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ORIGINAL RESEARCH

Long-term outcome of horizontal root fractures in 33 young permanent teeth: a clinical retrospective study

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Abstract

Background: Horizontal root fracture is a special type of dental trauma. The objective of this study was to evaluate the healing outcome and influencing factors of young permanent tooth horizontal root fractures. **Methods**: A retrospective study (Exclusion of 9 patients with lost-to-follow-up status) included 33 young permanent teeth with horizontal root fractures from 26 children (mean age 9.31 ± 1.76 years) treated from 2020 to 2022 with ≥24-month of follow-up. Treatment followed the International Association of Dental Traumatology (IADT) guidelines (repositioning, flexible fixation, long-term follow-up, apexification for infections). Healing was classified (Andreasen criteria) as calcified, connective, bone-connective tissue, or inflammatory (non-healing). Root development (Nolla 5–8 (very immature) *vs.* 9 (immature)) and fracture location (coronal/middle/apical 1/3) were analyzed. SPSS 13.0 was used for the chi-square test or Fisher's test (α = 0.05). **Results**: Overall healing rate was 93.9% (31/33): 18.18% calcified, 54.55% connective, 21.21% bone-connective tissue, and 6.06% inflammatory healing. Six teeth required apexification; 1 had diffuse pulp calcification. Fracture location, root development, and displacement did not affect overall healing ($p > 0.05$), but in the chi-square test, root development significantly influenced calcified healing ($p < 0.05$): 50% (3/6) in very immature *vs.* 11.1% (3/27) in immature teeth. However, in the Fisher's test, it did not have statistical significance. **Conclusions**: Standardized treatment yields favorable outcomes. Root development (not location/displacement) affects calcified healing, with higher rates in very immature teeth. Emphasis on timely treatment, long-term follow-up, and pulp preservation in very immature teeth is recommended.

Keywords

Horizontal root fractures; Healing rate; Influencing factors; Young permanent teeth

1. Introduction

Young permanent teeth, characterized by immature root development and incomplete mineralization of dental tissues, are highly susceptible to horizontal root fractures due to their exposure to accidental trauma during childhood and adolescence, with maxillary central incisors being the most commonly affected [1]. Horizontal root fractures, like common types of dental trauma such as crown fractures and crown—root fractures, can disrupt the integrity of dental pulp and periodontal tissues, potentially leading to complications such as pulp necrosis, root resorption, or loss of tooth function if not managed appropriately [2].

The prognosis of horizontal root fractures in young permanent teeth has long been a focus of clinical concern, with debates surrounding the impact of factors such as fracture location, root development stage, and apical fragment displacement on healing outcomes [3, 4]. The International Association of Dental Traumatology (IADT) guidelines emphasize that the pulp and periodontal tissues of young permanent teeth possess strong regenerative potential, highlighting the importance of preserving pulp vitality and promoting fracture healing through standardized treatment [1]. However, existing studies have reported inconsistent findings [5, 6]. For instance, one study found that root fractures located in the coronal third had a significantly lower fracture healing rate compared with those in the middle and apical thirds, while other studies have demonstrated that the healing outcomes of horizontal root fractures in young permanent teeth are not significantly correlated with the fracture location, owing to their robust regenerative capacity [7–9].

To date, systematic analyses of healing factors specific to horizontal root fractures in young permanent teeth, particularly regarding the relationship between root development stages and healing patterns (*e.g.*, calcified healing *vs.* connective tissue healing), remain limited [2]. This retrospective study aimed to evaluate the healing outcomes of 33 young permanent teeth with horizontal root fractures from 2020 to 2022. With a follow-up period of over 24 months, this study analyzed the influence of fracture location, root development stage (assessed via Nolla classification), and fragment displacement on healing, aiming to provide clinical evidence for optimizing the management of such injuries [4].

