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Evaluation of Regenerative Endodontic Therapy in Young Permanent Teeth with Pulp Necrosis: A Retrospective Study

Pulpa Nekrozu Olan Genç Daimi Dişlerde Rejeneratif Endodontik Tedavinin Değerlendirilmesi: Retrospektif Bir Çalışma

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ABSTRACT

Objective: This retrospective study aimed to evaluate the clinical and radiographic outcomes of regenerative endodontic therapy using mineral trioxide aggregate in immature permanent teeth with pulp necrosis over a 24-month follow-up period.

Methods: The study included 26 pediatric patients aged 8–13 years who were treated at the Department of Pediatric Dentistry, Marmara University Faculty of Dentistry, . Clinical and radiographic records from these patients were analyzed. A standard two-visit regenerative endodontic therapy protocol was employed with MTA. The Periapical Index (PAI) and Cvek root development classification were utilized to evaluate the treatment outcomes. Clinical success was determined by the absence of symptoms such as spontaneous or provoked pain, sensitivity to percussion and palpation, the presence of fistula, abscess, or pathological mobility. Radiographic success was assessed based on PAI scores, root resorption, and lamina dura/PDL findings.

Results: The study found an overall clinical success rate of 54% after 24 months. Clinical failures were associated primarily with multi-rooted teeth, which exhibited a higher failure rate compared to single-rooted teeth. Radiographically, there was a significant improvement in root development (Cvek score) over time, with 54% of teeth showing complete root development with full apical closure by the end of the study period.

Conclusion: RET using MTA demonstrates moderate clinical success in treating immature permanent teeth with pulp necrosis. The findings highlight the importance of rigorous treatment protocols and careful monitoring to optimize RET outcomes, especially in managing microbial contamination and achieving adequate isolation in pediatric patients

Keywords: Young permanent teeth, pulp necrosis, regenerative endodontic therapy, mineral trioxide aggregate

ÖZ

Amaç: Bu retrospektif çalışmanın amacı, pulpa nekrozu olan genç daimi dişlerde, 24 aylık takip süresi boyunca mineral trikoksit agregat kullanılarak yapılan rejeneratif endodontik tedavilerin klinik ve radyografik sonuçlarını değerlendirmektir.

Yöntemler: Çalışmaya, 8–13 yaş aralığında, Marmara Üniversitesi Diş Hekimliği Fakültesi, Çocuk Diş Hekimliği Anabilim Dalı' nda tedavi edilen 26 çocuk hasta dahil edilmiştir. Bu hastaların klinik ve radyografik kayıtları değerlendirilmiştir. Standart iki-seanslı rejeneratif endodontik tedavi protokolü MTA ile uygulanmıştır. Tedavi sonuçlarını değerlendirmek için Periapikal İndeks (PAI) ve Cvek kök gelişim sınıflaması kullanılmıştır. Klinik başarı, spontan veya provake ağrı, perküsyon ve palpasyon hassasiyeti, fistül, apse veya patolojik mobilite gibi semptomların olmamasıyla belirlenmiştir. Radyografik başarı, PAI skorları, kök rezorpsiyonu ve lamina dura/PDL bulguları kullanılarak değerlendirilmiştir.

Bulgular: Çalışmada, 24 ay sonunda genel klinik başarı oranı %54 olarak bulunmuştur. Klinik başarısızlıklar çoğunlukla çok köklü dişlerde görülmüş, bu dişler tek köklü dişlere kıyasla daha yüksek başarısızlık oranı göstermiştir. Radyografik olarak, zaman içinde Cvek skorunda anlamlı bir yükselme görülmüş, tedavi süreci sonunda dişlerin %54'ünde tam kök gelişimi ile birlikte apikalde tam kapanma olduğu görülmüştür.

