Outcome of Endodontic Treatment in Horizontal Intra-Alveolar Root Fracture of Fully Developed Teeth: A Retrospective Study

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This certifies that the Master's Thesis
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ABSTRACT

Outcome of Endodontic Treatment in Horizontal Intra-Alveolar Root Fracture of Fully Developed Teeth: A Retrospective Study

This retrospective study aimed to evaluate the clinical outcomes of endodontic treatment in teeth with horizontal root fractures (HRFs) and fully developed roots. A total of 49 cases treated at a dental hospital were included, all of which received nonsurgical root canal treatment limited to the coronal fragment and had a minimum follow-up of three months. Clinical and radiographic assessments were performed to determine healing status, based on the criteria suggested by Andreasen and Hjørting-Hansen. Potential prognostic factors such as patient demographics, fracture location, diastasis between fragments, and the type of root canal filling material were initially assessed through univariate analysis and variables with potential significance were further evaluated using multivariate logistic regression with a stepwise backward elimination approach.

The estimated success probability was 87.8%, indicating a favorable outcome for endodontic management of HRFs. Among the variables analyzed, fracture location was found to be a statistically significant prognostic factor. Fractures located in the middle and apical thirds of the root showed significantly higher odds of healing compared to cervical third fractures. Although the presence of diastasis showed a tendency toward unfavorable prognosis, it did not reach statistical significance. No significant difference in healing outcomes was observed between teeth obturated with mineral trioxide aggregate (MTA) and those treated with gutta-percha (GP).

These findings suggest that when proper case selection and clinical protocol are followed, endodontic treatment can be a successful and conservative approach for managing HRFs in fully developed teeth. The study highlights the importance of fracture location in determining prognosis and supports the clinical applicability of both MTA and GP as obturation materials in such cases.

Key words: horizontal root fracture, endodontic treatment, mineral trioxide aggregate, gutta-percha, fracture location

1. Introduction

Horizontal root fractures (HRFs) typically occur as a result of direct trauma—such as falls, sports-related injuries, or traffic accidents—and are most frequently observed in the maxillary incisors. HRFs typically extend transversely or obliquely along the root, disrupting structures such as dentin, pulp tissue, cementum, and the periodontal ligament (1-3). The prevalence of HRFs varies by age, with approximately 2.5% in children, 4.6% in adolescents, and 8.7% in adults. Although overall HRFs in permanent teeth are reported to occur in about 0.5% to 7% of all traumatic dental injuries it suggest notably higher rates in older age groups, underscoring the need for age-specific diagnostic and therapeutic strategies (4).

Clinically, HRFs often present with signs such as increased tooth mobility, sensitivity to percussion, and in some cases, visible dislocation of the coronal fragment (5, 6). Radiographic diagnosis can be challenging and often requires multiple angulated periapical radiographs or cone-beam computed tomography (CBCT) for accurate identification of the fracture line (5-7).

In previous studies, fracture location was determined by trisecting the root length from the CEJ to the apex, categorizing it into cervical, middle, or apical thirds (8-11). The location of the fracture—coronal, middle, or apical third—plays a crucial role in both the clinical approach and the expected prognosis. Notably, fractures located in the middle third of the root are most frequently observed and present with intermediate prognosis compared to those located apically (which tend to heal more favorably) or coronally (which often require more aggressive intervention) (8, 9).

The International Association of Dental Traumatology (IADT) recommends using a flexible splint for approximately 4 weeks in managing horizontal root fractures (12). However, when the fracture is located in the cervical third, the splinting period may be extended up to 4 months due to increased mobility and poor healing potential (12). Although HRFs generally have a favorable prognosis when properly diagnosed and managed, several complications can arise, particularly those related to the pulp. The most common pulpal complication is necrosis of the coronal fragment, often resulting from bacterial ingress through the fracture site or disruption of apical blood supply (8-11, 13-15). A systematic review analyzed 1,017 permanent teeth with horizontal root fractures and reported an overall pulpal necrosis rate of 26.9%, with individual studies ranging from 22% to 27%, with higher rates observed in teeth with displaced coronal fragments or delayed treatment (16-18).

The endodontic management of HRFs depends largely on the stage of root development and the pulpal status of the coronal fragment. In teeth with immature apices (open apex), vital pulp tissue is typically managed conservatively, without immediate endodontic intervention, unless signs of necrosis or infection are present (7, 13, 14, 19, 20). If pulp necrosis is confirmed, regenerative endodontic procedures such as revascularization or apexification may be considered to promote continued root development. In mature teeth with fully developed roots (closed apex), conventional nonsurgical root canal treatment (RCT) of the coronal fragment is generally indicated when pulp necrosis is diagnosed (13, 14, 16, 19, 20). Based on the guidelines by the International Association of Dental Traumatology (IADT) and the American Association of Endodontists (AAE), only the coronal segment should be managed endodontically in HRF cases, since the apical portion typically remains vital and does not require intervention unless pathological changes are present (12).

Traditionally, gutta-percha (GP) with sealers has been the conventional material for obturation in HRF treatment (10, 11). However, recent advancements in bioactive materials have introduced alternatives such as mineral trioxide aggregate (MTA), which offers superior sealing ability, biocompatibility, and the potential to promote hard tissue formation. Clinical studies have increasingly investigated the use of MTA in treating root fractures (1, 7, 10, 11, 21)For example, a study published in the Journal of Endodontics by Kim et al. (2016) found an 89.5% success rate in HRF cases treated with MTA, suggesting that material choice may significantly affect clinical outcomes (22).

Despite the growing body of literature on HRFs, most existing studies are limited by small sample sizes, heterogeneous treatment protocols, and short-term follow-up. Furthermore, many of these studies have focused predominantly on pediatric or adolescent populations, leaving a notable gap in the evidence concerning fully developed permanent teeth in adult patients. For instance, previous cohort studies have demonstrated favorable outcomes in younger individuals with HRFs; however, due to ongoing root development and differences in pulp healing capacity, these findings may not be generalizable to adults (4). Additionally, although several case reports and retrospective studies have explored outcomes of endodontic treatment in HRFs, few have directly compared the clinical performance of different obturation materials—such as gutta-percha (GP) and mineral trioxide aggregate (MTA) —under controlled conditions (1, 4, 21).

