quick decay rate of current. **(Parajuli *et al.*, 2010)**

1.4. Deleterious Effects of Tooth Movement

1.4.1. Temporomandibular dysfunction (TMD)

TMD is a condition that usually incorporates masticatory muscle pain, internal derangement of the temporomandibular joint (TMJ) disc and degenerative TMJ disorders either separately or in combination. Orthodontic treatment an extraction of teeth for orthodontic purpose especially during adolescence has been shown not to increase the risk for TMD signs and symptoms. Also, there is no prominent risk for TMD because of the use of any specific orthodontic mechanics or appliances. It has been recommended that orthodontic treatment ought not be initiated in patients with acute signs and symptoms of TMD. It should be deferred until the attack is controlled. If the patient acquires and shows signs and symptoms during the orthodontic treatment, then all active forces must be ceased without the need for the removal of the fixed orthodontic appliances. **(Sengupta *et al.*, 2020)**

1.4.2. Decalcification

Decalcification of enamel (white spots) can lead to cavitation. **(Sengupta *et al.*, 2020)** (figure 1.2)

White spot lesions are due to subsurface demineralization with a decrease in porosity and consequent changes in the optical properties of enamel and can be arrested or reversed while the surface is intact. **(Santosh *et al.*, 2017)**

It is reported that decalcification of enamel occurs in 50% of orthodontic patients and maxillary incisors are the ones that are mostly affected. **(Sengupta *et al.*, 2020)**

Figure 1.2 Decalcification of the tooth surfaces **(Sharudin, 2020)**

The most common teeth affected are upper lateral incisors representing 23% of cases. **(Sharudin, 2020)**

The decalcifying lesions can progress within four weeks (approximate time taken for orthodontic follow-up). This could be prevented by **(Sengupta *et al.*, 2020)**

1. ensuring proper plaque control through brushing of the teeth
2. fluoridated tooth paste
3. daily rinsing with a 0.02% or 0.05% sodium fluoride solution
4. application of fluoride varnish twice a year or a combination of antibacterial and fluoride varnish

1.4.3. Periodontal disease

The factors on which the periodontal responses depend due to OTM and the forces exerted by various orthodontic appliances are host resistance, systemic diseases and the amount and composition of dental plaque. Other factors such as lifestyle (including smoking), can also jeopardize periodontal support. (**Sengupta *et al.*, 2020)**

Orthodontic forces may lead to the destruction of periodontal bone support through the induction of pro-inflammatory cytokines and also by decreasing the expression of matrix proteins and osteogenic protein. Gingival and Periodontal changes related to orthodontic treatment are, in general transient with no permanent damage. Loss of attachment and alveolar bone loss are known to occur during orthodontic treatment, but are reported to be temporary. **(Santosh *et al.*, 2017)**

Orthodontic treatment especially using fixed appliances has been shown to stimulate and increase the volume of dental plaque thus causing a shift in the type of bacteria. Therefore, fixed orthodontic treatment could lead to localized gingivitis, which infrequently progresses to periodontitis. (figure 1.3) Hence, it is mandatory to provide oral hygiene instructions to the patients, regarding regular brushing, use of electrical and ultrasonic tooth brushes, interproximal brush in addition to the orthodontic brush and toothpaste with stannous fluoride. Orthodontic treatment of patients with active periodontal disease is contraindicated because of the increased risk factor for additional periodontal damage. It is thus mandatory to examine of the level of attached gingival preceding any comprehensive orthodontic treatment. The level of attached gingival is measured from the free gingival margin to the mucogingival junction minus the depth of the gingival sulcus. **(Sengupta *et al.*, 2020)**

Orthodontic intrusion at healthy sites can lead to new cementum formation and new collagen attachment, whereas for sites lacking proper oral hygiene, results vary from a moderate new attachment development to a worsening of the alveolar bone loss. **(Thomas *et al.*, 2022)**

Literature states that the apical part of the root has relatively minor importance for total periodontal support and approximately 3 mm of apical root loss is equivalent to 1 mm of crestal bone loss. **(Santosh *et al.*, 2017)**