Sonuç: MTA kullanılarak yapılan RET, pulpa nekrozu olan genç daimi dişlerde ortalama düzeyde klinik başarı göstermiştir. Bulgular, özellikle çocuk hastalarda mikrobiyal kontaminasyonun yönetimi ve yeterli izolasyonun sağlanması için dikkatli tedavi protokollerinin ve düzenli takip süreçlerinin önemini vurgulamaktadır

Anahtar Kelimeler: Genç daimi dişler, pulpa nekrozu, rejeneratif endodontik tedavi, mineral trikoksit agregat

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INTRODUCTION

Deep dentin caries, dental trauma, restorative procedures, and iatrogenic factors can significantly impact the pulp in immature permanent teeth. The primary goal in managing such teeth is to promote the completion of root development and maintain the tooth in a healthy condition within the arch, even in cases of pulp degeneration.[1]

Immature permanent teeth are characterized by roots with open apices and thin dentin walls.[2] Hertwig's epithelial root sheath (HERS) plays a crucial role in guiding the differentiation of odontoblasts and the formation of root dentin, while also determining the root's shape, number, and size.[3] Despite the high sensitivity of HERS to trauma and inflammation, root development can persist under certain conditions, such as adequate vascularization in the apical region, even when pulp inflammation or necrosis is present.[4] However, complete destruction of HERS halts root development. Notably, this does not necessarily preclude hard tissue deposition at the root apex. In cases of HERS damage, although odontoblast differentiation ceases, hard tissue formation may continue through the activity of cementoblasts in the apical region and mesenchymal stem cells from the dental follicle and periodontal ligament, which differentiate following injury.[5]

Treatment options for devitalized immature teeth are broadly divided into two categories: apexification and regenerative endodontic treatment.[6] RET is a biologically driven procedure aimed at restoring the root and dentin-pulp complex in necrotic or irreversibly inflamed immature permanent teeth. This approach offers key advantages, including the resolution of clinical symptoms, healing of apical periodontitis, and the continued development of the root. The underlying principle of RET is to stimulate undifferentiated mesenchymal cells under appropriate conditions, enabling their differentiation into cementoblasts and facilitating root maturation.[7] The success of RET depends on three critical factors. First, the root canals must be effectively disinfected to eliminate microbial contamination. Second, mesenchymal stem cells must be recruited, and a scaffold must be established to provide support for cellular proliferation and differentiation. Finally, a coronal seal must be placed, and the tooth must be properly restored to ensure long-term success.[8] The primary objective of successful RET is to ensure that the treated tooth remains asymptomatic and that periapical lesion healing is achieved.[9]

Mineral trioxide aggregate (MTA) is a widely utilized material in pediatric dentistry for apexification, apexogenesis, and RET in devitalized immature permanent teeth. Its biocompatibility, bioactivity, hydrophilicity, radiopacity, sealing ability, low solubility, and high potential to induce mesenchymal stem cell differentiation make it an indispensable material for these procedures.[10, 11]

The aim of this study is to retrospectively evaluate the clinical and radiographic outcomes of immature permanent teeth treated with RET over a 24-month follow-up period.

METHODS

Ethical Approval

The ethical approval for the study was obtained from the Marmara University Faculty of Medicine, Clinical Research Ethics Committee under Date: September 26, 2021, protocol number 09.2021.81.

Sample Size Calculation

The sample size was determined using G*Power 3.1 software, with the significance level set at 0.05, effect size 0.5 and a statistical power of 0.8. The calculation indicated a total of 25 participants was required.

Study Design

The study was designed as a retrospective research and included 26 pediatric patients aged 8–13 years, who were treated at the Department of Pediatric Dentistry, Marmara University Faculty of Dentistry, İstanbul, Turkey between June 2018 and February 2020 and completed a 24-months regular follow-up. MTA was applied as part of the RET procedure to 26 necrotic immature permanent teeth of these patients. The demographic information, clinical records, and follow-up radiographs of the patients were retrieved and evaluated from the archive records of Department of Oral & Maxilofacial Radiology, Faculty of Dentistry Marmara University, Istanbul, Turkey. Teeth from healthy children with no systemic diseases underwent regenerative endodontic treatment with MTA, and pre-treatment and post-treatment radiographic records for 12, 18, and 24 months from the faculty archive were included in the study group. Teeth that had prior restorative procedures before RET were excluded from the study.

