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Orthodontically Induced Root Resorption- An Updated Review

SUMMARY

Background/Aim: *Root resorption is one of the most common consequences of orthodontic treatment. However, its mechanism, etiology factors, diagnostic methods and the possibility of root repair remain controversial topics. The aim of this paper is to provide an updated review of the current literature concerning the orthodontically induced root resorption.* ***Material and Methods:*** *A literature search was performed using Google Scholar, PubMed and Scopus search engines covering the period January 1930 until June 2019 corresponding to articles investigating the mechanism, etiology, methods of interpretation of root resorption and the stages of root repair.* ***Results:*** *The mechanism of orthodontically induced root resorption involves an interaction between several molecular signaling pathways, which result in the resorption of both cementum and dentin by odontoclasts/ cementoclasts. Root resorption can be the result of both treatment and patient-related factors. The main risk factors include prolonged orthodontic treatments, heavy forces, specific tooth movements, method of force application, systemic/genetic factors and aberrant root morphology. Nevertheless, root resorption is repaired to some extend by cellular cementum.* ***Conclusions:*** *Orthodontically root resorption is an unavoidable complication mainly due to its multifactorial etiology. However, its severity can be minimized with careful planning and radiographic monitoring.*

Key words: External Apical Root Resorption, Orthodontically Induced Root Resorption, Orthodontic Treatment, Resorption Repair

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Introduction

Root resorption is a common complication associated with orthodontic treatment. Approximately 90% of orthodontically treated teeth present some degree of external apical root resorption (EARR). However, 15% of teeth with EARR show severe apical resorption of more than 4 mm. The mean root reduction ranges between 0,5-3,0 mm[1] (Table 1).

Table 1. Classification of degree of EARR[2]

Mild	Until 2 mm reduction of the initial root length
Moderate	More than 2 mm reduction but less than 1/3 of the initial root length
Severe	Greater than 4 mm or 1/3 of the original root length

EARR describes the pathologic loss of the cementum and dentine resulting in tooth shortening (Figure 1). Orthodontically induced resorptions mainly cause mild

or moderate root reductions, thus they present clinical symptoms of low significance, such as slight tooth mobility[3] (Figure 2). However, severe resorptions can result to complete tooth loss[4].

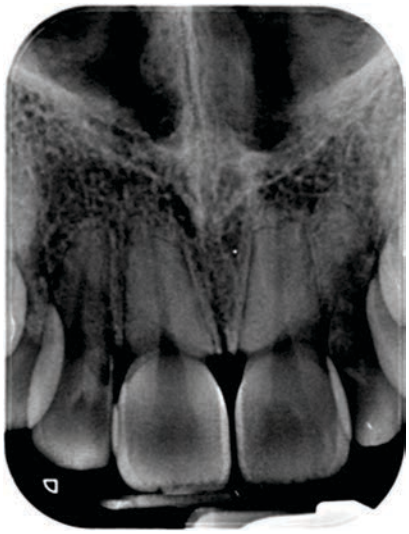

Figure 1. Digital Periapical radiograph of maxillary central incisors with severe EARR

Figure 2. Digital Periapical radiograph showing mild EARR of mandibular central incisors

The relationship between orthodontic treatment-related factors and EARR has been extensively investigated[4]. In more detail, the treatment duration and force magnitudes are considered as the most important risk factors for developing EARR[5]. While, the distance and the type of tooth movement, together with the treatment techniques appear to be partly responsible[6]. Maxillary central and lateral incisors seem to be the most susceptible to apical resorption[7].

Hence, it is mandatory to assess the treatment-related and patient-related factors resulting to EARR during orthodontic treatment, in order to avoid serious complications and to decrease root resorption incidences.

Material and Methods

A literature search was conducted using the online databases PubMed, Google Scholar and Scopus, searching for original research papers and review articles regarding orthodontically induced root resorptions. The search included articles published until June 2019. The following terms were searched to identify relevant publications: "orthodontically induced root resorption" OR "external apical root resorption" OR "diagnosis" OR "root repair". Inclusion criteria ranged from original research papers and review articles relevant to orthodontically induced root resorption to articles written in the English language. While the exclusion criteria were: Articles irrelevant to orthodontically root resorption, animal studies articles written in languages other than English. The reviewers for reliable results applied the criteria to each article independently.