Gum recession (thinning) may occur if tooth movement is uncontrolled during orthodontic treatment. **(Sharudin, 2020)**

Figure 1.3 Gingival Hyperplasia **(Sharudin, 2020)**

1.4.4. Pulpal changes

Pulpal side effects include altered pulpal respiration rate, internal root resorption, pulpal obliteration by secondary dentin and pulpal necrosis. **(Vendittelli *et al.*, 2013)**

After the application of orthodontic force, there is hyperemia in the pulp at the initial stages and mast cell degranulation occurs accompanied by cell damage and biochemical reactions. There is also an increased neural activity in the pulp and increased electrical stimulation threshold of the pulp after a few days. Due to the alteration in the metabolism of pulp occurring because of increased enzymatic activity; apoptosis and necrosis of pulp cells increases. The use of heavy uncontrolled, continuous orthodontic forces could result in loss of pulp vitality. Hence, an orthodontist should use optimal light forces during their treatment. **(Sengupta *et al.*, 2020)**

The respiration rate of dental pulp will be depressed inevitably in short term when tooth is subject to orthodontic force. **(Chih-Wei *et al.*, 2017)**

In a study comparing impacted canines to non-impacted canines, 21% of impacted canines displayed radiographic pulpal obliteration, 25% of them did not respond to electric pulp testing, and 3% of these teeth required root canal treatment. All of the control canines had normal pulpal responses and none required root canal treatment. Another study suggested that teeth with advanced periodontal bone loss are more susceptible to pulpal necrosis following orthodontic treatment, as these teeth have a limited ability to mitigate the forces on the neurovascular bundle. Changes in pulpal blood flow that occur as a result of orthodontic force normalize after 72 hours. **(Vendittelli *et al.*, 2013)**

Changes occurred in the pulp are considered to be reversible most of the time unless the pulp had previous damage. Orthodontic force will change vascularity and blood flow of periodontal tissueand this will induce the local synthesis and release of various molecules, such as neuropeptides, cytokines and growth factors. The neuropeptides include substance P (SP), calcitonin gene-related peptide (CGRP) and neurokinin A (NKA). The release of SP during inflammation can cause vasodilation and increase vascular permeability. These responds can increase blood flow to the inflammation sites. SP and CGRP can stimulate the production of interleukin (IL)-1β, IL-6, and tumor necrosis factor (TNF)-α from the fibroblasts in human dental pulp. **(Chih-Wei *et al.*, 2017)** (figure 1.4)

1.4.5. Pain

The peripheral sensory nerve system contributes to the development of acute and chronic inflammatory processes through local release of neuropeptides. When orthodontic appliance is activated, the transient inflammatory response may cause discomfort to patient for few days. **(Chih-Wei *et al.*, 2017)**

