Original Article

Effect of orthodontic treatment on traumatized teeth treated by regenerative endodontic procedure

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ABSTRACT

Objectives: To evaluate the effect of orthodontic movement on traumatized teeth treated with the regenerative endodontic procedure (REP).

Materials and Methods: The increase of the radiographic root area (RRA) of each REP tooth was measured at each follow-up visit after the end of orthodontic treatment. The study included two experimental groups of patients aged 7–17 with REP-treated teeth. The Ortho REP group consisted of eight patients who underwent orthodontic treatment, whereas the second group (no Ortho REP group) included seven patients who did not receive orthodontic treatment. The control groups comprised the same patients and their homologous or adjacent healthy teeth that did not undergo REP treatment.

Results: Orthodontic treatment did not negatively affect root development of immature, traumatized REP-treated teeth during the treatment or retention periods. Additionally, the increase in RRA in regenerated teeth was age-dependent, with the greatest RRA increase in young patients.

Conclusions: Close collaborative endodontic-orthodontic follow-up is recommended to ensure favorable results. The findings suggest that REP-treated teeth may undergo orthodontic treatment without adverse effects. (*Angle Orthod*. 2025;95:173–178.)

KEY WORDS: Orthodontic treatment; Regenerative endodontic procedure; Immature teeth; Platelet rich fibrin; Dental trauma

INTRODUCTION

Pulpal necrosis and the immediate arrest of continuous root development result from various etiologic factors,[1] with trauma in immature permanent teeth being the most common. Management of immature traumatized teeth is one of the biggest challenges in endodontics. Morphologic characteristics include thin dentinal walls, shortened roots, wide apical openings, and the absence of an apical stop, rendering disinfection and obturation procedures difficult and unpredictable. Historically, calcium hydroxide apexification has been the only treatment of choice.[2] Torabinejad and Chivian[3] offered treatment alternatives whereby the apical foramen is sealed with a mineral trioxide aggregate plug, which is currently considered the gold standard method. However, this treatment has the same disadvantages as calcium hydroxide apexification, leaving short roots and thin root canal walls with no further root development; thus, it does not contribute to quantitative or qualitative increases in root dimensions. In addition, immature teeth with formation of less than half the final root length at the time of trauma have a very poor prognosis.[4]

The regenerative endodontic procedure (REP)[5] was adopted by the American Association of Endodontists in 2012[6] and the European Society of Endodontology in 2016[7] because of its innovative outcome potential. The treatment principle is based on thorough disinfection and conditioning of the root canal dentin walls, and creation of a scaffold in the root canal as a base for stem cells and bioactive molecules (growth factors), followed by a tight coronal seal. This enables the development of vital tissues inside the root canal space and continuous

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Table 1. Endodontic and Orthodontic Data of Treated Patients

Case Number	Tooth	Sex	Severity of Trauma	Root Development (Cvek classification)	Age During REP: (yr)	Age During Ortho (yr)	Time Elapsed	Orthodontic Device Used:[a]	Status of Ortho Treatment:[b]	Orthodontic Treatment Duration: (mo)
1	12	M	Luxation	3	16	16:10	10	Inv	C	26
2	21	M	Not known	4	16	16:01	1	FA	C	15
3	21	M	Luxation	3	9	9:05	1	Hawley	C	16
						11:07	26	FA		18
4	21	M	Luxation	4	13	14:03	9	TB	C	7
						15:04	22	FA		11
5	21	M	Subluxation	4	10	11:10	18	Inv	D	8***
6	11	F	Not known	4	9	11:00	24	Inv	D	12***
7	11	F	Subluxation	3	9	12:01	34	FA	D	12***
8	11	F	Not known	3	12	15:04	35	FA	D	25***

[a] Orthodontic device used: Inv: Invisalign; Hawley: removable appliance; FA: fixed appliance; TB: twin block functional appliance.
[b] Status of ortho treatment: C: complete Treatment; D: during treatment.

development of the root, including narrowing of the apical foramen. Although the main goal of REP is to help induce continued root development and apical closure in teeth with necrotic pulps and open apices, REP was found to have other benefits such as the promotion of continuous root development through root widening and lengthening.[7] Periapical healing and continuous root development reportedly occur in 90%–100% and 50%–70% of cases, respectively.[8–10]

