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Diagnosis and Management of Orthodontically Induced Inflammatory Root Resorption: A Review

Zineb Safi-Eddine, Soukaina Sahim, Ghizlane Radif, Zouhair El Khalfi, Farid El Quars

Orthodontics Department, Faculty of Dentistry, University Hassan II, Casablanca, Morocco
Email: safieddine.zineb@gmail.com

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Abstract

Orthodontically induced inflammatory root resorption (OIIRR) is an unavoidable consequence of the force applied during orthodontic treatment, which triggers inflammation and leads to iatrogenic root resorption. Thus, a thorough understanding of the biological aspects of OIIRR, including its pathophysiology and repair processes, is essential for preventing or minimizing damage to the apical region. The traditional management of OIIRR, involving pausing active orthodontic treatment and using a passive archwire, has remained largely unchanged. However, new interventions like low-level laser therapy (LLLT) or photobiomodulation, low-intensity pulsed ultrasound (LIPUS), and mechanical vibrational force have been introduced to mitigate the risk or enhance the healing process of OIIRR.

Subject Areas

Dentistry, Orthodontics

Keywords

Orthodontics, Orthodontic Treatment, Orthodontically Induced Inflammatory Root Resorption, Root Resorption, Management

1. Introduction

Orthodontically induced inflammatory root resorption (OIIRR) also called external apical root resorption (EARR) is an undesirable pathologic sequelae of orthodontic treatment [1]. It is defined as the process that leads to the loss of the dentin and/or the cementum, resulting in the blunting and shortening of the root's apex [2].

It was first described by BATES in 1856. Later, in 1914, OTTOLENGUI linked it to orthodontics. Also, KETCHAM was the first to stimulate interest in apical root resorption as a consequence of orthodontic treatment, leading to significant subsequent research in this area [3].

OIIRR is considered as the second most common undesirable outcome of orthodontic treatment, trailing behind white spot lesions of the enamel [4]. Their prevalence ranges widely from 20% to 100% among orthodontic patients. Meanwhile, severe cases are infrequent occurring between 1% and 5% [5].

The alterations in root length caused by OIIRR can lead to an unfavorable crown-root ratio, particularly when patients are presenting concurrent alveolar bone loss [5]. Therefore, this matter warrants careful attention, especially as an increasing number of adults, who are more susceptible to periodontal diseases, seek orthodontic treatment. Such imbalances can potentially result in tooth loss and affect both the quality of life of patients and the outcomes of the orthodontic treatment.

2. The Pathophysiology

Orthodontic Tooth Movement involves bone resorption and formation in the compressed and stretched areas of the Periodontal Ligament (PDL), respectively. Thus, the application of orthodontic force disrupts the natural balance within the PDL, affecting blood circulation and localized conditions and triggering biochemical and cellular responses, which makes them initiate a localized inflammatory process [6]. This inflammatory response is crucial for both the tooth movement and the leading of root resorption. When orthodontic forces surpass the resistance and repair capacities of the periapical tissues, they result in a necrotic tissue zone called the hyaline zone [7]. Upon removal of the hyaline zone, the layer of cementoblasts on the outer surface of the tooth root may be removed, exposing the underlying highly dense and mineralized cementum [7] [8].

Resorption carries on until all necrotic tissue is removed or until the intensity of the orthodontic forces decreases [8]. The loss of substance resulting from this resorptive process increases the surface of the root. This leads to a decrease of the pressure that comes from the orthodontic force application [9].

Usually, cementum undergoes self-repair after orthodontic force cessation. However, in instances of significant defects, the damage remains unrepaired, leading to sustained root resorption.

Another point to considerate is that the apical third of the root is especially prone to iatrogenic harm from orthodontic procedures due to the periapical cementum's increased fragility and susceptibility to injury under intense forces and resulting vascular stasis.

In addition, the apical region of cementum has reduced hardness and elastic modulus compared with the cervical region, which makes the area more vulnerable to root resorption [7]-[9].

3. Risk Factors

The etiology of OIIRR is multifactorial and could be related to the combination of both host and mechanics factors [10].

Host factors are patient-related, such as age, gender, race, genetic predisposition, medical health and habits, family and dental history, alveolar bone density, the condition and the initial dental malocclusion.

They also encompass oral habits and parafunctions as well, such as bruxism, atypical swallowing, oral ventilation, thumb sucking, and onychophagia.

These habits involve complex patterns of muscle contraction that may increase the risk of OIIRR [10] [11].

Infectious inflammation of periapical tissues and periodontal diseases are also included as etiological factors that may induce OIIRR [10] [12].