One of the few studies addressing this gap was a retrospective investigation involving 125 teeth from 103 patients, which reported a favorable clinical outcome in 92% of cases. However, this study neither performed a comparative analysis of the obturation materials used nor focused specifically on teeth with fully developed roots. Moreover, the long-term survival and success rates in adult HRF cases following root canal treatment remain insufficiently investigated (4).

Given these limitations in the current literature, further research is clearly warranted to investigate the long-term clinical outcomes of endodontically treated HRFs in fully developed permanent teeth. Specifically, comparative studies evaluating the success and survival rates of different obturation materials are essential to support evidence-based clinical decision-making. Understanding the prognostic factors influencing healing—such as fracture location, material selection, and presence of preoperative symptoms—may significantly inform clinical protocols and improve patient outcomes.

Consequently, this retrospective study aimed to evaluate the outcome of endodontic treatment in horizontal intra-alveolar root fracture of fully developed teeth and determine the prognostic factors affecting the outcome. This study employs survival analysis to evaluate the long-term success and survival of endodontically treated teeth. Moreover, it directly compares gutta-percha (GP) and mineral trioxide aggregate (MTA) as obturation materials, providing valuable insights into the effectiveness of comtemporary treatment approaches. The null hypothesis was that there are no statistically significant differences between the obturation materials with respect to various influencing factors.

2. Material and Methods

2.1. Case Selection

This retrospective study was approved by the Yonsei University Committee for Research on Human Subjects (approval no. 2-2015-0064) and conducted at the Microscope Center of the Department of Conservative Dentistry, Yonsei University College of Dentistry and Dental Hospital, Seoul, South Korea. The study included patients with a history of horizontal root fractures who had undergone endodontic treatment from October 2005 to February 2025. Patient records were reviewed, and eligibility for inclusion in this retrospective study was determined based on the following inclusion and exclusion criteria.

The inclusion criteria were as follows:

1) Tooth with an intra-alveolar horizontal root fracture;
2) Tooth that received endodontic treatment limited to the coronal fragment; and
3) Tooth with clinical and radiographic records after a period of at least 3 months after the finish of endodontic treatment.

The exclusion criteria were as follows:

1) Tooth with an extra-alveolar root fracture;
2) Tooth with previous apical periodontitis or abscess;
3) Tooth that lost the coronal fragment;
4) Root fracture occurred on a previously treated tooth or a tooth undergoing endodontic treatment; and

5) Tooth did not have records for up to 3 months after the endodontic treatment.

The 3-month follow-up threshold was established as an inclusion criterion, based on previous studies suggesting that early healing responses in horizontal root fractures—such as pulp vitality status, radiographic changes, or signs of non-healing—can generally be observed within this timeframe (8, 10, 11). Although longer follow-up durations are preferable for evaluating long-term outcome, a 3-month period was considered adequate for initial outcome assessment in this retrospective study.

2.2. Diagnostic and Treatment Principles

Clinical procedures were performed according to standardized protocols based on the International Association for Dental Traumatology (IADT) guidelines for the management of traumatic dental injuries (12), and were conducted by endodontists or residents at the Department of Conservative Dentistry, Yonsei University Dental Hospital. Prior to treatment, diagnoses were established through clinical and radiographic examinations. Although minor variations existed among cases, a standardized treatment protocol was consistently followed.

On the first visit, both clinical and radiographic assessments were conducted. The clinical evaluation included visual inspection, percussion testing, assessment of tooth mobility, and pulp vitality testing using cold stimuli or an electric pulp tester (Parkell, Edgewood, NY, USA). Two periapical radiographs were obtained from different angles—orthoradial and approximately 20 degrees vertically—to verify the existence and details of the fracture. The fracture location, diastasis between fragments, and any accompanied injuries were recorded. If necessary, the coronal fragment was repositioned and stabilized using a resin-wire splint. Although splinting is generally maintained for approximately 4 weeks, this period can be extended up to 4 months in cervical fracture cases or when high mobility or poor healing potential is expected. The duration of splinting was determined by the clinician according to the fracture location,tooth mobility, and individual healing response (12).

If pulpal complications (e.g., discoloration, persistent or spontaneous pain, sinus tract, or abscess) developed during follow-up, nonsurgical root canal treatment was initiated and limited to the coronal fragment. Following standard procedures—such as pulp extirpation, working length determination, canal irrigation, and shaping—the coronal portion of the root canal was obturated using either mineral trioxide aggregate (MTA) or gutta-percha (GP) and sealer, depending on the clinical condition and operator preference. The adaptation of the obturation material was confirmed under high magnification using an operatig microscope.

In cases where MTA was selected as the obturation material, one of the following products was used at the operator's discretion: ProRoot MTA (Dentsply, Tulsa, OK, USA), Retro MTA (Bio MTA, Seoul, Korea) or Endocem MTA (Maruchi, Wonju, Korea). The material was delivered into the root canal using either an amalgam carrier or MTA gun, depending on the canal width, and condensed with a sterile paper point to the pre-measured working length. A moist cotton pellet was placed over the MTA, followed by temporary sealing with intermediate restorative material. At the subsequent visit, the setting of the MTA was confirmed, and the access cavity was restored with composite resin.

In cases where GP was selected as the obturation material, root canal filling was performed up to the fracture line using one of the following techniques —continuous wave technique, lateral condensation, or single-cone technique —depending on clinical judgment and canal morphology. The following root canal sealers were used according to the obturation technique and operator preference: AH Plus (Dentsply Sirona, Ballaigues, Switzerland), Tubliseal (Kerr Corporation, Orange, CA, USA), Sealapex (Kerr Corporation, Orange, CA, USA), Endoseal MTA (Maruchi, Wonju, Korea), Endoseal TCS (Maruchi, Wonju, Korea), and Ceraseal (Meta Biomed, Cheongju, Korea).Coronal restoration was subsequently performed in the same manner as in the MTA-treated cases.

If necessary, intracoronal bleaching was performed. In cases involving severe coronal desturtion, full-coverage restorations were placed.

Patients were recalled at 1, 3, and 6 months, at 1 year, and annually thereafter to monitor the treatment outcomes. At each recall visit, the treated teeth were evaluated both clinically and radiographically. Clinical assessment included evaluation of tooth mobility, presence of a sinus tract or swelling, and response to percussion and biting pressure. Tenderness, abscess formation, and pathological tooth movement were also recorded. Radiographic assessment focused on the healing status at the fracture line, and the periapical condition.

