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Review Article

The effect of orthodontic tooth movement on endodontically treated teeth

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ABSTRACT

There is often the need of moving teeth, which was endodontically treated or teeth still in endodontic treatment. Orthodontic movement of endodontically treated teeth was approached with suspicion for many years, and clinicians abstain from applying orthodontic movement to teeth. This movement inevitably causes biological reactions in periodontal ligament and pulp. Application of a severe orthodontic force for a long time can cause irreversible pulpitis and necrosis in pulp by increasing pulp inflammation process. Use of moderate and intermittent forces enables sufficient tooth movement, limits the damage in the pulp, and allows the damaged pulp healing. Microscopic root resorption occurs in all teeth during orthodontic treatment, which is clinically insignificant and cannot be determined radiographically. The aim of this review is to determine issues to be considered for endodontic terms before orthodontic treatment, the alterations which may be occurred in the pulp, hard tissues, and periapical region of the teeth during and after treatment and how these changes affect the results of treatment.

Keywords: Endodontic treatment, external apical root resorption, orthodontic tooth movement, pulp

INTRODUCTION

There is often the need of moving teeth, which was endodontically treated or teeth still in endodontic treatment. The goal of orthodontic treatment is minimizing the biological damage and pain besides enabling an adequate teeth movement. Orthodontic movement of endodontically treated teeth was approached with suspicion for many years, and clinicians abstain from applying orthodontic movement to these teeth. However, there are close relations between all professional fields of dentistry; the relation between endodontics-orthodontics has attracted the attention of researchers less frequently, and there have not been any definitive judgments on the subject. This makes planning and follow-up of the treatment difficult for clinicians and causes problems in terms of complications that may occur during the treatment and approaches to the complications.

The aim of this review is to determine issues to be considered for endodontic terms before orthodontic treatment, the alterations which may be occurred in the pulp, hard tissues, and periapical region of the teeth during and after treatment and how these changes affect the results of treatment.

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THE EFFECT OF ORTHODONTIC FORCE APPLICATION TO PULP

Orthodontic teeth movement is based on application force to the teeth in a certain period of time which may vary between months and years. This movement inevitably causes biological reactions in periodontal ligament and pulp. The clinical importance of pulpal alterations after orthodontic force depends on whether or not it will endanger the long-term vitality of the teeth.

Orthodontic force, which is called as controlled trauma,[1] can damage the pulp because the lack of collateral circulation in the pulp makes pulp one of the most sensitive tissues of the body. The symptoms, which can be diagnosed earlier in the pulp tissues, after orthodontic force is applied are hemodynamic changes with the increase in the volume of blood vessels[2] and circulatory disorders within the 1st h.[3] When an orthodontic force is applied, pulp tissue reacts with pulp hyperemia at first, and degranulation of mast cells is characterized with cell damage and biochemical reactions. These are the features of classical acute inflammation in which acute inflammatory mediators such as vasodilatation, bradykinin, neuropeptides, prostaglandins and growth factors, vascular permeability, and histamine, which causes a rise in blood flow with edema, are released. An increasing neural activity and an increasing response threshold to electrical stimulation of pulp develop after a few days.[4] Then, because of the alteration in the metabolism of pulp, which is stated with increased enzymatic activity, apoptosis, and necrosis of pulp cells increase.[5] The changes in the tissue respiration and possible hypoxia, which develop during orthodontic treatment, cause increase in aspartate aminotransferase (AST) activity levels and affect dental pulp tissue by changing pulpal neural response.[5] The presence of macrophages, the change of odontoblast layer, edema of connective tissue, and increase of progenitor cells and fibroblasts are the reports, which represent an adaptive process and inflammation of pulp tissue to the mechanic aggression caused by orthodontic force.[6] Long-term studies show the decrease of some protein expressions which block the regeneration and restoration of pulp structure.[7]

The studies which use of radiorespirometric methods report respiratory depression of pulps in teeth which are exposed to orthodontic teeth movement.[8] Hamersky *et al*.[9] observed a significant correlation between the amount of decrease in pulp tissue respiration rate and the age of the patients. They represented that age is more relative to pulp tissue respiration than orthodontic force. While there is a negative relation between age and respiration rate, a positive correlation between apical openness amount and respiration rate was stated.[10]

In the study in which Lazzaretti *et al*.[11] evaluated with split-mouth study design 34 maxillary first premolars of 17 patients, they applied intrusive force to the teeth in the experimental group for 21 days and examined the pulps histologically. Findings in the experimental group after orthodontic inclusion force showed certain changes in most of the teeth. Odontoblast aspiration, which is one of the first pulp reactions to external stimulus, was determined in 23.5% of the teeth in the experimental group. A dense connective tissue area (fibrous) was observed within the pulp. Vasodilatation was observed in most of the teeth in the experimental group. After 21 days, orthodontic intrusive force application caused vascular changes in the pulpal tissue and calcification number and presence of fibrosis in the pulp increased.