Dental trauma is common in children, affecting over 1 in 10, including the general population and orthodontic patients.[11] Orthodontic movement of traumatized teeth presents challenges, with some reports indicating increased risks of adverse effects during and after treatment,[12] including a debated higher risk of pulpal necrosis[12] in vital, mature traumatized teeth compared to nontraumatized teeth. Other common adverse effects are orthodontic root resorption and blunting of the root apex.[13] Invasive cervical root resorption, characterized by fibrovascular tissue invasion, related to orthodontic treatment[14,15] is another concern. Reports regarding the risks of root resorption are debatable. Some claim frequent resorption,[16] equal,[17] or reduced risks.[18] Overall, the impact of orthodontic treatment depends on factors including orthodontic force, trauma history, and type of root canal seal.[6,19] Therefore, thorough clinical and radiographic assessments are essential before treatment.

Although REP is becoming the legitimate treatment option for necrotic immature teeth,[9,10] little is known about the short- or long-term effects of orthodontic forces on REP-treated teeth. Additionally, modern orthodontic tools such as clear aligners, which enable the exclusion of traumatized teeth or application of lower forces on them during orthodontic movement, increase the need for thorough research on the effects of orthodontic forces on REP-treated teeth. Orthodontic treatment does not interfere with root development if performed on immature vital teeth, although it may delay the healing of periapical lesions in endodontically treated teeth.[20] Thus, it is recommended to delay orthodontic treatment for immature traumatized teeth with necrosis for at least 1 year[21] after REP to enable observation of periapical healing as well as the status of root development. Under certain circumstances, mild orthodontic movement may even improve periapical repair.

Although, some case studies[19,22–25] have reported the effects of orthodontic treatment on REP-treated teeth with or without complications, conclusions regarding long-term outcomes should be made with caution. The applied orthodontic force provides an additional inflammatory stimulus for the tooth, which might jeopardize successful regenerative outcomes.[24] This study was designed to acquire further knowledge regarding the impact of orthodontic treatment on teeth that have undergone REP. It uniquely explored how orthodontic forces affected continuous root development and overall outcomes in REP-treated immature teeth.

MATERIALS AND METHODS

All patients included in this study experienced trauma to one of their anterior teeth, which caused diagnosis of pulpal necrosis with or without periapical lesions.

Group Design

The study included two main groups with corresponding control groups (Table 1). The first group, the Ortho REP group, comprised eight REP patients aged 7–17 years who had undergone orthodontic treatment, with the homologous or adjacent tooth not requiring REP serving as the control (Ortho no REP group). The second group, the No Ortho REP group, included seven patients aged 7–17 years who did not undergo orthodontic treatment but had similar dental trauma. The homologous or adjacent tooth without REP treatment was the control (no Ortho no REP control group).

The traumatized teeth underwent a variety of movements, especially tipping and extrusion, within an average treatment time duration of 15.3 months.

Clinical Procedure

All traumatized teeth were diagnosed with pulpal necrosis, with or without apical periodontitis. All teeth were slightly tender to percussion, but not to palpation. Radiographic examination confirmed immature roots[26] and open apices. Accordingly, REP was performed with platelet-rich fibrin.

All patients were treated by a single endodontist. Medical and dental histories were obtained from all patients, followed by thorough oral and dental examinations. Mobility, percussion, cold sensitivity, and electric pulp tests were also performed. Two-dimensional diagnostic periapical radiographs were obtained, and a diagnosis was made. More details on each treated tooth and patient are summarized in Table 1. During the first visit, all patients received local anesthetic infiltration in the upper arch. Each injection included one cartridge of 2% lidocaine and 1:100,000 epinephrine (Safco, IL, USA). Treatment was performed under a surgical operating microscope (DOM; LaboMed, Prima, NY, USA) as described by Yoshpe et al.[8] After tooth isolation and access opening, all patients underwent REP according to the American Association of Endodontists (AAE) protocol[6] (as detailed in the Supplemental Table 1).