2.3. Evaluation Factors

The following data were collected: patient characteristics (sex, age and tooth location); trauma-related factors (fracture location, presence of diastasis, presence of crown fracture, accompanied injuryies and pulp vitality at the time of trauma); and treatment-related details (splint duration, intracanal medication, obturation material and clinician experience) (Table 1). Cases were excluded if documentation was insufficient or if the minimum required information could not be retrieved from the patient records.

Table 1. Evaluation factors for cases underwent endodontic treatment in horizontal root fractured teeth.

Category	Variables
Patient-related factors	Age Sex (male or female) Tooth location (maxilla or mandible)
Trauma-related factors	Fracture location (cervical, middle, or apical third) Presence of diastasis (yes or no) Presence of crown fracture (complicated, uncomplicated, or none) Accompanied injury (avulsion, luxation, or alveolar bone fracture) Pulp vitality (yes or no)
Treatment-related factors	Splint duration Use of intracanal medicament (yes or no) Canal filling material (gutta-percha or MTA) Clinician's experience (professor or resident)

Fracture location was classified by trisecting the root length from the crest of alveolar bone to the apex, although previous studies used the distance from the cementoenamel junction (CEJ) to the apex for trisection. Diastasis was assessed using preoperative periapical radiographs taken after trauma and prior to endodontic treatment. Fractures with a radiographic gap of ≥1 mm were categorized as having diastasis, whereas those with a gap of <1 mm were considered to have no diastasis. This threshold is consistent with previous literature suggesting that diastasis of 1 mm or more may negatively affect healing outcomes (8, 10, 11). Additionally, the presence of a crown fracture and other associated injuries —such as avulsion, luxation, or alveolar bone fracture —at the time of trauma was also documented.

2.4. Outcome Assessment

The success was determined in cases with clinical records and periapical radiographs obtained at least 3 months after tcompletion of endodontic treatment, in accordance with Andreasen et al. (23), who suggested that a reliable assessment of healing type can be made after 3 to 6 months. Clinical evaluation included assessment of signs and/or symptoms, functional impairment, tenderness to percussion or palpation, tooth mobility, presence of periodontal pockets, and sinus tract formation. Radiographic healing at the fracture line wasindependently evaluated by two examiners (H.Y. and D.K.) and classified into four types, according to the criteria proposed by Anderasen and Hjørting-Hansen (5) :

1. Healing with interposition of calcified tissue;
2. Healing with interposition of connective tissue;
3. Healing with interposition of connective tissue and bone; and
4. Interposition of granulation tissue without healing.

Evaluation criteria were standardized between the two examiners prior to assessment, and any discrepancies were resolved by consensus.

Treatment outcomes were categorized according to predefined clinical and radiographic criteria as follows:

1. Success: Defined as the absence of clinical signs and symptoms, along with radiographic evidence of healing characterized by interposition of calcified tissue, connective tissue, or a combination of connective tissue and bone (Types 1–3, according to Andreasen and Hjørting-Hansen).
2. Failure: Defined as the presence of any clinical signs and/or symptoms, or radiographic evidence of non-healing with interposition of granulation tissue (Type 4).

2.5. Statistical Analysis

All statistical analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA) and R version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria). The level of statistical significance was set at 0.05 with a 95% confidence interval (CI). Inter-examiner agreement was assesed using Cohen's kappa statistic, and the interpretation was based on the criteria proposed by Landis and Koch (24).

A survival analysis was conducted to assess the prognosis of endodontic treatment over time. Success rates were estimated using the Kaplan–Meier method. Subsequently, potential prognostic factors influencing the success of fragment reattachment were analyzed. Chi-squared or Fisher's exact test was used to examine the association between success outcomes and categorical variables such as age, sex, type of injury, dental arch, location of the fracture line, diastasis, crown fracture, accompanied luxation injury, intracanal dressing, and filling material. All variables were subjected to multivariate Cox proportional hazards regression analysis, followed by stepwise regression using the backward elimination method. Hazard ratios (HRs) and 95% CIs were calculated for variables significantly associated with failure.

3. Results

A total of 49 teeth from patients diagnosed with horizontal root fractures and treated endodontically were included in the study (32 males and 17 females; age range: 8–65 years; mean age, 33.3 years). The observation period ranged from 4 months to 19.4 years following endodontic treatment (mean, 6.34 ± 5.23 years). The Cohen's kappa value for inter-examiner agreement between the two evaluators (H.Y. and D.K.) was 0.82, which indicated excellent agreement.

The characteristics and distribution of success and failure cases based on evaluation factors are detailed in Table 2. Among the total 49 cases included in the study, 6 cases (12.2%) exhibited clinical or radiographic signs of failure over the observation period, while 43 cases (87.8%) showed favorable success outcomes~~.~~ Among the patient-related variables, age group, sex and tooth location did not show statistically significant difference with treatment outcome (~~all~~ $p > 0.05$). Likewise, neither the splint duration, the use of intracanal dressing ($Ca(OH)_2$), the type of root canal filling material (GP or MTA), nor the clinician experience show statistically significant difference with the healing success. Root canal filling material (GP vs. MTA) was not show statistically significant difference ($p = 0.688$), though GP cases had slightly higher success rate (90.5%) than MTA (85.7%).

However, fracture location was statistically significant difference ($p = 0.029$). The success rate for teeth with fractures in the cervical third was markedly lower (57.1%) compared to the middle third (93.9%) and apical third (88.9%). Another variable of interest was the presence of diastasis between fragments. Although it did not reach statistical significance (p = 0.098), the success rate was noticeably lower in cases with visible diastasis (79.2%) compared to those without (96.0%). Crown fracture type (complicated vs. uncomplicated vs. none) show no statistically significant difference with outcome (p = 0.368) and the accompanied injury (e.g., alveolar fracture, avulsion, luxation), pulp vitality at the time of trauma were not statistically significant (all p = 1.000).

Table 2. Baseline characteristics and distribution of cases included in the present study.