Transforming growth factor beta-1 (TGF-β1) and TGF-β3, which released during inflammatory process in the pulp, is responsible for not only the stimulation of reactionary dentin but also stimulation of reparative dentin after orthodontic force was applied.[12] Normally, increased blood flow recovers damaged tissues by removing inflammatory mediators but as dental pulp is limited in a narrow area (i.e., dentin walls), active dilatation of arterioles cause increase into pulp pressure and compression of venous return.[13] The possibility of controlled trauma which is inducted with orthodontic force prevents removing inflammatory mediators and healing of damaged cells spontaneously, which is resulted in tertiary dentin deposition.[13] Later changes of pulpal cell metabolism and pulpal vessel changes generally result in an increased deposition of repair dentin of both coronal and radicular sections of the pulp with a simultaneous increase in dystrophic mineralization.[10] However, it is asserted[10] that most of the changes in pulpal blood flow are reversible by orthodontic forces unless the pulp which was previously irritated with restorations, decays, or traumas, it is also stated[1] that orthodontic force creates a minor pulpal damage risk for the patient. Literature also puts forward that teeth which fully developed with mature apices are sensitive to irreversible pulp inflammation and immature teeth are not sensitive.

Angiogenic changes were found after orthodontic force, and there has been an increase in the number of microvessels expressing the rise in angiogenic growth factor in dental pulp.[14] Epithelial growth factor which is released after orthodontic force is applied has a significant role on angiogenic response of the pulp. After orthodontic loading of the teeth, expression of angiogenic growth factors within pulp tissues were defined by pulp

fibroblasts such as vascular endothelial growth factor, fibroblast growth factor-2, platelet-derived growth factor, and TGF-β.[15] Progression of inflammatory process is related to stimulation of neuropeptides and production of inflammatory cytokines such as interleukin-1 (IL-1), IL-3, and tumor necrosis factor-alfa.

Calcitonin gene-related peptide (CGRP) is a neuropeptide, which is released from C-type nerve fibers of the pulp after being injured. CGRP has the ability to initiate vasodilatation and plasma extravasations, immune system activation, chemotaxis, and regulation of inflammatory cells such as macrophages, mast cells, and lymphocytes.[16] Neuropeptides, which are released from C-type sensitive fibers by a mechanical stimulus, have the ability to regulate inflammatory reaction by controlling vascularity and blood flow and promoting a rapid and large arrival of immunocompetent cells and inflammatory mediators.[16] Microcirculation of pulp changes dynamically during the process. Removing metabolic residuals and continuation of harmonic interstitial pressure become harder and therefore pulp tissue edema and necrosis may develop.[17] CGRP was stated to expand the inflammatory effect of substance P (SP) by increasing inflammatory mediators.[16,17] CGRP also increases expression of bone morphogenetic protein-2 by stimulating odontoblasts in order to increase dentin deposition as a defense mechanism in human pulp cells.[8] Caviedes-Bucheli *et al*.[18] observed the highest CGRP values on the pulps with increased force. When compared to normal neuropeptides values, there has been a significant increase in CGRP expression of the teeth which submitted severe orthodontic force.[18]

Methionine enkephalin (ME) levels also change by the effect of orthodontic force. ME significantly decrease by an inverse linear relationship with the applied force magnitude. Robinson *et al*.[19] measured β-endorphin like immunoreactivity (BE-LI) in the human teeth pulps following acute mechanic stress. β-endorphin is an active peptide which is derived from precursor protein proopiomelanocortin and has a severe antinociceptive quality. A monotonic decrease in BE-LI concentrations was clear with the extraction of four premolars (all the first and second premolars were extracted as a part of orthodontic treatment plan). β-endorphin has the ability to modulate SP and play a significant role in the regulation of harmful impulses and while there is a positive relation between SP and ME concentrations in pulp, concentrations of both materials have a negative correlation with orthodontic force increase.[20]