Results

Mechanism

Orthodontic treatment is based on the coordinated tissue resorption and apposition of the surrounding bone and periodontal ligament. Forces generated during the orthodontic treatment attack the cementum and subsequently compress the vasculature resulting in ischemia, necrosis and hyalinization of the periodontal ligament and adjacent alveolar bone[8]. Then, macrophage-like cells, multinucleated cells, osteoclasts, and cementoclasts/odontoclasts remove the necrotic and hyalinized tissues in the compressive zone of the periodontium[9]. However, since, the exact mechanism of EARR is still obscure; it is likely that clast cells-mediated directly damage the superficial layer of the cementum, without necrosis and hyalinization of the periodontal tissues[10].

Etiology

The etiology of orthodontically induced root resorptions is complex and multifactorial. Multiple biological and mechanical factors are considered responsible for root resorption.

Treatment-related factors

Several factors attribute to the development of orthodontically induced root resorptions, including treatment duration[11-15], magnitude of the applied

forces[4,11,14,16-18], direction of tooth movement[17,19] amount of apical displacement[12,14], force application method (continuous vs. intermittent)[8,19], type of appliance[21] and treatment technique[21,22].

Treatment duration

It has been noted in many clinical studies that prolonged orthodontic treatments (over 3 years) are positive correlated with severe EARR[4,14,18]. A recent meta-analysis also confirmed the association between root resorption and treatment of long duration[15].

Magnitude of orthodontic force and Direction of tooth movement

Force application is one of the primary causes of EARR. In more detail, light orthodontic forces usually tend to result in mild root resorption, while archwire sequencing, bracket prescription and self-ligation appear to do not affect the root length[23]. During tipping movement, the apex absorbs all the compressive stress, resulting in increased stress per unit surface area[4,24,25]. In contrast, translation movement generates compressive stress to the entire root surface, which causes cementum resorption at the sides of periodontal ligament compression. However, resorptions, due to translation, are rare and milder than those observed by tipping[26]. Though, extrusive movements happen effortlessly, they can also cause orthodontically induced root resorption at the cervical third of the root. During intrusive tooth movement, almost all the stress is concentrated in the apex; thus, again in this situation the risk of EARR rises significantly[22]. It should be noted that during intrusion movements the roots get resorbed about four times more than during extrusion movements[19].

Force application method (continuous vs. intermittent)

Tooth movement induced by orthodontic force should resemble the physiologic balance between the tooth movement and the bony adaptation[14]. Schwarz[27] stated that when force exceeded the threshold of the optimal force level for tooth movement (between 7 and 26 g per cm^2) root resorption occurs. While, when the pressure is below this threshold, root resorption incidences decrease[28]. This was also confirmed by another clinical study, which concluded that light forces produce mild EARR, whereas intermediate or heavy forces resulted in severe resorptions[29].

Types of Orthodontic Technique

Root resorption is an inevitable drawback of all orthodontic techniques.

Root Resorption and Fixed Orthodontic Treatment

Due to the inaccurate positioning of brackets and the incongruity between preadjusted brackets and tooth shapes, several months are required to complete a Fixed Orthodontic Treatment (FOT). As a result, during FOT teeth often undergo a back-and-forth movement, which decrease significantly the root length. Thus, treatment method is considered as a high-risk factor for EARR. In more detail, in a study, the mean reduction of root in the straight wire group was 8,2 %, while the conventional edgewise group showed 7,5% reduction of the initial root length[30]. Moreover, children with Angle Class II malocclusion, who underwent two-phase treatment (functional removable appliance and fixed appliance) present less amount of root resorption than one-phase treatment cases[31]. EARRs in cases treated with Damon3 self-ligating braces are similar to those of conventional brackets. In addition, although several studies have confirmed a strong correlation between Rapid Maxillary Expansion (RME) and EARR [33,34]; a recent Cone Beam Computed Tomography (CBCT) study showed a primary statistically significant resorption of the cervical region[35].