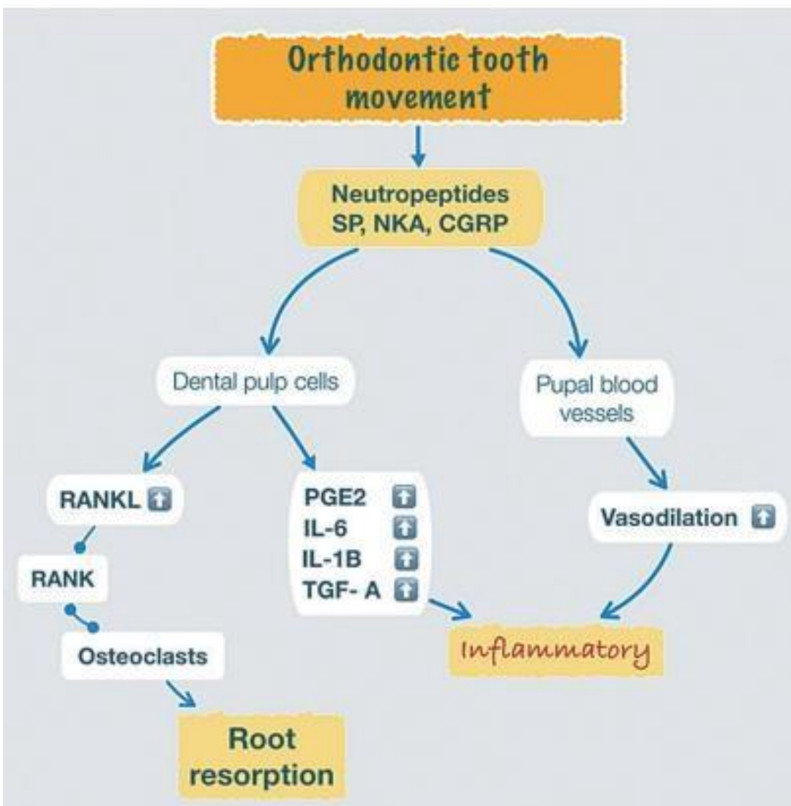

Figure 1.4 Pulpal inflammatory process to orthodontic force. **(Chih-Wei W *et al.*, 2017)**

The pain has been stated to begin 4 hours after the placement of separators or orthodontic wires, and the intensity is found to be increased on the second day of treatment and usually lasts for seven days. Pain in the anterior teeth is supposed to be greater than the posterior teeth. The patient could be advised to chew on plastic wafers or chewing gums containing aspirin to control the ensuing pain. This mode of treatment to combat the pain, hypothetically increases the circulation in the periodontal ligament, which reduces the pain and discomfort. Apart from this, clinicians are advocated to prescribe analgesics like acetaminophen pre-operatively and for a short course after the placement of separators and initial wires. **(Sengupta *et al.*, 2020)**

1.4.6. Root resorption

Apical root resorption (RR) is generally considered to be a common result following orthodontic treatment. **(Sengupta *et al.*, 2020)**

Root resorption occurs when the pressure on the cementum exceeds its reparative capacity and dentin is exposed, allowing multinucleated odontoclasts to degrade the tooth substance. **(Santosh *et al.*, 2017)**

It is a general belief amongst dental practitioners that external apical root resorption (RR) is an inevitable consequence of OTM. **(Sengupta *et al.*, 2020)**

RR is undesirable because it can affect the long-term viability of the dentition. **(Weltman *et al.*, 2010)** Root resorption of greater than 1-2 mm is considered as clinically significant. **(Santosh *et al.*, 2017)**

Apical root resorption causes loss of mineralized tissues such as dentin, cementum and alveolar bone. Root resorption due to orthodontic treatment is typically related to inflammatory process in the periodontal ligament, resulting in shortening of the tooth apex. External apical RR is irreparable and can commence at early leveling period of orthodontic treatment. It is typified by apical rounding. Apex or lateral surfaces of roots can be resorbed but only apical root resorption can be observed by radiographic analysis wherein more than 1/3rd of original root length is lost in severe external apical RR. **(Sengupta *et al.*, 2020)**

Root resorption usually take place on the apical and lateral root surfaces especially on upper and lower incisor teeth. **(Sharudin, 2020)** (figure 1.5)

Figure 1.5 Periapical radiograph shows root resorption of upper central incisor teeth **(Sharudin, 2020)**

It has been established through several researches that heavy forces produced considerably more root resorption than light forces. Compressive forces cause more resorption than tensile forces. Intrusion of teeth causes about four times more root resorption than extrusion. Intrusive forces along with lingual root torque and wiggling movement persist to be the most prominent forces in causing apical RR. **(Sengupta *et al.*, 2020)**

The duration of force application is also one of the predisposing factors, as prolonged treatment is directly related to an increase in root resorption. **(Sharudin, 2020)**

The risk for periapical lesions and bone destruction after orthodontic treatment was significantly increased for teeth receiving inadequate endodontic treatment compared with those receiving adequate endodontic treatment. Calcium hydroxide can be used to fill the root canal thus helps to reduce the risk of external apical

RR until morthodontic treatment is completed. If root resorption ensues and is evident in radiographs, then the patient must be informed that the on-going orthodontic treatment has to be stopped for at least 3 months. **(Sengupta *et al.*, 2020)**