In medicine, clinic enzymology is used in order to help diagnose of localized inflammatory lesions before clinic symptoms are developed. AST is an enzyme which is normally limited by cell wall but released extracellular area after cell death. It was shown that AST activity increased in the pulps of orthodontically treated teeth by reflecting metabolically changes in the pulp.[21] Veberiene *et al*.[5] stated that AST activity significantly increased by 7 days intrusive force. In an another study[4] showed no significant difference between 7 days of orthodontic intrusive force and 14 days of force in terms of AST activity levels. This finding supports the hypothesis that orthodontic treatment caused a temporary metabolic change in pulp tissue during orthodontic treatment, and these changes are reversible.

Neural responses and release of specific neural transmitters during orthodontic tooth movement were also evaluated. Pulpal axon response to orthodontic movement was examined by Bunner and Hohnson.[22] However, the number of myelinated axons is more than unmyelinated axons, no significant differences were observed between myelinated axons and unmyelinated between experimental (orthodontic movement) and control (without orthodontic treatment) teeth. The authors concluded that there was not any irreversible problem in the healthy teeth treated conservative orthodontic treatment.

According to Grünheid *et al*.[23] some pathological symptoms in rats' pulp tissue increase to maximum within 24 and 72 h and they turn back to initial values after 168 h after force was applied. Researchers draw the conclusion that controlled mechanic forces during orthodontic treatment can cause temporary changes in the pulp unless they are not excessive.

Laser Doppler flowmetry was commonly used in human studies[2,24-26] which were carried out to evaluate pulpal blood flow changes associated with orthodontic treatment. There was a decrease in basal blood flow regardless of type of the moved teeth and teeth movement in the most of the studies.[2,24,25] In the other study,[26] no change was stated in the pulpal blood flow in the first 4 min after intrusive force was applied. There were conflicting results on the magnitude of the applied force for increase related[2] and not related[25,26] to force. Javed *et al*.[27] asserted that applying severe force to the teeth for a long time may affect pulpal blood flow than short-term application of the same forces.

Pulp calcifications commonly occur in the population. They are generally related to age, and the number and size of pulpal calcifications increase within the patients who are orthodontically treated for a long time. Large nodules of root canal space and total calcification are among dystrophic calcification findings related to orthodontic forces.[11] Popp *et al*.[1] radiographically evaluated pulp sizes of orthodontically treated and untreated teeth and found a decrease in pulp cavity

volume in both groups. However, obliteration of pulp cavity can be determined radiographically during and after teeth movement, the insufficiency of the detail in the dentin prevents the dentist to realize it until the findings are clinically clear. It cannot be diagnosed by the dentist unless they cause a radiological radiolucency, narrowing of pulp cavity by irritation dentin when compared to the adjacent teeth, discoloration in teeth crown, and signs and symptoms of the patient. Therefore, necrosis in the tooth may take place.

Venkatesh *et al*.[13] examined cone beam computed tomography views (CBCT) of 48 patients in six maxillary anteriors before and after the treatment. They discovered statically significant differences between pulp cavity volumes before and after orthodontic treatment both in experimental and control groups. It was discovered that decrease in pulp cavity volume in the experimental group was more than the control group. They asserted that tertiary dentin deposition caused the decrease in pulp tissue volume in their study.

Pulp changes which depend on orthodontic treatment are determined through periapical radiographs, pulp vitality tests, histological sections, and scanning electron microscope.[13] Magnification errors and problem of reiterative ability of traditional radiographs makes the method questionable. The area of measured pulp cavity is held two-dimensional which is not accurate as pulp cavity has three dimensions. However, histological studies clearly define the change which is inducted in the pulp orthondically, for routine clinic use of histological evaluation the tooth, so it has not got any value in clinic implementation during or after orthodontic treatment. CBCT created important innovations in the treatment plan and treatment in orthodontic recently.