2. Materials and methods

2.1 Study subjects

Children who were first diagnosed with horizontal root fractures in the Department of Pediatric Dentistry between 2020 and 2022 were recruited for this study. The researchers explained the purpose of the study to the parents or guardians of the children, obtained their permission to retrieve the children's medical records for observational research, and ensured that written informed consent was signed. A total of 35 children were enrolled from January 2020 to the end of December 2022. Upon the completion of the study in late 2024, all recruited patients were retrospectively summarized and subjected to statistical analysis in accordance with the following inclusion and exclusion criteria.

Inclusion criteria:

(1) observation period >24 months;
(2) excellent patient compliance;
(3) complete case data;
(4) regular follow-up visits as scheduled.

Exclusion criteria:

(1) loss to follow-up during treatment and observation;
(2) occurrence of secondary trauma;
(2) or receipt of orthodontic treatment.

Ultimately, 9 children were excluded from the final analysis. Among them, 3 were lost to follow-up due to residential relocation, and another 3 were lost to follow-up because they failed to attend regular follow-up visits for various reasons. Two children sustained recurrent traumatic impacts after initial treatment for horizontal root fracture, while one child was excluded due to the administration of orthodontic treatment for dental malocclusion. Consequently, these patients were excluded from the analysis.

A total of 33 affected teeth from 26 children were collected in this study, including 14 males and 12 females, with a mean age of 9.31 ± 1.76 years. Among the 33 affected teeth, 20 were maxillary right central incisors (60.61%), 12 were maxillary left central incisors (36.36%), and 1 was a mandibular left central incisor (3.03%). Since all 26 pediatric patients in this study sought medical attention within 24 hours after trauma, with an average consultation time of 6.58 ± 1.39 hours, no significant correlation was observed between time to consultation and healing outcomes. The study protocol was approved by the Institutional Review Board (PJ2023-161-001). Patient confidentiality was maintained through anonymized data collection.

2.2 Treatment methods

According to the guidelines of the IADT, comprehensive judgment is made based on factors such as the location of the root fracture, tooth mobility, pulp status, and patient age. The core goals are to preserve pulp vitality, promote root fracture healing, and maintain tooth function. The specific treatment methods are as follows: (1) Conduct a detailed oral examination before surgery, and perform X-ray periapical films (Intraoral X-ray unit, FOCUS, Tuusula, Finland) or CBCT (NewTom 5G, QR Srl, Verona, Italy). Scanning parameters: 110 kV, voxel size 0.3 mm, scanning field 18 cm × 16 cm, exposure time 3.6 s. For routine examination of dental trauma, X-ray periapical films are the first-line imaging modality. However, if indistinct fracture lines are observed on the apical films, we will consider performing a CBCT to confirm the diagnosis. In cases of complex dental trauma or suspected alveolar process fractures, CBCT is also employed for comprehensive oral examination. The interpretation of X-ray films and CBCT was performed by two pediatric dentists with over ten years of clinical experience. A standard consistency test was conducted prior to interpretation, yielding a kappa value >0.8. In cases where the two examiners disagreed, a dental radiologist was involved to make the final decision. (2) If there is displacement at the fracture site, repositioning the tooth under local infiltration anesthesia as soon as possible should be done, followed by elastic fixation (resin splints, full-arch occlusal pads, or orthodontic bracket fixation). The fixation period is usually 4–8 weeks (it can be appropriately extended for young permanent teeth). (3) Follow-up observations should be conducted at 1, 3, 6, 9, 12, 15, 18, 21, and 24 months after the trauma. The re-examination content includes imaging examinations (to observe the healing of the fracture site, such as whether bone bridge formation or root resorption has occurred) and pulp vitality tests. (4) For young permanent teeth with pulp infection or periapical infection during follow-up, apexification should be performed.

2.3 Analysis of factors affecting root fracture healing

The 33 affected teeth were analyzed based on the location of the tooth fracture, the degree of root development, and whether the fractured ends were displaced after fracture. The fracture locations were divided into the coronal 1/3, middle 1/3, and apical 1/3 of the root. For evaluation of root development stage at the time of trauma, the degree of root development was classified into two stages according to the Nolla classification: Very immature: The apical foramen is open (Nolla stages 5–8) with insufficient root length development; Immature: The apical foramen is large (Nolla stage 9) with basically a completed root length development.