Clinical Evaluation

The demographic information of the study population, the etiology affecting the pulp (dental caries or trauma), tooth number, and clinical symptoms were retrieved from archive records and documented. A clinical diagnosis of pulp necrosis was made on the basis of a preoperative negative response to electric pulp test. All the included teeth underwent standard RET due to pulp necrosis caused by deep caries or trauma. A standard 2-visit revascularization treatment protocol, based on the American Association of Endodontists (AAE) Clinical Guidelines, was applied under dental dam isolation by a research assistant with at least 2 years of experience from the Department of Pediatric Dentistry at Marmara University Faculty of Dentistry. The RET procedure is detailed in Table 1. The clinical successes of immature permanent teeth treated with RET for the the 24-month follow up were evaluated based on the following factors: the presence of spontaneous or provoked pain, sensitivity to percussion and palpation, the presence of fistula, abscess or pathological mobility in the tooth. If any clinical findings or symptoms were detected, the treatment was considered as clinically unsuccessful.[12]

Table 1. Description of the applied standard RET procedure

	Procedure	Content
FIRST VISIT	Local anesthesia	
	Isolation	Rubber dam
	Removal of necrotic tissue remnants	No instrumentation was per formed
	Irrigation solution	5,25% sodium hypochlrite
	Intra canal dressing	Triple antibiotic paste (clindamycin, ciprofloxacin, metronidazole)
	Temporary filling	Glass ionmer cement
SECOND VISIT	Local anesthesia	Anesthesia without vasoconstructor
	Isolation	Rubber dam
	Removal of triple antibiotic paste	No instrumentation/ centle irrigation with sterile saline
	Irrigation solution	Irrigated with of 17%EDTA
	Bleeding	25-K file beyond the apex by 2 mm
	MTA	Over the blood clots/3mm thickness
	Final restoration	MTA coronal barrier was sealed with a thin glass ionomer base/same visit composite resin

Radiological Evaluation

For the radiological evaluation of teeth treated with RET, panoramic or periapical radiographs stored in the faculty's radiology archive system were utilized. Panoramic radiographs were obtained with parameters of 69 kV and 6 mA, while periapical radiographs were taken with 60 kV, 7 mA, and 0.08 seconds. All radiographs were saved in JPEG format in the archive system. The images from panoramic and periapical radiographs

were analyzed on a 22" LCD screen with a resolution of 1920x1080 pixels. A single observer conducted the evaluations. The Periapical Index Scale (PAI) was used to evaluate treatment success based on parameters such as periapical radiolucency, the presence of internal or external root resorption, and the condition of the lamina dura.[13] The PAI criteria used for scoring are presented in Table 2, and the reference radiograph is shown in Figure 1. The root development status of immature permanent teeth was assessed on radiographs using the Cvek classification.[14] The scoring criteria for the Cvek classification are provided in Table 3, and the reference radiograph is shown in Figure 2. Based on the combined clinical and radiographic findings, the following assessment criteria were used:[15, 16]

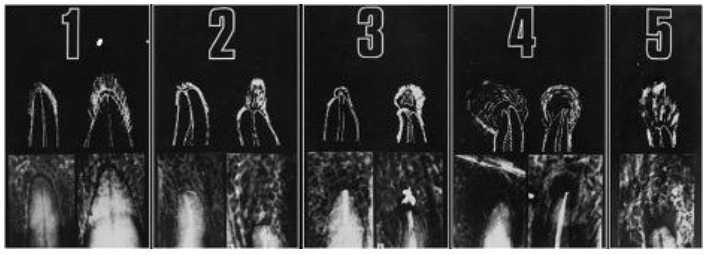

Figure 1. The reference radiograph used for evaluating the roots with PAI. [13]