It is also known that the health and integrity of dental pulp are important for tooth survival. Pulpal sensitivity tests are considered not to be trustworthy during orthodontic treatment.[28] The response of pulp to electric stimulation becomes inconsistent in the patients whose pulps are considered to be healthy before orthodontic treatment.[29] Seven days of intrusive force significantly changed the response of pulp to electric pulp test (EPT).[5] Approximately, 3.5 times increased response threshold to EPT was found in the pulp tissue of affected teeth.[5] It was considered to be caused by pressure on apical nerve fibers.[29] In EPT values, which were measured after 14 days of intrusive force or 7 days of intrusive force and 7 days of resting period, an increased response threshold was found compared to the group that was applied force for 7 days.[4] The effect begins just after the treatment and can continue up to 9 months.[30] Alomari *et al*.[31] compared vitality of maxillary incisors and canines within 43 patients who are orthodontically treated and 23 patients without orthodontic treatment before, during, and retention phases with EPT and cold thermal test. After 2 months from the beginning of orthodontic treatment, the number of teeth negative responses was maximum, and there was a decrease in the number of teeth negative response after this period. The decrease has continued in the retention phase. Near the end of observation period, the values before the treatment were reached by a decrease. It was stated that lateral incisors, central incisors, and canine teeth were unsuccessful in more responses. Teeth in the experimental group presented significantly higher response threshold than the teeth in the control group. The authors concluded that pulpal sensitivity test must be interpreted carefully in orthodontically treated patients, and thermal tests are more reliable than EPT.

Patients with Class 2 Division 1 occlusion were defined as possible predisposed factors because of increased overjet and inadequate lip coverage in terms of exposing dental damage. These patients need orthodontic treatment, so they have many teeth having possible trauma story after and during orthodontic treatment. There are limited studies about the effect of orthodontic treatment on pulpal vitality of teeth with trauma. Bauss *et al*.[32] compared vitality of traumatized teeth during orthodontic treatment with traumatized teeth without orthodontic treatment and not traumatized teeth having orthodontic treatment in their retrospective study. A significant pulpal necrosis occurred in teeth which were exposed to trauma during orthodontic treatment. Being suffered to severe periodontal damage and subsequently total pulp obliteration increase the necrosis risk of pulp in the following orthodontic treatment phases. The capacity of pulp blood vessels is insufficient to enable an adequate pulpal blood flow during the following orthodontic treatment in the teeth which are exposed to severe periodontal damage. Severe periodontal injuries can cause damage and decrease of apical vessel, and these teeth can be more sensitive to pulp necroses during orthodontic treatment. Pulpal condition should be monitored by periapical radiographs after orthodontic treatment begins again after trauma and if progressive pulp obliteration occurs the orthodontic treatment of the teeth must be ended or limited, or the forces must be decreased to minimum.[32]

In a study,[33] which evaluated orthodontic intrusion effect on pulpal vitality of permanent incisors that were exposed to trauma before, pulp necrosis in traumatic teeth having orthodontic treatment was found 10.4% which was discovered more than teeth with orthodontic treatment only or being exposed to trauma only. In most of the cases in which pulp necrosis was developed during orthodontic intrusion, especially in the initial intrusion period. In a retrospective study,[34] the effect of

orthodontic extrusion on pulpal vitality of traumatized maxillary incisors was examined. 9.1% pulpal necrosis occurred in the traumatic teeth with orthodontic treatment which is significantly more than teeth with orthodontic treatment or trauma solely.

In a systematic review, the reactions of pulp to orthodontic force in human were searched.[35] The authors stated that orthodontic force application can cause pathological changes in dental pulp tissue but underlined that there is limited information on the relation between dental pulp reaction and orthodontic force. The data showed that there is a certain balance between the continuation of pulp health and being necrosis during orthodontic tooth movement. In a last systematic review[27] in which teeth were exposed to trauma were included, it was stated that there are insufficient scientific data in order to assert that the health of dental pulp will be threatened in terms of orthodontic forces cause irreversible alterations on the cellular response of pulp and decrease of pulpal blood flow. However, it is stated that trauma can be a risk factor for pulp vitality loss during orthodontic treatment.

As a result, it was asserted that long-term excessive orthodontic forces can increase pulp inflammation, and irreversible pulpitis and necrosis may develop afterward.[36] Use of moderate and intermittent forces enables sufficient tooth movement, limits the damage in the pulp and allows the damaged pulps recover. Therefore, controlled forces and long resting periods are offered in order to enable esthetic and functional goals of orthodontic treatment without triggering a severe inflammatory reaction which can stimulate irreversible damages to dental pulp and periapical tissues.[18] In the review of Hamilton and Gutmann,[10] they stated that orthodontic tooth movement can cause degenerative and/or inflammatory responses in the dental pulp of the teeth of which apical formations were completed. They concluded that incidence and severity of these changes can be affected by previous or continuous problems to dental pulp such as trauma or decays while pulps in teeth without complete apical foramen include lower risks for these responses.