Concerning root morphology, it influences the susceptibility of teeth to resorption, with compression areas being more prone. It has been suggested that teeth with relatively short roots prior to orthodontic treatment are more likely to develop resorption during the treatment. The shape of the root also seems to be associated with varying amounts of OIIRR. Teeth with pipette-shaped roots, apical bends, or other abnormal shapes (pointed, eroded, blunt, bent, or bottle-shaped) tend to have a higher risk of OIIRR [12].

Some teeth are more likely to be affected. The most commonly concerned, in order, are maxillary incisors, mandibular incisors, canines, maxillary premolars, and finally, the distal roots of the lower molars [12].

Orthodontic movement of teeth that have previously experienced trauma is linked to adverse effects on the pulp and periodontal tissues. An increased rate of root resorption is observed in previously traumatized teeth, especially in moderate and severe traumas such as extrusive, lateral or intrusive luxations and avulsions [13].

The host factors are beyond the clinician's control. Nonetheless, it's crucial for orthodontists to identify them and pinpoint high-risk patients prior to starting treatment. Patients flagged as high-risk should be made aware of the potential for OIIRR and get monitored by periodic radiographic examination.

Meanwhile, mechanics factors are more of a concern to the clinician because they can be manipulated and adjusted during orthodontic treatment to minimize progressive root resorption.

Indeed, orthodontic treatment techniques, magnitude of the used forces and prolonged treatment duration can increase the risk of root resorption [10] [13]. Studies showed that prolonged orthodontic forces lead to higher prevalence of severe root resorption. Continuous forces increase the risk of root resorption compared to intermittent forces, which allow for repair mechanisms to reduce resorption [10] [14].

Concerning the direction of orthodontic forces, intrusive movements pose the highest risk due to concentrated forces on the tooth's apical region. To minimize the impact of intrusion on the root resorption, it is recommended to use lighter forces while controlling force direction and tooth positioning [10] [15].

Positioning TADs further forward (between the maxillary lateral incisor and canine) for incisor intrusion may exert stronger apical forces and increased compression on blood vessels, potentially leading to greater OIIRR compared to TADs placed further back (between the maxillary second premolar and the first permanent molar) [16].

Retraction and torque movements may not directly increase the risk of OIIRR, but factors such as the magnitude of applied forces, distribution of stress and total apical displacement can enhance their impact on OIIRR. A greater extent of apical displacement may indicate prolonged force application, leading to hyalinization and subsequent OIIRR [1] [17].

Concerning the impact of the type of orthodontic device, OIIRR does not appear to be affected by the type of bracket ligation method (conventional/self-ligating) bracket prescription or the use of straight wire or standard edgewise brackets [1] [16]. There was also no observed difference in OIIRR associated with different archwire sequences [16] [18].

Studies suggest that aligners result in less incidence and severity of root resorption compared to fixed appliances [5] [19] [20]. This may be due to the nature of intermittent and relatively light forces with these appliances, the simpler types of tooth movement leading to smaller amounts of tooth displacement or apical movement [16].

The decision between extraction and non-extraction orthodontic treatments has a notable impact on OIIRR. Extraction of four bicuspids is associated with a higher risk of OIIRR compared to non-extraction cases [21] [22]. This is likely due to the greater distance that teeth need to be moved in extraction cases. Longer movement distances require more force and treatment time, potentially leading to increased OIIRR.

4. Diagnosis and Monitoring of OIIRR

A structured diagnostic approach is important to detect resorptions that can occur during and/or after the active phase of orthodontic treatment.

4.1. Radiographic Methods

Radiographs provide clinicians with valuable information about the overall condition of the dentition, presence of any pathology, root morphology, and bone levels.

Currently, the primary method used to diagnose and monitor root resorption involves radiography, where periapical, panoramic radiograph and lateral cephalogram are used.

Three-dimensional imaging technique such as Cone Beam Computed Tomography (CBCT) is not routinely recommended unless specifically indicated, due to concerns about radiation exposure and costs [9].

However, using 2D measurements to assess root resorption has shown inferior accuracy and reliability compared to 3D measurements, as supported by various studies [19] [22] [23]. They have demonstrated that root resorption values are often misestimated and less precise with 2D radiographs compared to CBCT. Cephalometric radiographs commonly encounter superimposition, magnification, and distortion. Likewise, panoramic radiographs are prone to distorting tooth positions and inclinations. This imaging methods can potentially alter the perceived length of roots due to differences in tooth inclination or angulation.

Concerning periapical radiographs, they serve as a useful screening tool for root resorption, offering more accurate images with minimal distortion particularly when using the paralleling technique compared to the bisecting technique [9].