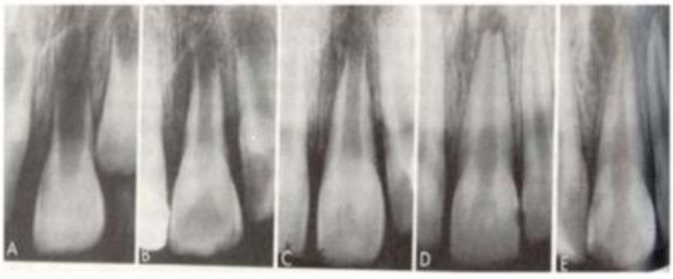

Figure 2. Stages of root development according to Cvek classification (A: Stage 1, B: Stage 2, C: Stage 3, D: Stage 4, E: Stage 5)

- If the tooth is clinically asymptomatic and has a PAI score of 1 or 2, the treatment is considered successful.
- If the tooth is clinically asymptomatic but has a PAI score of 3, 4, or 5, the treatment is considered unsuccessful.
- If the tooth exhibits clinical symptoms, the treatment is considered unsuccessful regardless of the PAI score.

Statistical Evaluation

The normality of numerical variables was assessed using the Shapiro-Wilk test. For variables with a normal distribution, comparisons between two independent groups were made using the Student's t-test. For variables that did not follow a normal distribution, the Mann-Whitney U test was used for comparisons between two independent groups. ANOVA was applied to assess the effect analysis. All statistical analyses were performed using the SPSS 22.0 (IBM SPSS Corp., Armonk, NY, USA) software package, with a significance level set at $P < .05$.

Table 2. Periapical Index Scale[13]

Scales	Description
1	No radiolucency or very slight radiolucency around the apex. This is considered normal or healthy.
2	Small periapical radiolucency, but without any major bone loss. There may be slight changes in the bone surrounding the root apex.
3	Moderate periapical radiolucency, indicating moderate bone loss around the root apex.
4	Large periapical radiolucency with significant bone loss. There is clear evidence of periapical pathology or infection
5	Severe radiolucency and very large periapical lesion, indicating advanced infection or cystic changes, with extensive bone loss around the root apex.

Table 3. Cvek' s root development scale[14]

Scales	
1	Initial root formation, root length less than 50%
2	Root formation with continued open apex, root length 50%
3	Partial root formation, root length 66%
4	Near completion of root development
5	Complete root development with full apical closure

RESULTS

The study included 26 pediatric patients aged 8–13 years, with an equal gender distribution of 13 females and 13 males. The mean age was 9,01± 1,803. There was no statistically significant difference in age or gender between the groups (P>.05). The distribution of teeth included in the study comprised 7 incisors (27%), 3 premolars (12%), and 16 molars (61%). The etiological causes of necrosis showed that 19 cases (73%) were attributed to dental caries, while 7 cases (27%) were due to dental trauma.

When analyzing the clinical success rates of RET in immature permanent teeth, 14 cases (54%) were deemed successful, while 12 cases (46%) were unsuccessful. The success rates of single-rooted and multi-rooted teeth were equal with 7 cases (27%) in each group. However, multi-rooted teeth demonstrated a higher failure rate, with 9 cases (35%), compared to single-rooted teeth, which had 3 cases (12%).

Clinical Findings

In the clinical evaluation at the 24-month follow-up of immature teeth treated with RET in the study, clinically symptomatic teeth were classified as failures. Among the 12 failed cases, 9 (75%) exhibited percussion sensitivity, and all 12 (100%) demonstrated pain upon palpation. Of the failed cases, one tooth presented with an abscess, while no cases showed fistulas or pathological mobility. Among the 12 failed teeth, 5 (42%) underwent root canal therapy, and 7 (58%) were extracted.