2.4 Biological healing of root fracture in permanent teeth

According to the criteria for root fracture healing proposed by Andreasen *et al*. [10], healing was classified into 4 types: (1) Calcified tissue healing: The two ends of the fracture are healed by calcified tissue, with the fracture line distinguishable on X-ray films and the fractured fragments in close contact; (2) Connective tissue healing: X-ray films show that the fractured fragments are separated by a radiopaque line, with rounded edges of the fragments; (3) Bone and connective tissue healing: X-ray films reveal an obvious bone bridge separating the fractured fragments; (4) Inflammatory healing: X-ray films show a widened fracture line, a radiolucent area corresponding to the fracture line, or both becoming clearly visible.

Calcified tissue healing, connective tissue healing, and combined bone and connective tissue healing were classified as “healed”, while inflammatory healing was classified as “unhealed”.

2.5 Statistical analysis

Statistical analysis was performed using SPSS 13.0 software (IBM Corp., Armonk, NY, USA). Continuous data following a normal distribution were expressed as mean ± standard deviation, while those not following a normal distribution were expressed as median and interquartile range. The total healing rate of root fractures was calculated. The chi-square test or Fisher’s test was used to test for the difference test between qualitative data. The test level was set at $\alpha = 0.05$.

3. Results

3.1 Statistics on root fracture location, root development status, and root fracture healing type

As shown in Table 1, among the 33 affected teeth, 5 (15.15%) had root fractures in the coronal 1/3 of the root, 19 (57.58%) in the middle 1/3, and 9 (27.27%) in the apical 1/3. Regarding root development status: 6 teeth were very young (Nolla stages 5–8), accounting for 18.18%; and 27 teeth were young (Nolla stage 9), accounting for 81.82%. There were 22 teeth with no obvious displacement of the fracture ends (66.67%) and 11 teeth with obvious displacement of the fracture ends (33.33%).

Among the 33 teeth with horizontal root fractures, 31 healed, resulting in a healing rate of 93.9%. Specifically, 6 teeth (18.18%) healed with calcified tissue, 18 (54.55%) with connective tissue, 7 (21.21%) with a combination of bone and connective tissue, and 2 (6.06%) with inflammatory healing. Additionally, 6 out of the 33 teeth experienced pulp infection or periapical inflammation, which led to arrested root development. As a result, apexification treatment was performed on these teeth. One tooth developed diffuse pulp canal calcification.

3.2 Analysis of factors influencing root fracture healing

Healing with calcified tissue, healing with connective tissue, and healing with bone and connective tissue were classified as healed, while inflammatory healing was classified as unhealed. Statistical analysis showed that root fracture location, root development status, and fracture end displacement had no significant effect on root fracture healing ($p > 0.05$), as shown in Table 2.

Healing with connective tissue, healing with bone and connective tissue, and inflammatory healing were classified as non-calcified healing. Statistical analysis showed that root fracture location and fracture end displacement had no significant effect on calcified healing of root fractures ($p > 0.05$), while root development status had a significant effect on calcified healing ($p < 0.05$), However, in the Fisher’s test, it did not have statistical significance, as shown in Table 3.

3.3 Typical cases

Typical Case 1: A case of calcified healing of horizontal root fracture in a young permanent tooth.

A 6-year-9-month-old female presented with maxillary anterior tooth trauma for 1 day. Initial examination: Teeth 11 and 21 were intact, with grade I mobility; no obvious color change was observed, and there was no significant gingival recession around them; Percussion tenderness. Initial X-ray (Fig. 1A): Root development of tooth 11 was 2/3 complete (Nolla stage 8), and a horizontal root fracture line was seen in the middle 1/3 of the root of tooth 11. Diagnosis: Horizontal root fracture of tooth 11. Treatment: Full dentition occlusal pad elastic fixation was performed on teeth 11 and 21 for 4 weeks, with regular follow-up examinations to monitor pulp vitality and root development. During the follow-up period, Fig. 1B–F correspond to 3 months, 6 months, 1 year, 1.5 years, and 2 years after the trauma, respectively. Normal root development and pulp vitality of tooth 11 were observed, with calcified healing of the horizontal root fracture line and reduction in the pulp cavity morphology.