Radiographic methods present various drawbacks and limitations when monitoring the progression of OIIRR, including the need for repeated radiation exposure, the demanding methods of standardization, concerns about accuracy, and the inability to detect early root resorption (approximately 60% - 70% of the mineralized tissue is lost prior to the identification) [24]-[26].

4.2. Methods Using Biological Markers

The use of biomarkers offers a more sensitive, specific, and safer approach compared to conventional radiographs for detecting early root resorption. They are based on the principle that orthodontic forces applied during treatment trigger an inflammatory process, remodeling of alveolar bone (formation and resorption), and subsequent root resorption. This sequence of events can be represented and identified using appropriate biomarkers [9] [27].

Blood, saliva, and gingival crevicular fluid (GCF) are used as mediums to detect OIIRR during active orthodontic treatment.

Various types of biomarkers have been explored for detecting OIIRR, including inflammatory markers like tumor necrosis factor and interleukins markers related to bone remodeling such as receptor activator of nuclear factor kappa B (RANKL), and markers of dentine matrix proteins like dentine phosphoprotein (DPP), dentine sialoprotein (DSP), dentine matrix protein 1 (DMP 1), and dentine sialophosphoprotein (DSPP) [28] [29].

Pro-resorptive cytokines mainly interleukin IL-6 is identified as a key biomarker for orthodontic tooth movement (OTM), as its levels increase significantly during resorption. IL-6 production by periodontal ligament cells is influenced by compressive forces, with heavy forces potentially inducing IL-6 release and subsequent osteoclast activation, contributing to OIIRR [9] [29].

Several studies have also highlighted the potential of dentine matrix proteins as specific biological indicators for OIIRR. This is due to their high specificity to dentine, being absent in bone, cartilage, soft tissues, or other oral tissue components.

These proteins are found in the periodontal ligament space solely during active root resorption, as dentine lacks remodeling capabilities like cementum or bone. Consequently, the concentration of these proteins correlates with the severity of OIIRR [30] [31].

Other biomarkers may also be associated with OIIRR: Alkaline phosphatase levels increase significantly in patients with OIIRR, though the relationship with thyroxine hormone remains controversial [22].

Calcitonin reduces orthodontic movement and may positively affect root resorption, while osteocalcin administration in animal studies has been linked to accelerated movement and potentially severe OIIRR. Parathyroid hormone (PTH) and calcitonin work together to regulate bone calcium levels, with elevated PTH associated with faster tooth movement and potentially increased OIIRR [28] [31] [32].

5. Management of OIIRR

Patients must be informed about the risk of root resorption before beginning orthodontic treatment as part of the informed consent process. It is also crucial to convey that orthodontists cannot currently predict which individuals might experience severe root resorption.

Several methods can help minimize OIIRR. These include using light intermittent forces, particularly for intrusive and torque movements, reducing treatment duration, controlling habits, and assessing family and medical history beforehand.

It is also recommended to avoid starting with large gauge wires and/or skipping wire sizes, to avoid “back and forth” movements and high-risk tooth displacements and to minimize the use of intermaxillary elastics [33] [34].

Annual radiological monitoring is recommended at 6 months of orthodontic treatment. In Case of dental trauma, 3 months observation period is recommended before treatment for mild trauma and 6 months observation period before treatment for moderate to severe trauma [13].

When OIIRR is detected, treatment plans should be reassessed to balance the risks and benefits of continuing treatment. The latter may be continued, modified, or terminated depending on OIIRR severity [35].

OIIRR typically requires at least 8 weeks for anatomical repair [36]. Therefore, if the decision is to continue active treatment, whether with or without modifications, it is suggested to pause treatment for at least three months with passive archwires or the exclusion of affected teeth from active forces [35] [37].

This enables the healing of cellular cementum and prevents further root resorption.

Follow-up radiographs should be taken before resuming treatment to ensure that the resorption has stabilized. If resorption is still progressing, alternative treatment options should be considered, and patients should be kept informed with regular follow-up examinations.

After the orthodontic appliance is removed, resorption typically stabilizes. If it does not, sequential root canal therapy with calcium hydroxide may be considered [38].

Different procedures have been suggested, aiming to reduce the occurrence of OIIRR, or to potentially repair it. These suggestions included several drugs, such as steroidal and non-steroidal drugs [37], fluoride [39], calcitonin [32], and tetracycline [40].

Other non-invasive adjuncts have been proposed for the same purpose, such as low-level laser therapy (LLLT) or photobiomodulation (PBMT), low-intensity pulsed ultrasound (LIPUS) and mechanical vibrational force.