Radiological Findings

Comparison of the PAI scores between the initial evaluation and the 12th, 18th, and 24th months revealed an increase in scores of 1 and 2, indicating treatment success. However, the change in PAI scores over time was not statistically significant (P=.601) (Table 4). When comparing root resorption findings between the initial evaluation and the 12th, 18th, and 24th months, no cases of internal resorption were detected, and external resorption was observed in only one tooth. Lamina dura/PDL findings showed improvement at the 24-month follow-up compared to the initial evaluation, although this change was not statistically significant (P=.087) (Table 5). The number of teeth with a Cvek score of 5, indicating complete root development with full apical closure, increased from 1 case (4%) to 14 cases (54%). The change in Cvek root development scores over time was statistically significant (P=.001) (Table 6).

Table 4. Distribution of PAI Scores over time

	PAI scores						
	1 n (%)	2 n (%)	3 n (%)	4 n (%)	5 n (%)	total n (%)	*P*
Initial	8 (30,8)	4 (15,4)	7 (26,9)	4 (15,4)	3 (11,5)	26 (100)	.601
12. month	9 (36)	3 (12)	6 (24)	6 (24)	1 (4)	25 (100)	
18. month	9 (37,5)	4 (16,7)	5 (20,8)	3 (12,5)	3 (12,5)	24 (100)	
24. month	12 (50)	2 (8,3)	1 (4,2)	5 (20,8)	4 (16,7)	24 (100)	

Table 5. Radiologic evaluation of Lamina dura/ PDL over time

	Lamina Dura/PDL			Total	
	Normal n (%)	Enlargement n (%)	Lost n (%)	n (%)	*p*
Initial	6 (23,1)	12 (46,1)	8 (30,8)	26 (100)	0,087
12. month	7 (28)	9 (36)	9 (36)	25 (100)	
18. month	11 (45,8)	6 (25)	7 (29,2)	24 (100)	
24. month	13 (54,2)	4 (16,7)	7 (29,1)	24 (100)	

Table 6. Cvek root development scores over time

	Cvek root development scores						
	1 n (%)	2 n (%)	3 n (%)	4 n (%)	5 n (%)	Total n (%)	*p*
Initial	0	1 (3,9)	6 (23,1)	18 (69,1)	1 (3,9)	26 (100)	0,001*
12. month	0	1 (4)	6 (24)	14 (56)	4 (16)	25 (100)	
18. month	0	1 (4,2)	3 (12,5)	9 (37,5)	11 (45,8)	24 (100)	
24. month	0	1 (4,2)	3 (12,5)	6 (25)	14 (58,3)	24 (100)	

DISCUSSION

Young permanent teeth are defined as teeth with incomplete root development and apex formation.[17] Pulpal injuries in these teeth occur due to deep caries, dental trauma, or iatrogenic causes. In teeth with incomplete root development affected by pulpal injury, the primary goal is to ensure the continuation of root development and to maintain the tooth within the oral cavity.[18] In recent years, the use of MTA in RET has become a preferred approach for achieving revascularization and enabling continued root development in immature permanent teeth.[19-23] MTA was developed as a bioactive and biocompatible material for root-end fillings and the repair of furcation perforations.[24] Because of its many advantages, MTA is widely used in pediatric dentistry for various procedures; in vital young permanent teeth direct pulp capping and pulpotomy procedures, in non-vital or necrotic young permanent teeth apexification and RET procedures.[10] The AAE recommends that young permanent teeth treated with MTA should be monitored annually for at least two years to evaluate the outcomes of the treatment.[9] This study aimed to evaluate the outcomes of RET procedures using MTA on immature young permanent teeth with necrotic pulps caused by deep caries or trauma. Over a two-year period, the continuation of root development, the condition of periapical lesions, and clinical success rates were monitored and analyzed.