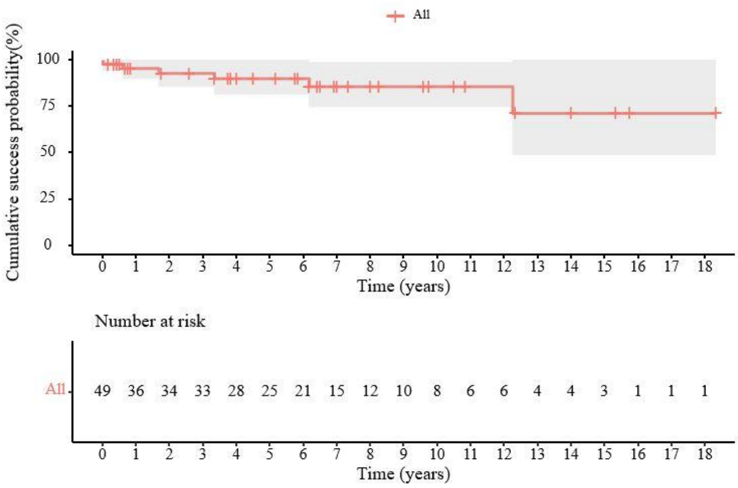
	Success N (%)	*Failure N (%)*	*P**
Total	43 (87.8%)	6 (12.2%)	
Age group (y)			0.757
< 20	13 (86.7%)	2 (13.3%)	
20-40	15 (83.3%)	3 (16.7%)	
> 40	15 (93.8%)	1 (6.2%)	
Sex			0.650
Male	27 (84.4%)	5 (15.6%)	
Female	16 (94.1%)	1 (5.9%)	
Tooth location			1.000
Maxilla	36 (87.8%)	5 (12.2%)	
Mandible	7 (87.5%)	1 (12.5%)	
Fracture location			0.029
Cervical	4 (57.1%)	3 (42.9%)	
Middle	31 (93.9%)	2 (6.1%)	
Apical	8 (88.9%)	1 (11.1%)	
Diastasis			0.098
Yes	19 (79.2%)	5 (20.8%)	
No	24 (96.0%)	1 (4.0%)	
Crown fracture			0.368
Complicated	2 (66.7%)	1 (33.3%)	
No	34 (89.5%)	4 (10.5%)	

	Success N (%)	*Failure N (%)*	*P**
Uncomplicated	7 (87.5%)	1 (12.5%)	
Injury			
Alveolar bone fracture	4 (100.0%)	0 (0.0%)	
Avulsion	4 (80.0%)	1 (20.0%)	
Luxation	11 (84.6%)	2 (15.4%)	
No	24 (88.9%)	3 (11.1%)	
Pulp vitality			1.000
Yes	11 (91.7%)	1 (8.3%)	
No	32 (86.5%)	5 (13.5%)	
Splint duration (w)			0.172
< 4	4 (100.0%)	0 (0.0%)	
1-4	30 (90.9%)	3 (9.1%)	
> 4	7 (70.0%)	3 (30.0%)	
Intracanal dressing			0.321
Yes	33 (91.7%)	3 (8.3%)	
No	10 (76.9%)	3 (23.1%)	
Filling material			0.688
GP	19 (90.5%)	2 (9.5%)	
MTA	24 (85.7%)	4 (14.3%)	
Clinician's experience			1.000
Professor	15 (88.2%)	2 (11.8%)	
Resident	28 (87.5%)	4 (12.5%)	

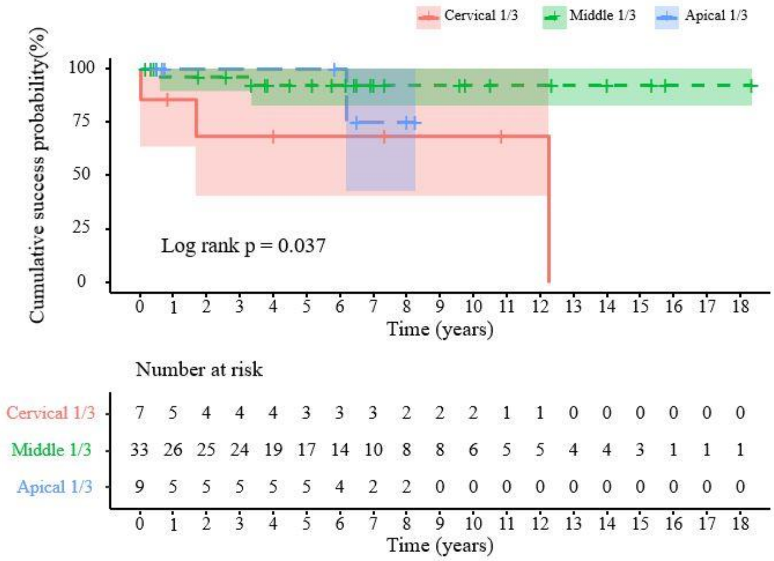
* *The p from chi-squared test or Fisher's exact test.*

Survival analysis revealed estimated success probabilities of endodontically treated teeth with horizontal root fractures to be 95.6% at 1 year (95% CI, 89.7–100.0), 92.9% at 3 years (95% CI, 85.4–100.0), and 90.1% at 5 years (95% CI, 81.3–99.9), respectively (Fig. 1a). Figure 1b presents the Kaplan–Meier survival curves stratified by fracture location (cervical, middle, and apical thirds). Teeth with cervical third fractures exhibited the lowest survival probabilities over time, with an early declinewithin the first 3 years and a prodounced drop around 12 years. In contrast, fractures located in the middle and apical thirds maintained relatively stable and high survival rates throughout the observation period. The log-rank test indicated a statistically significant difference among the three groups (p = 0.037), highlighting the prognostic significance of fracture location.

Figure 1. Kaplan-Meier survival curve presenting success probabilities for endodontic treatment in horizontal root fractured teeth



(a) Survival curve for all endodontically-treated horizontal root fractured teeth included in the present study



(b) Survival curve in relation to fracture location

To further examine the influence of individual variables on the risk of failure, Cox proportional hazards regression analysis was conducted. Table 3a summarizes the result of the univariate analysis. Variables with a p-value < 0.20 were included in the multivariate model using backward stepwise elimination. Table 3b presents the results of the multivariate analysis. In this model, fracture location in the middle third emerged as a significant protective factor against failure. Compared to fractures in the cervical third (reference group), teeth with middle third fractures demonstrated a hazard ratio (HR) of 0.103 (95% CI, 0.016–0.655; p = 0.016), indicating a substantially reduced risk of treatment failure. Although fractures in apical third also showed a trend toward better prognosis (HR = 0.347), the result did not reach statistical significannce (p = 0.377).