Risk factors of root resorption include: **(Weltman *et al.*, 2010, Sharudin, 2020, Jacob *et al.*, 2020)**

1. Pipette-shaped root
2. history of trauma and/or had root canal treatment
3. Treatment of the impacted canine tooth may increase the risk of root resorption to the lateral incisor and first premolar teeth
4. ‘rectangular’ arch-wires or Class II elastic traction
5. Habits like bruxism **(Sharudin, 2020)** and others such as nail biting and tongue thrusting must be taken care of as it has been shown that such patients are susceptible to more severe root resorption.
6. patients more than 11years old
7. Female > male
8. genetic influences
9. nabumetone
10. hypothyroidism
11. hypopituitarism
12. root proximity to cortical bone
13. chronic alcoholism

It has been suggested that developing teeth with a more open apex area could be more resistant to the blood flow effects of orthodontic force, as larger blood vessels can better enter the pulp. **(Huokuna *et al.*, 2022)**

Follow-up radiograph (periapical or panoramic) at 6–12 months after the initiation of orthodontic treatment is suggested. **(Sengupta *et al.*, 2020)**

1.5. Attempts to minimize deleterious effects

Doctors and patients attempt to accelerate orthodontic tooth movement with a minimally invasive surgery approach. **(Fu *et al.*, 2019)**

Forces between 50 cN and 100 cN seem optimal for OTM, patient comfort and potentially exhibit fewer side effects. **(Theodorou *et al.*, 2019)**

OTM may be accelerated by the use of force in conjunction with other biologically potent means which can generate a local response and this study has demonstrated that electric currents, in that range of 10 to 20 microamperes, can be used successfully for this purpose. **(Parajuli *et al.*, 2010)**

There are no significant adverse effects of surgically accelerated orthodontic techniques on periodontium, root length, or tooth vitality. **(Pouliezoi *et al.*, 2022)**

1.6. Clinical Case

Case by **(Topkara *et al.*, 2012),** outlines the prognosis of a case of severe apical root resorption (RR) in a patient with an open bite who was subjected to extremely long-term orthodontic treatment.

A 10-year-old boy presented to a university hospital for orthodontic treatment with the following findings:

- Skeletal and dental Class I malocclusion
- Vertical growth and a high mandibular plane angle
- Severe anterior and bilateral open bite (figure 1.6)

- Sigmatism (a speech impediment characterized by faulty pronunciation of sibilant sounds)
- Mouth breathing, habitual tongue thrust, and incompetent lips
- Maxillary arch length deficiency
- A medical history of allergic reactions
- A family history of allergies and asthma

After evaluation of the patient, Frankel IV appliance therapy was immediately initiated; this course of treatment began in 1989. After two years, the patient still had an anterior and bilateral open bite with occlusal contacts solely on the molars (figure1.7). As seen on the panoramic x-ray, the transition from mixed dentition to permanent dentition was completed in 1991 (figure 1.7). However, the apexification of some teeth was still progressing.

Figure 1.6 Initial intraoral photographs, taken in 1989. **(Topkara *et al*., 2012)**

Figure 1.7 Panoramic x-ray taken before fixed appliance treatment in 1991. **(Topkara *et al*., 2012)**

The patient came back to the hospital approximately one year later with a degree of open bite relapse. A short course of fixed appliance therapy was planned and restarted in 1995 at the age of sixteen. After a while, the patient moved to another city for his education and presented to a private orthodontist to continue his treatment. The new orthodontist did not obtain x-rays or the patient's previous dental records. Intraoral elastics were used for a long time period to close the open bite. The treatment was terminated before completion as a result of the diagnosis of severe apical RR, using x-rays taken at the university hospital in 2001 (figure 1.8). Upper and lower fixed retainers were subsequently bonded, and the patient was submitted to follow-up. The last records of the patient were taken using CBCT at the University of Alabama Department of Orthodontics.