In numerous studies in the literature, radiological findings of young permanent teeth have been assessed in terms of the presence of external/internal resorption, root development, periapical lesions, and the condition of the lamina dura/ PDL. Clinical findings have included evaluations of percussion sensitivity, palpation sensitivity, pain, the presence of fistulas, abscesses, and pathological mobility.[12, 25, 26] The Periapical Index (PAI) has been widely used to evaluate the periapical conditions of teeth treated with MTA.[12, 25, 26] In studies, teeth that are clinically asymptomatic and have a PAI score of 1 or 2 are considered successful, whereas teeth that are clinically symptomatic or have a PAI score of 3 or higher are considered unsuccessful. These criteria have been commonly applied in studies.[12, 15, 16] In our study, after a 24-month follow-up of RET, the rate of cases with a PAI score of 1 and 2 was found to be 58.3%. Similarly, in a study by Alobaid et al., a PAI score of 1 and 2 was observed in 58% of the regeneration group after a 19-month follow-up.[27] In the study conducted by Kahler et al., unlike our study, a PAI score of 1 and 2 was observed in 90% of the cases following regeneration treatment after an 18-month follow-up.[19]

The development of the root is crucial for tooth function. In revascularization, an alternative treatment for necrotic immature teeth, it is hypothesized that stem cells from the apical papilla, presumed to remain viable in the apical region, can differentiate into secondary odontoblasts. This process is expected to support the continued development of root tissue, resulting in increased root length, apex closure, and thickening of the dentinal walls.[28, 29] The Cvek root development classification has been widely used in various studies to assess the root development status of immature permanent teeth.[14, 27, 30] Kahler et al.[19], and Silujjai et al.[30] in their respective studies, found no statistically significant difference in the root development progression of teeth undergoing regenerative therapy when analyzed over months, differing from the findings of our study.

In our study, it was observed that 23% of cases treated with regenerative therapy initially exhibited normal lamina dura/PDL findings, which increased to 54% at follow-up. Similarly, Alobaid et al. found improvements in apical periodontal changes in 58% of cases during follow-up.[27] In addition, some studies in the literature report higher rates of improvement in apical periodontal changes after regenerative therapy, ranging from approximately 77% to 95%.[15, 23, 31, 32]

A meta-analysis study reported an average success rate of 79% to 100% for regenerative therapy with MTA.[33] The success rate of regenerative therapy in our study was determined to be 54%. Alobaid et al. similarly reported a success rate of 58% in the regenerative therapy group.[27] Bukhari et al. found a success rate of 75%, which is comparable to our findings.[20] One of the primary challenges in pulp regeneration (PR) is the persistence of microorganisms in the pulpal space, even after thorough disinfection protocols.[34] This microbial presence can negatively impact the function and viability of stem cells within the treated area, potentially compromising the regenerative process.[22] As a result, the success of pulp regeneration (PR) is at risk if residual intraradicular infection persists, which prevents periapical healing from occurring.[35] We believe that the differences between our study and the success rates reported in the literature may be due to challenges in achieving effective isolation during canal disinfection in the pediatric patient population, lack of compliance between sessions, and the technical difficulties associated with performing regenerative therapy.

CONCLUSION

The findings indicate that RET resulted in a moderate clinical success rate in immature permanent teeth. The Cvek score indicating complete root development with full apical closure significantly improved over the study period, demonstrating the potential of RET to enhance root development in immature teeth despite initial challenges in achieving isolation and managing microbial contamination. These results underscore the importance of meticulous treatment protocols and monitoring to optimize RET outcomes.

Ethics Committee Approval: The ethical approval for the study was obtained from the Marmara University Faculty of Medicine, Clinical Research Ethics Committee under date September 26, 2021 protocol number 09.2021.81.

Informed Consent: Since this is a retrospective study, a consent form was not obtained.

Peer-review: Externally peer-reviewed

Conflict of Interest: The authors have no conflicts of interest to declare.

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Use of Artificial Intelligence: No use of artificial intelligence.

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Hasta Onamı: Bu çalışma geriye dönük bir çalışma olduğundan, onay formu alınmamıştır.
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