Root Resorption and Clear Aligners

Clear Aligners Treatment (CAT) causes mostly mild root shortening, since they can be preprogrammed to control the magnitude of the force applied on teeth, and consequently, the stress on the apical area could be controlled to prevent or even minimize the incidences of orthodontically- induced root resorptions[36,37]. The treatment time of CAT is comparable to that of the FOT even though they present a slower tooth movement velocity, at least in non-extraction cases. In addition, the continual interproximal enamel reduction during CAT reduces the crowding severity and as a result, decreases the amount of tooth movement. Nevertheless, Gay et al. [38] noted that root resorption incidences resulted by clear aligners are similar to that described when light forces are applied (approximately 10% of the initial root length). On the contrary, a study recently found a similar predisposition for apical root resorption using either removable aligners or fixed appliances[39]. It was suggested that in both cases, orthodontic forces trigger cellular and molecular responses, which result in root resorption.

Extraction cases

Extraction cases have 2,72 times more chances of developing severe EARR[40]; since, the retraction mechanics used for the anterior teeth increase the apical movements and the treatment duration[41].

Patient-related factors

Chronological age and Dental age

Since periodontal membrane vascularity decreases and bone density increases with age, chronological age can be considered as a risk factor[42]. However, some studies do not approve this correlation[23,43]. Regarding dental age, it has been observed that teeth with incomplete apex undergo less root resorption compared to those with complete root. The most likely explanation is that during orthodontic treatment, the apices do not stop to develop until they reach their full root length[43].

Gender

An association between gender and root resorption has not been confirmed yet[44]. Males and females have equal chances to develop root resorption.

Ethnicity

Ethnicity is one of the contributing factors for root shortening. This can be proved by a study of Sameshima and Sinclair[45], who evaluated the root resorption indices of patients, who were treated with fixed edgewise appliances. They observed that Asian patients develop significantly less EARR than white or Hispanic patients. However, this may represent an ethnic difference based on genetic, environmental or even cultural factors.

Systemic factors

Allergy and asthma appear to increase the risk of EARR[28,46]. Decreased level of estrogens and hyperthyroidism may enhance orthodontic tooth movement. In contrast, hypothyroidism might result in increased root resorption. While, calcitonin inhibits the activity of odontoclasts[47].

Genetic Factors

Genetic factors are one of the predominant causes of root resorptions. A twin retrospective study proved that monozygotic twins present twice as many EARR as the dizygotic twins. Thus, a strong genetic component of root resorption is indicated[48]. Al-Qawasmi *et al*.[49] found a significant association between EARR in maxillary central incisor and a polymorphic marker, called D18S64. This marker is related to the TNFRSF11A gene, which is an essential signaling molecule in osteoclast differentiation and function. Thus, it can be concluded that this locus or a similar one has a critical role in the development of EARR[50]. Moreover, Interleukin-1β (IL-1β) is a stimulus for osteoclastic cell recruitment and bone resorption during orthodontic treatment. Therefore, in cases of low IL-1β levels, the alveolar bone resorptive response is inhibited and thus bone resorption becomes a more laborious procedure, resulting in prolonged stress against the root[51].

Root Shape and Tooth Specificity

Thin and irregular apices (e.g. long, curved) are at greater risk of getting resorbed, possibly due to decreased resistance of the apices to overcome the mechanical stimuli[14]. Regarding tooth specificity, upper and lower incisors appear to be more susceptible to EARR[52]. More specifically, maxillary lateral incisors followed by mandibular incisors show the highest prevalence of resorption[10,13,15].

Alveolar Bone Density

Thin and elastic type of alveolar bone has the ability to absorb increased orthodontic mechanical stress than thick and more rigid alveolar bone[25.] As a result, alveolar bone density has a critical role in the development of root resorption[26].