Figure 1.8 Last panoramic x-ray, taken in 2010, the patient was 31 years old. **(Topkara *et al.*, 2012)**

2. Chapter Two: Discussion

The optimal force for tooth movement may differ for each tooth and for each individual patient. It appears that this kind of a force, that starts in a continuous mode and then becomes interrupted, is biologically favorable, particularly when its initial magnitude is low. In a study by **Pilon *et al.* (1996**) in dogs, application of 2 forces (50 and 100 cN) to second premolars resulted in the same rate of tooth movement and thus, it was concluded that force magnitude plays only a subordinate role in orthodontic tooth movement. **(Parajuli *et al.*, 2010)**

The use of CIFs produces fewer hyaline areas, facilitating their elimination, PDL repair as well as tooth movement. The CFs produce more hyaline areas with greater potential for the development of root resorption than interrupted and IFs. The IFs produce hyaline areas similar to interrupted forces, however, permit a recurrence of the movement. **(Cuoghi *et al.*, 2021)**

von Bohl *et al.*, (2009) found a clear relationship between force level, timing, and extent of hyalinization could not be found. Even with a force as low as 5 cN, hyalinization occurred and the timing of the event seemed to be independent of the force level. The assumption that higher forces lead to more hyalinization cannot be confirmed. An interesting finding from a recent study, however, was that an initially light and gradually increasing force resulted in less hyalinization than a heavier initial force that increased to the same end force level.

A study performed by **(Abdulameer, 2021)** involved adult participants needing upper 1st premolar extraction as part of orthodontic treatment. One side was subjected to heavy forces of 225g while the contra-lateral received light force of 25g. Samples were pooled from GCF of teeth at baseline, 1hr, 1 day, 7 days, 14 days, 21 days and 28 days then teeth were extracted at day 28. It was observed that the heavy forces resulted in 3 times greater root resorption than light force groups. GCF samples exhibited elevation of 5 types of proteins implicating their possible use as predictors for root resorption.

A randomized clinical trial of four split-mouth studies compared fixed orthodontic light (25 g) continuous force with fixed heavy (225 g) continuous force in patients needing premolar extractions to relieve crowding or overjet. Mean volume of the resorption craters was 11.59 times greater in the heavy-force group than in the control group. **(Weltman *et al.*, 2010)**

It was observed that a statistically significant difference exists in the resorption process when extraction and non-extraction groups were compared; among the extraction groups, the extraction of all first premolars showed the greatest resorption potential. **(Alfuriji *et al.*, 2014)**

There still remains an ambiguity whether there is any ideal or optimal force delivery method for moving teeth without causing root resorption and whether root resorption is truly predictable. **(Jacob *et al.*, 2020)**

Appropriate clinical and radiographic evaluation is imperative prior to planning the course of treatment to guarantee the best treatment outcome. **(Sengupta *et al.*, 2020)**

Recently, externally applied, cyclical, low magnitude forces (CLMF) have been shown to cause an increase in the bone mineral density of long bones, and in the growth of craniofacial structures in a variety of animal models. In addition, CLMF is well tolerated by the patient and produces no known adverse effects. **(Blake, 2010)**

3. Chapter Three: Conclusion and Suggestions

3.1. Conclusions

- Orthodontic tooth movement suffers from multiple deleterious effects
- Some effects can be minimized by careful titration of force and duration of tooth movement
- Root resorption is neglected by many practitioners which creates a legal liability on the shoulder of orthodontists

3.2. Suggestions

- Uncovering the exact risk factors for negative effects of orthodontic tooth movement can be a tricky task due to multiple variables. However, with careful consideration and elimination of these factors through case control studies, we can unlock the secrets to creating more targeted and effective treatment plans.
- To achieve the best orthodontic results possible, it's crucial to use force control and movement acceleration methods that prioritize the health of the periodontal attachment. By taking this approach, we can ensure that patients receive the most effective and comfortable treatment possible.
- Following up with patients after malocclusion correction is a critical step in intercepting any potential side effects of orthodontic treatment. By taking a proactive approach to addressing any issues that arise, we can help patients maintain optimal oral health and prevent long-term complications.

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