The use of low-level laser therapy (LLLT) has been shown to significantly reduce root resorption during orthodontic treatment.

LLLT is a nonthermal and biostimulatory technology that promotes cellular absorption of laser by the mitochondria of target tissues, which activates signaling pathways and encourages vascularization, epithelialization and collagen synthesis. It reduces inflammation and enhances bone repair.

Additionally, LLLT provides analgesic, biomodulatory, and anti-inflammatory effects on dental tissues, which may positively influence OIIRR [41]. AlGaAs and InGaAs are used for decreasing induced inflammatory root resorption, with wavelength ranging from 660 nm to 980 nm. The average radiant power was ranging from 20 to 360 mW, which 100-mW irradiation could be sufficient to offer a positive impact on root reduction [42].

In clinical trials where laser therapy was applied to patients undergoing orthodontic procedures, those who received laser treatments had notably less root resorption compared to those who did not receive laser therapy [36] [43].

Comparisons between different methods of laser application, such as pulsed versus continuous therapy, did not show a significant difference in effectiveness.

While the optimal laser wavelength for LLLT is still undetermined, lower wavelengths may not deliver sufficient energy to the target tissues. In fact, studies using lower laser wavelengths indicated less success in reducing root resorption, suggesting that higher wavelengths might be more effective [36] [43].

Current findings reflect the effects of LLLT during the initial stages of orthodontic treatment, highlighting the need for further research to explore the impact of LLLT throughout the entire treatment duration and to identify the most effective laser wavelength for optimal results [44] [45].

Various application protocols have been reported in the literature. Some require a high frequency of patient visits, which is considered a major drawback. For instance, protocols involving laser treatments on days 0, 3, 7, 14, and then every 2 weeks demand frequent recalls. Alternatively, other protocols have been proposed with less frequent laser treatments, such as every 3 weeks, offering greater convenience to patients [46].

It has been shown that photobiomodulation application at single wavelength application is more effective than cumulative increased wavelength application in reducing percentage of resorption and resorption lacunae depths [47] [48]. However, some studies have shown that PBMT does not impact OIIRR, neither increasing nor decreasing its occurrence [47]-[49].

Low-intensity pulsed ultrasound (LIPUS) is a noninvasive technique that has been shown to enhance the healing process of OIIRR. Studies suggested that LIPUS has emerged as a promising intervention in this regard, displaying clinically meaningful results in reducing the severity of OIIRR [50] [51].

This method transmits mechanical energy into tissues as pressure waves, serving both diagnostic and therapeutic purposes [50]. It has a bio-stimulatory effect on both osteoblasts and osteoclasts and increases the number and activity of cells within the periodontal ligament (PDL) [52].

The mechanical stimulation from LIPUS is detected by receptors on the cell membrane, such as integrins and G-protein coupled receptors (GPCR), activating various mechanotransduction pathways in bone cells. Thus, it involves distributing stress concentration in the periodontal ligament (PDL) and enhancing the expression of receptor activator of nuclear factor kappa-B ligand (RANKL) in fibroblasts and osteoclasts. This process may suggest a potential for reducing OIIRR [53] [54].

The parameters influencing the application of LIPUS are determined by the type of the device used (transducer) and the study protocol. These include pulse width, frequency, pulse repetition frequency and the intensity at the transducer's surface area [55].

In general, the intensity of LIPUS falls within the range of ultrasound intensities typically used for diagnostic purposes (1 - 50 mW/cm^2). The devices emit an average of 200 μs bursts of 1.5 MHz acoustic sine waves, which are repeated at a modulation frequency of 1 kHz, delivering a global peak pressure of 30 mW/cm^2 [47].

Typically, the device is used at home by the patient for 20 minutes daily, for a duration ranging from 4 weeks to the entire treatment period [47] [55].

Despite recommendations for using mechanical vibration to shorten treatment duration and reduce root resorption in orthodontics, there is insufficient evidence to support these claims [56]-[58].

6. Conclusions

- Understanding the risk factors, the basic cellular events of tooth movement, and the biological aspects of OIIRR is essential for preventing and/or minimizing damage to the apical region.
- A well-established diagnosis and monitoring, the adherence to biological principles, and the application of optimal orthodontic forces are crucial for managing OIIRR.
- Various interventions, such as low-level laser therapy (LLLT) or photobiomodulation, low-intensity pulsed ultrasound (LIPUS) and mechanical vibrational force, have been introduced to reduce the risk of OIIRR or enhance the healing process. However, further studies are needed to develop proper usage protocols and evaluate the long-term effects of these methods.

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Conflicts of Interest

The authors declare no conflicts of interest.

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