Table 3. Results of cox proportional hazard regression analysis for variables associated with outcome

(a) Results of univariate analysis

Variables	Estimate	Std. Error	z value	OR	LCL	UCL	p
Sex (Male vs Female)	0.903	1.096	0.824	2.468	0.288	21.159	.4100
Tooth location (Mx vs Mn)	-0.555	1.127	-0.493	0.574	0.063	5.221	.6221
Fracture location (Middle vs Cervical)	-2.015	0.914	-2.206	0.133	0.022	0.799	.0274
Fracture location (Apical vs Cervical)	-1.090	1.177	-0.926	0.336	0.033	3.377	.3543
Diastasis (≥1mm vs <1mm)	1.518	1.096	1.384	4.561	0.532	39.117	.1664
Vitality (Yes vs No)	-0.365	1.104	-0.331	0.694	0.080	6.045	.7408
Crown fracture (None vs Complicated)	-0.823	1.136	-0.725	0.439	0.047	4.066	.4686
Crown fracture (Uncomplicated vs Complicated)	-0.596	1.428	-0.418	0.551	0.034	9.049	.6762
Provider (Resident vs Faculty	0.136	0.882	0.154	1.145	0.203	6.445	.8777
Age (20–40 vs <20)	0.341	0.929	0.367	1.407	0.228	8.690	.7133
Age (>40 vs <20)	-0.682	1.230	-0.554	0.506	0.045	5.637	.5794
Dressing ($Ca(OH)_2$ vs None)	-0.871	0.818	-1.064	0.419	0.084	2.082	.2873
Filling material (MTA vs GP)	0.078	0.870	0.090	1.081	0.197	5.950	.9284

**Statistically significant at $p < 0.05$*

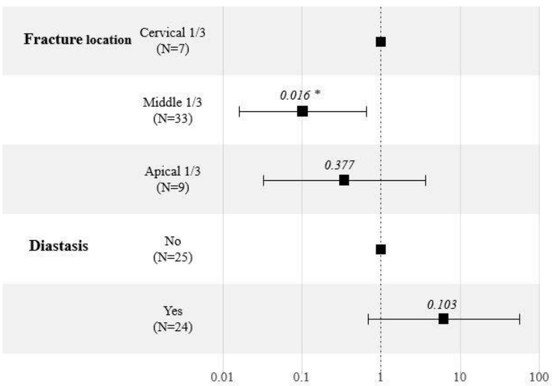
(b) Final model after backward elimination

Variables	Category vs. Reference	OR	95% CI	p-value
Fracture location	Middle vs. Cervical	0.10	0.01–0.65	0.016*
	Apical vs. Cervical	0.34	0.03–3.63	0.377
Diastasis	Yes vs. No	6.23	0.69–56.28	0.103

**Statistically significant at $p < 0.05$*

Similarly, the presence of diastasis was associated with an increased hazard of failure (HR = 6.230; 95% CI, 0.690–56.279), although this finding did not reach statistical significance (p = 0.103). These results are visually summarized in Figure 2, which presents a forest plot of the final multivariate model, displaying point estimates and confidence intervals for each variable.

Figure 2. Forest plot of multivariate Cox proportional hazard regression analysis. (HR: hazard ratio; CI: confidence interval)



Representative radiographs demonstrating successful healing following endodontic treatment with mineral trioxide aggregate (MTA) are shown in Figure 3. These include cases exhibiting healing through the interposition of calcified tissue (Fig. 3A–C), connective tissue (Fig. 3D–F), and a combination of connective tissue and bone (Fig. 3G–I), with follow-up periods exceeding 2 years. Similarly, Figure 4 presents representative cases treated with gutta-percha (GP) and sealer, showing comparable healing patterns —calcified tissue, connective tissue, and connective tissue with bone— observed in radiographs taken more than 2 years post-treatment(Fig. 4A–I).

In contrast, failure cases are depicted in Figure 5, where the teeth maintained clinical function but radiographically exhibited interposition of granulation tissue, consistent with Type 4 healing. These cases represent unsuccessful healing despite adgerence to standard endodontic treatment protocols using either MTA or GP, underscoping the complexity of healing in HRFs and the potential influence of additional risk factors, such as fracture location or diastasis.