Method of Measurements

Clinical outcomes were assessed based on the presence or absence of signs and symptoms. Radiographic outcomes were assessed by the presence or absence of periapical lesions and an increase in the radiographic root area (RRA) percentage. The immediate postoperative and follow-up periapical radiographs were adjusted to similar sizes and pixels using Freeware Image J software (version 1.47; National Institutes of Health, MD, USA) together with the TurboReg plugin tool (Philippe Thevenaz, Biomedical Imaging Group, Swiss Federal Institute of Technology Lausanne, Switzerland).[27] Thereafter, the "Images to Stack" and "Stack to Images" functions were used to equalize the number of pixels in the radiographs. Subsequently, the radiographs of each patient were aligned and normalized using the TurboReg plugin tool. Only patients with at least 12 months of follow-up were included. All cases were reviewed separately by two examiners. Differences between examiners were resolved by discussion. The changes in root dimensions were calculated as percentages (Figure 1).

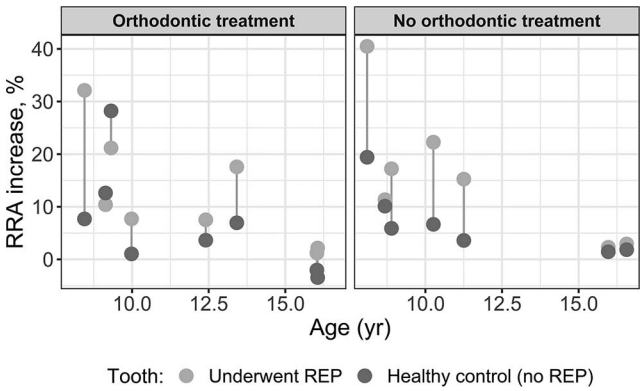

Figure 1. Increase in radiographic root area in traumatized teeth treated with regenerative endodontic procedures compared to that in control teeth. Left: Orthodontically treated teeth; Right: Teeth without orthodontic treatment; Vertical lines connect pairs of observations performed in the same patient.

Data Collection

Patient age and root development stage at the time of trauma, sex, tooth type, and the number of months elapsed between the trauma and REP were recorded. The etiology of the trauma, orthodontic appliance used, and duration of treatment were also recorded.

Statistical Analysis

Data were analyzed using R software (version 4.2.1; R Foundation for Statistical Computing, Austria). Within each group, multiple linear regression was employed using orthodontic treatment (a two-level factor) and patient age as independent variables to assess the main effect of the treatment and potential interactions between these variables simultaneously. Continuous variables (RRA percentage and age) were log-transformed to account for apparent nonlinearity.

RESULTS

All findings for the REP-treated teeth compared with those for the neighboring or homologous control teeth are shown in Figure 1. Except for two cases (13% of all cases), the traumatized regenerated teeth showed greater RRA percentage increases than did the matched control teeth. The outcome (RRA% increase) was age-dependent in all groups, with the largest increase in patients under age 11. Statistical analysis showed a significant main effect of age on the REP-treated teeth (model coefficient $P < .05$). In addition, a separate analysis performed for the control teeth showed the same result ($P < .05$). However, after comparing based on patient age, no significant main effect of orthodontic treatment on either the REP-treated ($P > .05$) or control teeth ($P > .05$) was found, with no significant interaction

between age and orthodontic treatment (REP, $P > .05$; control, $P > .05$).

DISCUSSION

Although REP has evolved greatly in recent years and seems to be used at an increasing rate,[28] little is known about the effect of orthodontic movement on REP-treated teeth. Endodontically treated teeth can successfully undergo orthodontic treatment.[29] However, for traumatized teeth with arrested root development, the evidence is inconclusive.[12] The current study comprised eight traumatized, immature maxillary incisors in eight patients who underwent REP followed by successful orthodontic treatment. The teeth showed an improvement in remodeling and repair of apical tissues, with enhancements in the root length and thickness throughout the orthodontic treatment and up to 2.5 years after its completion. Similar outcomes of successful orthodontic treatment after REP in traumatized nonvital immature teeth have been reported in three separate case reports.[19,23,24] Posttreatment radiographs in these case reports indicated remodeling of the periapical tissues and complete resolution of the periapical infection. The teeth responded favorably to orthodontic treatment during the active phase and showed no symptoms during the retention period (0.5–1.5 years, compared to 2.5 years in this observation). Root resorption is one of the most common complications of orthodontic tooth movement and may be observed in both endodontically treated and vital teeth.[13] In the present study, no root resorption was observed in the REP-treated teeth in patients undergoing orthodontic treatment, independent of the orthodontic treatment modality or appliance used (fixed or removable).