The relation between orthodontic treatment and external root resorption

Movement of endodontically treated teeth was approached with doubt in practice since 1990s. However, it was not methodologically based; there was almost a consensus that these teeth had more root resorption risk during the orthodontic movement.[37] It is highlighted that root resorption risk did not increase nor decrease in successfully endodontic treatments after Spurrier *et al*. study was published in 1990.[38]

Several general and specialist dentists believe that external apical root resorption (EARR) is an inescapable result of orthodontics and orthodontist is responsible for it when it develops during orthodontic treatment. The concerns about EARR as a result of orthodontic treatment are confirmed by high incidence levels.[39]

EARR is an irreversible undesirable side effect of orthodontics[40] and can begin at early leveling period of orthodontic treatment.[41] Orthodontic EARR is considered to be a type of surface resorption which is caused by mechanical dental traumas, surgical operations, and orthodontic forces or over pressure of teeth or tumors.[42] It is characterized by apical rounding morphologically or radiographically but it can present different degrees from slight blunted to round apex to over resorbed apex.[10] Apex or lateral surfaces of roots can be resorbed but only apical root resorption can be observed by radiographic analysis. More than one-third of original root length is lost in severe EARR.[43]

However, EARR is multifactorial, and its reason is not totally understood, several studies sought to identify risk factors including EARR during orthodontic treatment. Certain factors can generally be classified as mechanical or biological. Mechanic factors include the magnitude, direction, and duration of the orthodontic forces.[44] Biological factors include traumatic injury history,[45] follicle with ectopic tooth eruption,[46] and presence of periapical lesion,[47] root morphology, previous root resorption,[48] individual susceptibility,[49] and genetic predisposition.[50] Adult patients are more prone to resorption because periodontal membrane becomes less vascularized, inflexible, and narrower, and cement becomes thinner and teeth movement becomes more difficult with aging.[48]

Animal studies presented contradictory results on teeth with root-filled and vital teeth with similar[51,52] or less[53] EARR levels. In addition, previous clinical studies which compared EARR extents in humans in teeth with root-filled or vital teeth after orthodontic treatment did not lead to a final decision. Spurrier *et al*.[38] and Mirabella and Artun[54] found a protective effect to resorption in endodontically treated teeth when compared to vital teeth, Esteves *et al*.,[55] Llamas-Carreras *et al*.,[56,57] and Castro *et al*.[58] could not find significant statistical differences.

The latest systematic reviews[59,60] on the subject stated that there are a small number of studies on the subject in the literature and concluded that EARR risk did not increase in teeth with root-filled. On the other hand, there was not a complete result for proof for less resorption in teeth that are treated endodontically after orthodontic treatment.[61]

Different genetic profiles of the individuals define a wide range of inflammatory and immune responses to common external stimulus. Recent findings[50,62] on the subject enabled a new perspective on the subject with specific genetic variables on IL-1 beta (IL1B) and IL-1 alpha (IL1A) which has an increasing genetic predisposition to EARR in vital teeth after orthodontic treatment. IL-1 is one of the leading cytokines, which is related to vessel wall inflammation during tooth movement and pulp tissue is an important releaser of this protein.[63] IL-1 molecules create a pro-inflammatory environment by increasing healing and transfer of leukocyte, which is a prerequisite for tooth movement and enable the continuation when inflammation begins. Dental response to inflammation is quite different in root-filled teeth because pulp tissue of the teeth is totally removed and filled with an inorganic filling material. Therefore, EARR in orthodontic treatment of root-filled teeth is significantly related to various intermediary genetic variations to inflammatory response.[64] Iglesias-Lineras *et al*.[64] had samples for DNA analysis from 93 patients in the study they carried out to find if genetic variations of an IL-1 gene cluster in root canal filled teeth are positive or negative in terms of EARR after orthodontic treatment. Inheriting a specific allele of the IL-1 cytokine agonist gene may be predisposed for EARR after orthodontic treatment in root-filled teeth.