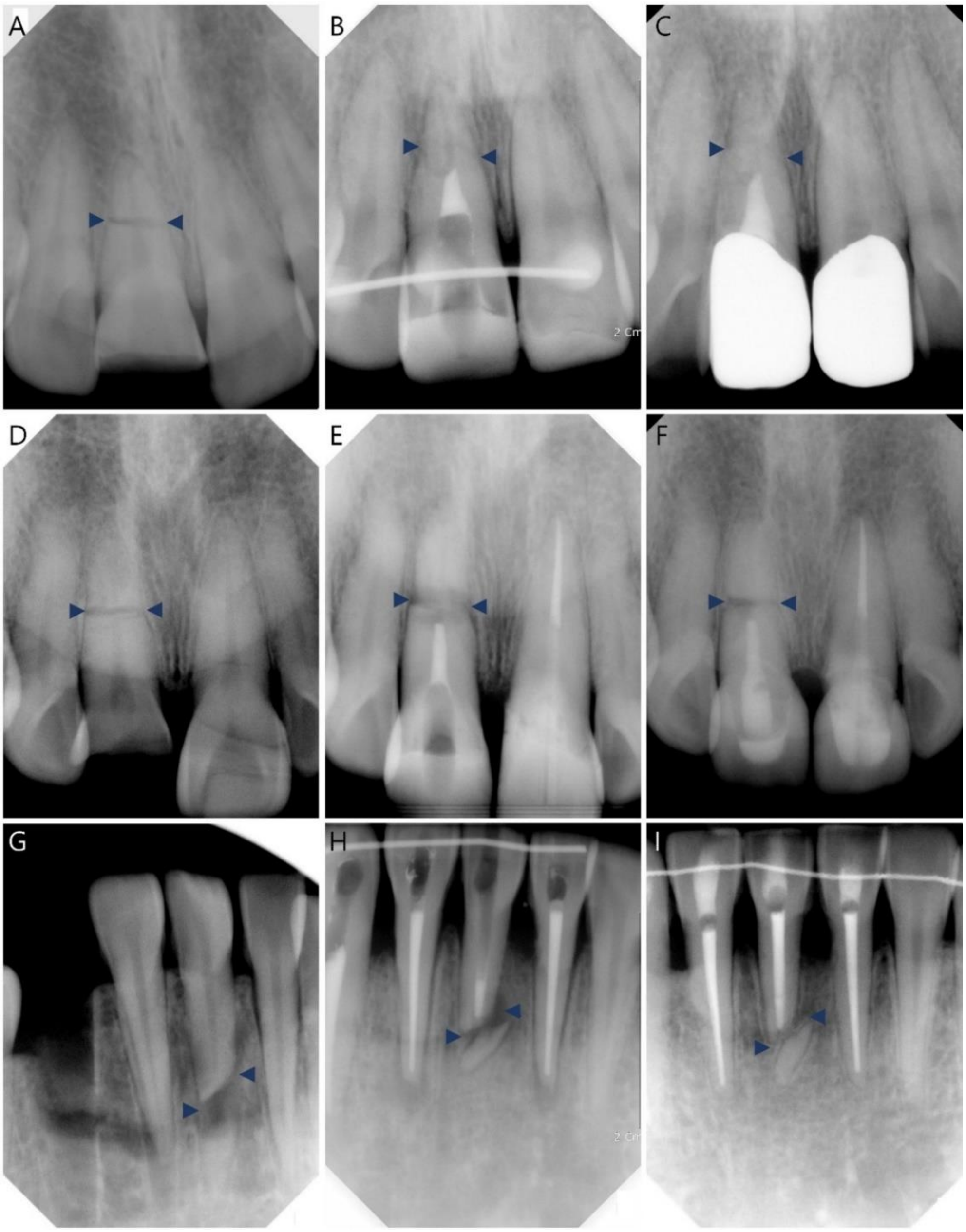


Figure 3. Success cases treated with MTA. The preoperative, postoperative, and final follow-up (more than 2 years) radiographs of success cases treated with MTA. The arrowheads of each radiograph indicate the fracture line: (A–C) Healing with calcified tissue. (D–F) Interposition of connective tissue. (G–I) Interposition of connective tissue and bone.

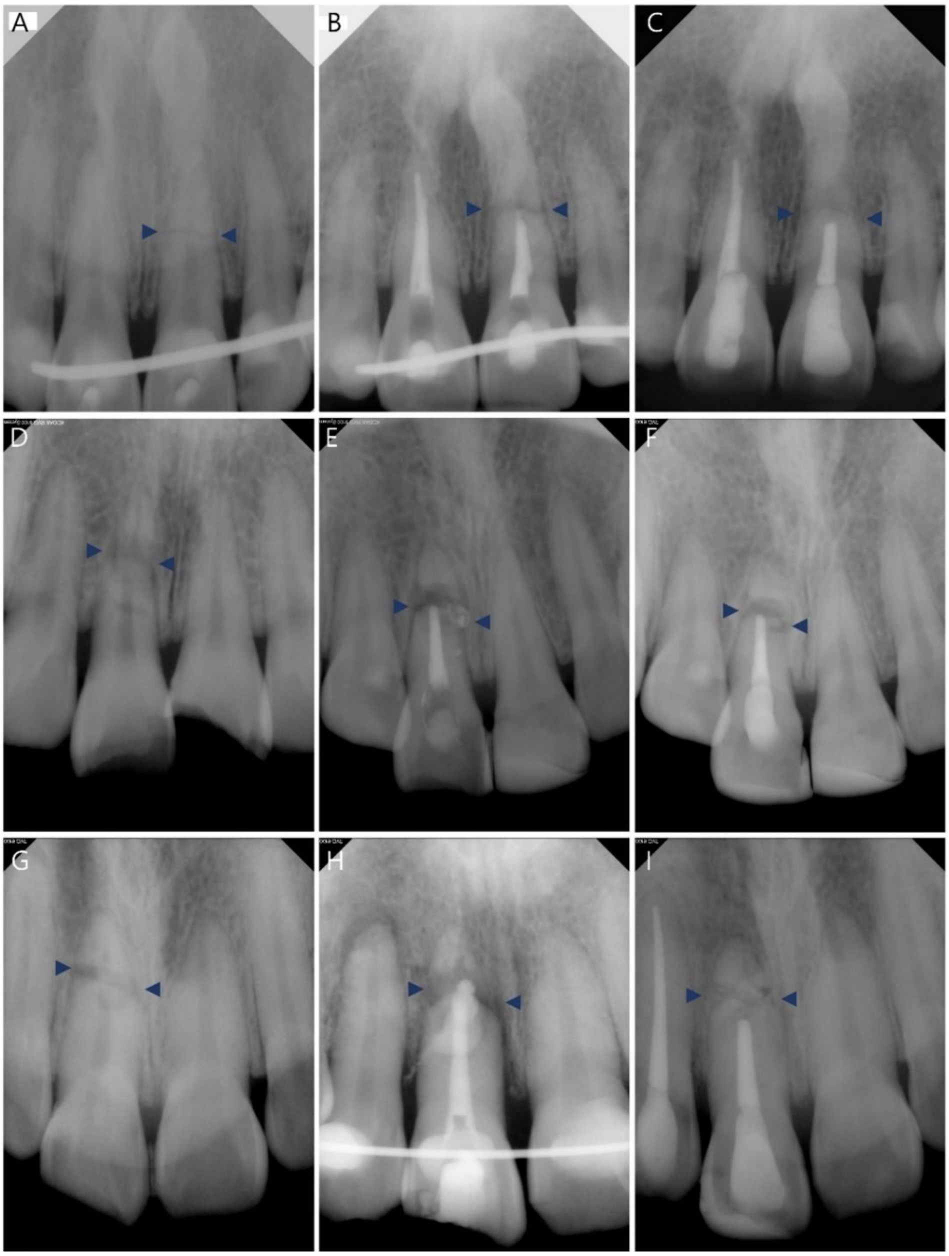


Figure 4. Success cases treated with gutta-percha and sealer. The preoperative, postoperative, and final follow-up (more than 2 years) radiographs of success cases treated with gutta-percha and sealer. The arrowheads of each radiograph indicate the fracture line: (A–C) Healing with calcified tissue. (D–F) Interposition of connective tissue. (G–I) Interposition of connective tissue and bone.