The highest percentage (Figure 1) gain in RRA at a young age is presumably due to the highest growth potential at this age. In addition, a better RRA percentage gain was obtained in the REP-treated teeth than in neighboring teeth. After REP, almost all teeth gained a higher RRA percentage than did the matched healthy control teeth. The teeth that stopped development after the trauma apparently showed compensatory growth, possibly due to the growth factors originating from the new tissue inside the root canal[30]. This was the first study to measure the RRA percentage in traumatized REP-treated teeth successfully.

Although these successful results of REP teeth treated during orthodontic treatment and the first few years of retention are known, the long-term stability of REP teeth treated by orthodontics is unclear. Alharbi et al.[31] described the recurrence of apical periodontitis with a sinus tract 6 years after successful REP and orthodontic treatment. The reason for this late failure may have been a fractured composite filling and canal recontamination.[32] Additionally, long-term complications after orthodontic treatment were also observed 4, 8, and 11 years after successful REP for traumatized teeth.[32] These included invasive external cervical resorption, tissue necrosis, and internal resorption with unclear causes. As the tissue that develops in the root canal after REP is unspecific and lacks an odontoblastic layer and pre-dentin, it may be more vulnerable to internal resorption. In addition, REP-treated teeth may be highly susceptible to inflammation and apical root resorption.[33] In general, orthodontic forces might have triggered the initiation of these complications. Therefore, good patient compliance is necessary during treatment, aimed at reducing the overall treatment time and minimizing unnecessary orthodontic forces for moving REP-treated teeth. As root development continues before, during, and after orthodontic treatment, strict endodontic control and monitoring are required. In all eight cases, close endodontic follow-up was performed every 3–6 months, as recommended.[24] When REP-treated teeth need to be treated orthodontically, special caution must be observed when making decisions regarding the overall treatment plan, appliance choice, force parameters, and whether to include or exclude these teeth in the treatment. Cautious application of orthodontic forces to REP-treated teeth is essential. Thus, limitations or modifications of the treatment objectives at treatment initiation should be considered. When possible, partial or complete exclusion of REP-treated teeth from orthodontic forces may be beneficial.[24] Use of light, short-acting force was suggested to be used for orthodontic movement of REP-treated teeth in a previously published case report.[24] Invisalign clear aligner therapy (Case 1, 5 and 6 in Table 1) enabled the exertion of light forces as well as a short treatment duration.[34] In the case of mandibular skeletal deficiency (Case 3 in Table 1), the first treatment stage involved functional appliance therapy,[24] which ensured minimal orthodontic force with no active or retentive components, minimizing complications.[35] Case 3 underwent two treatment phases. The first phase, at the age of 9 years and 5 months, involved a Hawley appliance for 16 months. The second phase, approximately 2 years later, at the age of 11 years and 7 months, involved a functional appliance for 18 months.

In this study, five of eight patients exhibited luxation and subluxation, with a similar favorable healing response. Thus, the long-term survival of teeth with severe trauma, such as avulsion or intrusion, treated with REP followed by orthodontic treatment remains unclear.

Orthodontic complications appear to be primarily associated with REP healing patterns. The timing of orthodontic treatment initiation after REP was highly variable in this study, ranging from 1 to 35 months, depending on the patient's age and customized goals for orthodontic treatment. Therefore, the specific waiting

time for orthodontic force application after REP remains unclear.

The main limitations of the present study were the small number of cases and their heterogeneity. However, many parameters in a clinical study, such as trauma severity, tooth developmental stage, time elapsed between trauma and REP treatment, and time of orthodontic treatment initiation after REP, as well as the type of orthodontic treatment, prevented a study design involving equal parameters.

CONCLUSIONS

- This study contributes valuable data on the effects of orthodontic treatment on REP-treated teeth.
- The findings add valuable information that should be considered during clinical decision-making and patient care in an area based only on empirical data.
- The current findings indicate that orthodontic treatment does not appear to be detrimental to root development in teeth that have undergone REP, refining treatment paradigms, and this may lead to improved patient outcomes.

SUPPLEMENTAL DATA

Supplemental Table #1 is available online.

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