Endodontically Treated Teeth

The association between endodontically treated teeth and root resorption has been adequately investigated. In the literature, endodontically treated teeth may develop more[53,54], equal[55], or even less root resorption[56] compared to vital teeth. However, in a recent systematic review endodontically treated teeth present less root resorption than vital teeth [57].

Visualization and diagnosis of root resorption

Radiographic Examination

The assessment of EARR is mostly evaluated by using two dimensional (2D) conventional imaging. In more detail, periapical radiographs, panoramic radiographs, and less often lateral cephalometric radiographs are used. However, 2D radiographs and especially, panoramic X-rays can increase the loss of the root length by 20%[58]. Apajalahti & Pelatola[59] tried to overcome this issue by measuring the pre and post treatment, rather than calculating the absolute values of apical root loss. Besides, angulations, especially of incisors, change during orthodontic treatment and thus the actual measurements of root lengths alter. In further detail, buccolingual inclinations, ranging between 0 and 10 mm, might cause a difference of 5%[2]. This could easily be attributed to the fact that the relative position of the focal trough to the dental arch during imaging. Thus, the 2D radiographs can be characterized insufficient to evaluate the location and the severity of orthodontically induced root resorption. Besides, orthodontically induced root resorptions extend in all aspects of root structure, therefore 2D images might decrease significantly the amount of root reduction. In contrast, Cone beam computed tomography (CBCT) creates a three-dimensional (3D) visualization of samples and it produces images in axial, coronal and sagittal slices[60].

Serial Sectioning and Light Microscopy

This method is primarily used for research purposes. At first, extracted teeth have to be sectioned longitudinally in a buccolingual direction and then examined under the microscope. Since resorptions can vary in both size and depth; light microscope can facilitate the investigation of craters. Irregular shape craters, apical resorptions and resorptions in the middle third of the root are frequently partially or completely overlooked in 2D images[4].

Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) has certain advantages in comparison to the 2D methods, since it allows the analysis of root samples in multiple planes[4]. However, it is very frequent to obtain a plain image, which suffers from data loss, especially in premolars area, due to their curved root surfaces. Therefore, miscalculations can occur during the assessments[61].

Micro-Computer Tomography (Micro-CT)

Micro-CT is an X-ray imaging method used for the diagnosis of mineralized tissues in 3D and it is characterized by its increased resolution and magnification[62]. Moreover, root resorptions can be evaluated in vitro in animals and ex vitro in humans, due to its diameter image restrictions (at most 68 mm)[4].

Repair of root resorption

Repair of root resorption starts immediately after the discontinuation of the orthodontic force or the decrease under a certain level[63]. Following the detachment of cementoclasts/odontoclasts, root repair starts around the resorption lacunae. Later on fibroblast-like cementoblastic cells produce non-collagenous matrix proteins and collagen fibrils in order to cover the lacunae with the new cementum and new periodontal ligament[64, 65].

Several factors can determine the amount of root repair such as the magnitude of applied force, the type of orthodontic appliance and other patients' related aspects. However, it should be mentioned that cementum repair is promoted during the application of interrupted or intermittent orthodontic forces.

In addition, in a study of Owmann-Moll *et al.*[66] the histological degrees of root repair have been illustrated as follows:

- Partial Repair: The cervical part of the root is repaired with cellular or acellular cementum
- Functional Repair: The apical part is repaired with cellular cementum
- Anatomic Repair: The middle part of the root is repaired with acellular cementum.

Conclusions

Based on the available studies with a high level of evidence, it can be concluded that both treatment-related and patient-related factors can cause root resorption. Prolonged orthodontic treatments, heavy forces, fixed orthodontic appliances, extraction cases, thick alveolar bone, aberrant tooth morphology, genetic background and several systemic factors increase the risk of EARR. Orthodontic patients, who due to patient-related factors, are more prone to EARRs, require careful examination and meticulous orthodontic treatment planning. Moreover, though, orthodontically root resorption is an unavoidable complication of orthodontic treatment; some degree of repair with cellular cementum occurs. The development of root resorption can be minimized by regular radiographic examinations and careful planning.

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