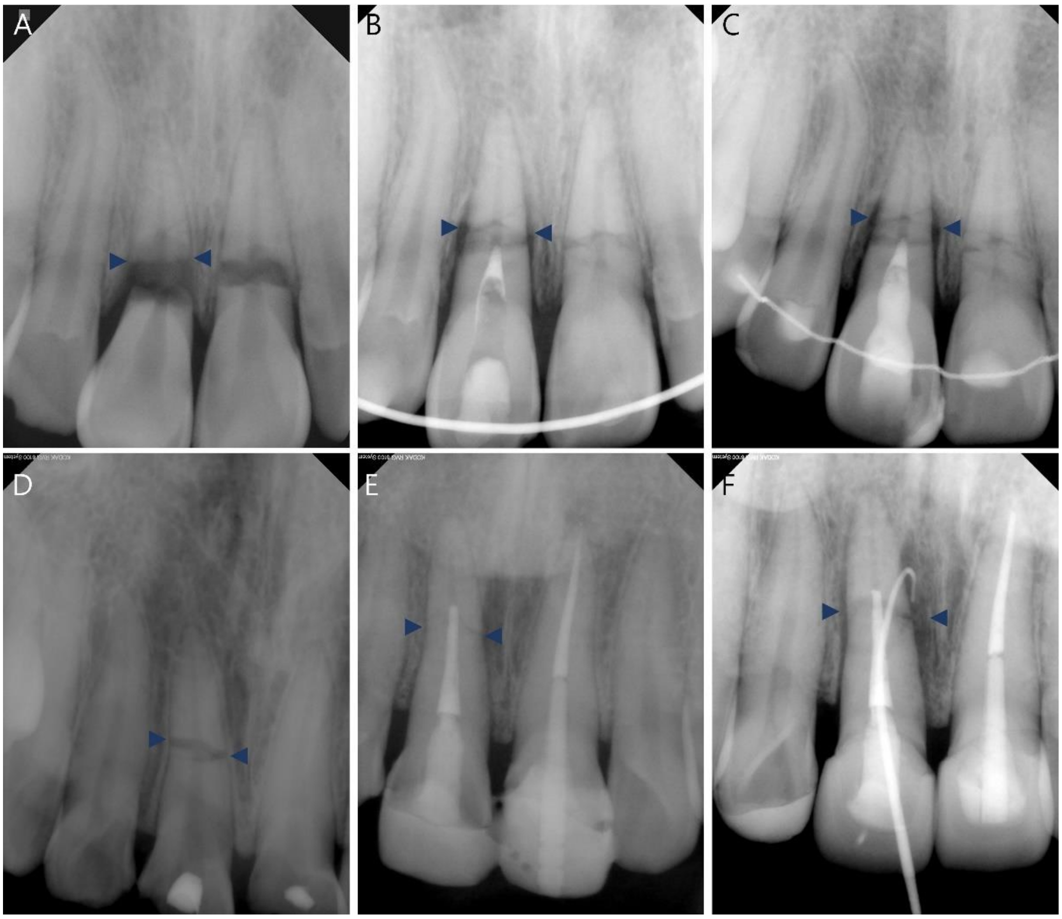


Figure 5. Failure cases. The arrowheads of each radiograph indicate the fracture line. (A) The preoperative radiograph of root-fractured maxillary central incisors. (B) Endodontic treatment was performed on the right incisor 1 month after trauma, and MTA was filled. (C) The 3.5-year follow-up radiograph. The tooth was still functioning; however, it was assessed as ‘‘interposition of granulation tissue’’ in the radiograph. (D) The preoperative radiograph of root-fractured maxillary central incisors. (E) Root canal treatment was performed 1 month after the trauma, and obturation was completed using gutta-percha (GP). (F) At the 3.5-year follow-up, the tooth remained functional; however, it was assessed as ‘‘interposition of granulation tissue’’ in the radiograph.

4. Discussion

The purpose of this retrospective study was to assess the long-term clinical outcomes of endodontic treatment in cases of horizontal root fractures (HRFs), which have fully developed roots, with particular attention to the influence of various prognostic factors and obturation materials. Among the 49 cases that met the inclusion criteria, the overall success rate was 87.8%, which is comparable to—or slightly higher than—that reported in previous studies evaluating fractured teeth with or without endodontic intervention (5, 22).

The observed success rate of 87.8% is comparable to or—slightly higher than—that reported in previous studies involving root-fractured teeth treated endodontic treatment. For example, Cvek and Andreasen (2001) reported success rates ranging from 80% to 90% in younger patients with middle or apical third fractures managed conservatively (8, 19). However, many of these earlier studies did not distinguish cases by root development stage or evaluate the influence of different obturation materials.

Importantly, this study addressed a significant gap in the existing literature by focusing exclusively on fully developed permanent teeth treated with endodontic therapy. While most previous studies have examined the healing potential of HRFs in pediatric or adolescent populations (1, 10, 11), data on adult teeth with complete root formation remain limited. Moreover, many earlier studies included cases without endodontic intervention, making it dificult to isolate the specific impact of root canal treatment on healing outcomes. By restricting the sample to cases in which endodontic treatment was confined to the coronal fragment and by ensuring a minimum follow-up period of three months, the present study provides robust evidence supporting the predictability of conservative endodontic management in HRFs.

Furthermore, to the best our knowledge, this is one of the few studies that directly compare obturation materials—gutta-percha (GP) and mineral trioxide aggregate (MTA)—in a relatively homogenous cohort treated under standardized protocols with long-term follow-up. In terms of obturation materials, no statistically significant difference in success rates was observed between the GP and MTA groups. While GP has long been used as the conventional root canal obturation material due to its stability and clinical reliability, MTA has gained attention as a bioactive alternative with superior sealing ability, antimicrobial effects, and excellent biocompatibility. Although previous studies have reported favorable outcomes with MTA in HRF cases (22), few have conducted direct comparisons between MTA and GP under controlled clinical conditions. The present findings suggest that, with appropriate cases selection and adgerence to standarized techniques, both materials can yield favorable outcomes in the endodontic management of HRFs.

A distinctive aspect of the present study lies in its approach to classifying the location of root fractures. Unlike conventional methods that trisectedthe root length from the cementoenamel junction (CEJ) to the apex (10, 11), the study adopted a classification system based on the distance from the alveolar bone crest to the apex, as visualized on periapical radiographs. This approach was intendedto more accurately reflect the clinical context of intra-alveolar fractures and to address a key limitation of previous methods, which did not account for variations in periodontal bone levels or the vertical position of the alveolar crest. Given that horizontal root fractures are confined within the alveolar socket, CEJ-based trisection may misrepresent the actual fracture location—especially in teeth with periodontal bone loss or altered CEJ levels resulting from trauma or restorative procedures.