Castro *et al*.[58] evaluated EARR by CBCT after an orthodontic treatment of 22 months without any tooth extractions. Incisors were not included in the study because they might have a trauma history and they compared root canal treated teeth with contralateral teeth in a split-mouth study design. They found that root shortening level was minimum after the orthodontic treatment, and there were not any statistically significant differences between root-filled teeth and vital teeth. In another prospective study,[65] which made evaluations with CBCT, 152 patients were examined. The teeth which were shortened the most after the treatment was upper lateral incisors and upper central incisors. 94% of the patient had at least one tooth which shortened more than 1 mm. Almost 7% of the patients had at least one tooth with approximately 4 mm of resorption. In general, there was more shortening in maxillary teeth than mandibular teeth and anterior teeth than posterior teeth. A positive correlation between age and resorption was observed.

Llamas-Carreras *et al*.[57] compared EARR in maxillary incisors, which are orthodontically treated, with vital contralateral teeth in 38 patients in split-mouth design. The evaluation was carried out with digital panoramic films before and after the orthodontic treatment. They did not found any significant statistical differences between untreated teeth and teeth with endodontic treatment in terms of EARR. In another split-mouth study[56] with a population of 77 patients, EARR evaluation was carried out by panoramic views in all tooth types. A significant difference was not found between root-filled teeth and contralateral vital teeth. Incisor teeth underwent root resorption more frequently.

Picanço *et al*.[66] evaluated 99 patients whose orthodontic treatment was completed in a study in which they studied predisposed factors of external resorption associated with orthodontic treatment. They found that increased age and prolonged treatment had significant effects on severe root resorption and sex, malocclusion type, morphology of the roots, and bone crests were not risk factors. They stated that treatment protocols including extraction of teeth increased the risk of severe apical resorption. Esteves *et al*.[55] compared EARR in root canal treated maxillary central incisors with homolog vital contralateral in a limited population with 15 patients. They observed more resorption on root-filled teeth in half of the cases and in vital teeth in the other half. Lempesi *et al*.[67] examined apical root resorption of impacted maxillary canines after orthodontic treatment with traction and surgery. They compared an experimental group with 24 impacted canine teeth with 24 normal canine teeth, and they recorded similar levels of root resorption. They concluded that maxillary canine impaction was a weak determinant in EARR.

The effects of materials that are used during root canal treatment to EARR were also examined. de Souza *et al*.[68] filled the canals with a calcium hydroxide (CH) based sealer after CH medication of 14 days in a group and another group was filled with a zinc oxide-eugenol-based sealer at the first session on their study with dogs. Orthodontic force was applied to the teeth afterward. Histomorphological parameters of teeth, which are filled with CH based sealer, presented a significant rate of recovery. Alkaline pH neutralizes acidic products of clastic cells and prevents dissolution of mineral components. The authors asserted that high concentrations of calcium ions deriving from CH would activate alkaline phosphate, creating new calcific tissue formation which may be the reason of possible a decrease in resorption.

Cervical invasive root resorption (CIRR), which is a progressively developing destructive form of external root resorption that is characterized with clastic resorbing cells adjacent to dentin and invasion of root dentin by fibrovascular tissue, was also searched as an effect of orthodontic treatment. It was found out that orthodontic treatment was the most frequent predisposed factor in the development of CIRR in the analysis of 257 teeth of 22 patients.[69] Trauma and intracoronal bleaching are among the most frequent factor besides orthodontic

treatment. Possible mechanisms for the cause of these lesions in orthodontically treated teeth were not understood. As mandibular molars serve as anchoring tooth for most of the orthodontic forces, and they are subject to stronger forces for longer, they are found to be the most frequently affected teeth. Thönen *et al*.[70] evaluated molar teeth of 108 patients, which are treated with fixed orthodontic treatment, clinically in terms of CIRR, radiographically by bite-wing radiographs and CBCT. While all molar teeth were found healthy clinically, CIRR in one tooth and surface resorption in three teeth were observed in the CBCT of 18 patients.