Nevertheless, the classification method used in this study has inherent limitations. First, most fracture locations were assessed using two-dimensional periapical radiographs, as cone-beam computed tomography radiographs (CBCT) data were available for only 11 cases. Although periapical radiographs are commonly used in clinical settings and offer acceptable diagnostic reliability, they are limited in visualizing the bucco-palatal inclination of fracture lines. Many horizontal root fractures occur obliquely, and the position of the fracture line can differ substantially between the buccal and palatal aspects. Additionally, variations in alveolar bone levels between these aspects may further complicate accurate localization. In this study, fracture location was estimated by measuring the midpoint between the alveolar crest and the visible fracture line on orthoradially oriented periapical radiographs. While this method ensured consistency across all cases, it lacks the three-dimensional precision that CBCT imaging could provide. The use of periapical radiographs alone was justified not only by the limited availability of CBCT data, but also by the need to apply uniform criteria across the dataset and thereby minimize measurement bias.

The retrospective design of this study introduces the possibility of selection bias, and the sample size—although larger than that of many previous studies—may still be insufficient to detect subtle differences between subgroups. In addition, variability in operator technique, follow-up duration, and radiographic interpretation may have influenced the outcomes. The minimum follow-up duration of three months, while consistent with previously published standards (12, 25), may not have been sufficient to identify late failures or long-term complications such as root resorption or reinfection. As previously noted, reliance on two demensional periapical radiographs for fracture classification may have introduced dimensional inaccuracies. Finally, the absence of standardized protocols for obturation material selection or intracanal medication use reflects real-world clinical practice but limits the ability to draw definitive conclusions regarding the superiority of specific treatment approaches.

Despite these limitations, the present study has several notable strengths. Most importantly, fracture location emerged as a statistically significant prognostic factor. Cervical third fractures exhibited the lowest success rate and the highest hazard of failure, consistent with previous reports attributing this to biomechanical instability and compromised vascular supply in cervical fractures (12). In contrast, diastasis—defined as a separation of ≥1 mm between fracture fragments on post-trauma radiographs—was associated with a trend toward poorer outcomes, although this did not reach statistical significance. This finding aligns with earlier studies suggesting that greater fragment separation may impair healing and increase the risk of pulp necrosis (8, 10, 11, 21). Among cases with recorded splinting duration, the mean splint duration was longer in the failure group (92.6 ± 63.1 days) than in the survival group (60.8 ± 52.4 days); however, this difference was not statistically significant (Mann-Whitney U = 198.0, $p = 0.149$). These findings suggest the extended splinting duration does not necessarily correlate with improved clinical outcomes.

From a clinical perspective, these results underscore the importance of comprehensive case evaluation, particularly with respect to fracture location and diastasis, as key prognostic indicatoes. The findings also suggest that the choice of obturation material—whether gutta-percha or MTA—

may be of secondary importance when fundamental treatment principles are appropriately applied.

Future studies should aim to validate and expand upon these results through prospective longitudinal designs with larger sample sizes, standardized treatment protocols, and extended follow-up periods. Moreover, additional research focusing on adult populations and the standardized assessment of obturation materials will be essential to refine evidence-based clinical guidelines for management of horizontal root fractures.

5. Conclusion

This retrospective study demonstrated a high overall success rate (87.8%) in endodontically treated horizontal root fractures of fully developed permanent teeth. Fracture location significantly influenced outcomes, with cervical third fractures associated with lower success rates. The type of obturation material—MTA or gutta-percha—did not significantly affect healing, supporting the use of either when proper case selection and technique are applied. While diastasis showed a trend toward negative prognosis, it did not reach statistical significance.

These findings suggest that successful outcomes in HRF cases can be achieved through careful diagnosis, conservative endodontic management, and individualized treatment planning—regardless of the filling material used.

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Abstract in Korean

성숙 영구치의 수평적 치조골내 치근파절에 대한 근관치료 결과: 후향적 연구

본 후향적 연구는 완전 근단 형성을 보인 치아의 수평적 치조골내 치근파절 (horizontal root fracture, HRF)에 대해 근관치료를 시행한 증례의 임상 결과를 평가하고자 하였다. 본 연구에는 총 49증례가 포함되었으며, 모두 상부 단편(coronal fragment)에 국한된 비외과적 근관치료가 시행되었고, 최소 3개월 이상의 추적관찰이 이루어졌다. 치유 상태는 Andreasen과 Hjørting-Hansen가 제시한 기준에 따라 임상적 및 방사선학적으로 평가되었다. 환자의 인구학적 정보, 파절 위치, 파절편 간 이개(diastasis), 근관충전 재료 등과 같은 잠재적 예후인자를 이변량 분석을 통해 선별하였고, 유의 가능성이 있는 변수들은 단계적 후진 제거법(stepwise backward elimination)을 이용한 다변량 로지스틱 회귀분석으로 추가 평가하였다.

전체 성공률은 87.8%로, 수평적 치근파절에 대한 비외과적 근관치료의 예후가 전반적으로 양호함을 보여주었다. 분석된 변수 중 치근파절의 위치는 통계적으로 유의한 예후인자로 확인되었으며, 치근 중간부 및 근단부에 위치한 파절은 경부 파절에 비해 유의하게 높은 치유 가능성을 보였다. 파절편 간 이개가 존재할 경우 불량한 예후 경향을 보였으나 통계적 유의성에는 도달하지 못하였다. 또한, 근관충전 재료로서 mineral trioxide aggregate (MTA)와 gutta-percha (GP)를 사용한 군 간

에는 유의한 차이가 관찰되지 않았다.

이러한 결과는 적절한 증례 선정과 임상 원칙이 준수된다면, 성숙 영구치의 수평적 치근파절에 대해 근관치료가 성공적이고 보존적인 치료 방법이 될 수 있음을 시사한다. 또한 본 연구는 치근파절의 위치가 예후를 결정하는 주요 요인임을 강조하며, MTA와 GP 모두 임상적으로 유효한 근관충전 재료임을 뒷받침한다.

핵심 되는 말 : 수평적 치근파절, 근관치료, Mineral Trioxide Aggregate (MTA), Gutta-percha, 파절 부위