Methods which are used in order to evaluate external apical root resorption and limitations

In general, extraoral radiographs are less accurate than periapical films in measuring EARR extent. Using panoramic films to measure root resorptions before and after the treatment could overestimate or underestimate root loss amount after orthodontic tooth movement.[57] Root apex can place out of focal trough, especially in the frontal regions in panoramic radiographs. The benefits of lateral cephalometric radiography in the determination of root resorptions are limited because of the superposition of the teeth.[71] It was presented that the most important reason for failure in panoramic radiographs is the head position, which is dependent tilting. Stramotas *et al*.[72] found out in the panoramic radiographs, which were taken at different times, that linear measurements become accurate enough if occlusal level is positioned similarly in two points and extent of tilting is not more than 10°C.

Computerized tomography can be used for diagnosis in the maxillofacial region, but high radiation doses and prices prevent them being a standard vehicle for dental viewing. CBCT, which enables more accurate view of root resorption including posterior teeth than traditional radiographs, is a reliable diagnostic device.[61] CBCT provides repeatable views without distortion.[65] Therefore, CBCT views are recommended to define different types of resorption along root surface.[73]

Teeth length can be measured by using a dynamic method, which is called axial guided navigation in which teeth are measured in their maximum long axial length from root apex to its corresponding cusp tip[58] or based on the greatest distance from incisal/occlusal edge to cementoenamel junction.[56] Cusp tips are expected to be preserved after orthodontic treatment, and there will be no significant occlusal abrasion during the interval of orthodontic treatment (initiation of treatment and after treatment).[58] The anatomic formation can change along a cervical region in the measurement of the enamel-cement junction.[58]

There are some doubts on the evaluation of incisors in the studies EARR inducted with orthodontic treatment. Incisors are more likely to be subject to trauma. It is known that trauma can be subclinic and cannot be remembered by patients or their parents which increases the bias.[58]

Split-mouth study designs clear away most of the variation between individuals, but it is also a fact that split-mouth study designs do not guarantee similar conditions with orthodontic tooth movement. There can be differences between positions of contralateral teeth, and asymmetric orthodontic biomechanics can be necessary which causes variations in EARR extent.[58]

The route for endodontically treated teeth

It was stated that there was not a need for orthodontic planning for orthodontic movement of root-filled teeth unless there is not an EARR, which was not interpreted by other etiologic factors.[58]

If orthodontic movement does not change pulp biology in terms of morphology or age, it also do not affect cellular and tissular phenomenon of tooth movement. The forces can be applied a few days later after endodontic treatment is completed from a biological perspective and based on knowledge on pulp biology and orthodontic movement. Exudates (liquid) and inflammatory leakage (cells) are absorbed and leave from the region after 15 and 30 days.[37]

If there is a failure on the teeth with endodontic treatment, which are applied orthodontic force months or years later, it must not be related to the applied tooth movement. The applied forces do not affect pathogenic and virulence of microbiota or biology of microbial biofilms and chronic inflammatory periapical lesions. The failure must be interpreted as a result of limits about endodontic treatment.[37]

Approach for tooth with periapical lesions

When there is a need for orthodontic treatment in patients having teeth with apical periodontitis, clinicians who have doubt about this topic, experience problems about the treatment plan. The periapical environment of teeth with apical periodontitis can be changed with higher bacterial endotoxic concentration, presence of inflammatory reaction, and bone and root resorption.[74] The existence of these factors can complicate the healing process by increasing inflammatory reaction and root resorption so it can be a concern for orthodontic movement.[75]

There are limited histomorphological data in the literature on the orthodontic movement after root canal treatment of teeth with apical periodontitis. de

Souza *et al*.[75] concluded that healing process of chronic periapical lesions was faster in the experimental group which does not include orthodontic movement in their study in which they defined dogs' teeth with apical periodontitis submitted or not to orthodontic movement after root canal treatment. After root canal treatment which was received CH dressing, orthodontic movement of teeth with chronic periapical lesion delayed the healing process, but it did not prevent the healing.

Paduano *et al*.[76] reported a successful treatment with endodontic and orthodontic combined treatment in a case presentation of a patient who had cyst-like lesion signs radiographically with a severe deep bite and upper central incisors are necrosed by the trauma. After nonsurgical endodontic treatment of an 18-year-old patient, orthodontic treatment was carried out, and it was observed that large periapical lesion was totally healed after 2 years. The authors stated that orthodontic tooth movement can be applied without a need to wait for completely healing after root treatment of periapical cyst-like lesions was completed. In another case report,[77] the treatment of a large periapical lesion, which developed in relation to a previous trauma in the maxillary anterior region of a patient whose orthodontic treatment began 2 months ago was stated. In the treatment, apical openness was obturated by calcium-enriched mixture and the treatment was completed in the first session. Lesion completely healed after 2 years follow-up.

Other results such as persistence, partial regression, or increase of the previous lesion as a result of endodontic treatment are independent from orthodontic movement. Endodontic treatment and complete elimination capacity of microbiota must be evaluated in these cases. Another different morphology such as apical deltas, dilacerations, and developmental grooves can complicate elimination of microbiota by endodontic treatment. The reason of failure in teeth which are orthodontically treated is not an orthodontic movement.[37]

Orthodontic movement in tooth with apical surgery

It was discovered in the literature that there is a limited number of information on the effect of teeth with apical surgery to orthodontic movement. Long-term prognosis of these teeth is a subject which is still unclear in the literature. In Baranowskyj's study,[78] the health rate of hard and soft alveolar tissues was evaluated in dogs' teeth in the early intrusive orthodontic forces to root-filled and previously managed with surgical endodontic procedures teeth. Histological evaluation of examples from 6 weeks showed that healing was late in the teeth with root-filled and root-end resection. There is a small number of data about the problems which can be caused by movement of teeth which were subject to endodontic surgery. There are evaluations stating that more apical resorption will develop as dentin becomes clear in the root surface which was applied resection, irritation of root-end filling material, permanent inflammation, or insufficient obturation by root end filling material.

Do the teeth which had endodontic treatment affect orthodontic movement?

It was stated that teeth which had endodontic treatment can be moved as easy as teeth with vital pulp.[51,79] It does not affect orthodontic movement unless ankylosis develops. There are publications which state that root canal must be cleaned, shaped and filled with CH, restored occlusally in order to prevent bacterial leakage, and canal must be filled after orthodontic tooth movement is completed if there is a need for endodontic treatment during orthodontic movement.[10]

One of the most important factors affecting success when teeth, which were endodontically treated, are orthodontically treated is the magnitude and duration of the force. Orthodontic forces also cause dental traumas in the teeth in different degrees.

Problems caused by orthodontic procedures during endodontic treatment

Endodontic applications in orthodontic patients can be difficult because of teeth isolation, dental bands, and braces so root canal treatment must be performed in coordination with orthodontist and dentist or endodontist and/or pedodontist. Individual adaption of clamps and other retentive devices must be carried out.[80] Lingual orthodontic braces can cause problems when access cavity is being opened. Removing the braces from the teeth and having them braced again after endodontic treatment can be easier and faster. The applied orthodontic attachments decrease the accuracy of evaluation of radiographic view and pulp vitality tests. Endodontic or periodontal symptoms can be interfered with orthodontic pains. Apical resorption generally breaks natural construction of dentinocemental junction, creating an extremely irregular, rough, notched, and gapped root end three dimensionally.[10]

CONCLUSION

Application of a severe orthodontic force for a long time can cause irreversible pulpitis and necrosis in pulp by increasing pulp inflammation process. Use of moderate and intermittent forces enables sufficient tooth movement, limits the damage in the pulp, and allows the damaged pulp healing. Controlled mechanic forces during orthodontic treatment can cause temporary

changes in the pulp unless they are not severe. Pulp sensitivity test must be interpreted carefully in orthodontically treated patients, and thermal tests are more reliable than EPT. The risk of necrosis in pulp increases as a result of orthodontic forces to teeth having a trauma history.

It is important to complete the treatment of teeth, which need endodontic treatment with a careful clinical and radiographical evaluation before orthodontic treatment. A successful endodontic treatment is a must for a successful orthodontic movement. The quality of previous root canal treatment, the health of periodontal membrane and careful application of orthodontic forces are among the factors that need attention during the treatment.

Microscopic root resorption occurs in all teeth during orthodontic treatment, which is clinically insignificant and cannot be determined radiographically. If the quality of endodontic treatment is good in root-filled teeth, orthodontic forces applied to teeth do not increase external apical root resorption.

Teeth which were subject to trauma are more sensitive to orthodontic movement so clinical and radiographic evaluations must be carried out carefully before force is applied to these teeth. The patient must also be informed about the possible complications and the possibility of prolongation of treatment period.

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Conflicts of interest
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