Typical Case 2: A case of connective tissue healing of horizontal root fracture in the middle part of a young permanent tooth.

A 6-year-and-10-month-old female presented with maxillary anterior tooth trauma for 1 day. Initial examination: Blood crusts were seen on the gingival margin of the maxillary anterior region. Teeth 12 and 11 were extruded, with tooth 12 exhibiting Grade III mobility and tooth 11 exhibiting Grade II mobility. The crown of tooth 21 was intact with grade I mobility. Initial X-ray (Fig. 2A): Tooth 12 was extruded from the alveolar socket; the periodontal membrane space at the apex of tooth 21 was widened; an indistinct fracture line was visible at the apex of tooth 21. Diagnosis: Extrusive luxation of teeth 12 and 11; suspected root fracture of tooth 21? Treatment: Teeth 12 and 11 were repositioned, followed by elastic fixation with wire and resin for 4 weeks, then full dentition occlusal pad fixation for another 4 weeks. Regular follow-up examinations were conducted to monitor pulp vitality and root development. During the follow-up period, no pulp symptoms occurred in tooth 21, and root development continued. At the 3-month follow-up (Fig. 2B), the root fracture line of tooth 21 became clear; at the 6-month follow-up (Fig. 2C), the fracture line thickened; from 1 year to 2 years after the trauma (Fig. 2D–F), a clear and thickened root fracture line was observed, showing connective tissue healing.

Typical Case 3: A case of bone and connective tissue healing of horizontal root fracture in a young permanent tooth.

A 7-year-and-3-month-old female presented with maxillary anterior tooth trauma for 1 day. Initial examination: Upper lip edema and laceration of the inner mucosa of the upper lip were observed; teeth 11 and 21 were intact with no obvious color change; tooth 11 had grade II mobility, and tooth 21 was extruded with grade III mobility. Initial X-ray (Fig. 3A): Root development of teeth 11 and 21 was 2/3 complete (Nolla stage 8); a horizontal root fracture line was seen in the apical 1/3 of the root of tooth 11; tooth 21 was extruded from the alveolar

TABLE 1. Composition rates of healing types and factors.

Influencing Factors	Groups	Number (cases)	Composition Ratio (%)
Root fracture location			
	Coronal 1/3 of the root	5	15.15
	Middle 1/3 of the root	19	57.58
	Apical 1/3 of the root	9	27.27
Root development status			
	Very immature	6	18.18
	Immature	27	81.82
Fracture end displacement			
	No obvious displacement	22	66.67
	Obvious displacement	11	33.33
Healing Types			
	Healing with calcified tissue	6	18.18
	Healing with connective tissue	18	54.55
	Healing with bone and connective tissue	7	21.21
	Inflammatory healing	2	6.06

TABLE 2. Effect of 3 factors on the healing rate of horizontal root fractures.

Influencing Factors	Groups	Number of healed teeth	Number of unhealed teeth	Chi-square value	*p*-value
Root fracture location					
	Apical 1/3 of the root	8	1	0.747	0.688
	Middle 1/3 of the root	18	1		
	Coronal 1/3 of the root	5	0		
Root development status					
	Very immature	5	1	1.449	0.229
	Immature	26	1		
Fracture end displacement					
	No obvious displacement	21	1	0.266	0.606
	Obvious displacement	10	1		

TABLE 3. Effect of 3 factors on calcified healing.

Influencing Factors	Groups	Calcified healing	Non-calcified healing	Chi-square *p*-value	Fisher's test *p*-value
Root fracture location					
	Apical 1/3 of the root	0	9	0.157	
	Middle 1/3 of the root	4	15		
	Coronal 1/3 of the root	2	3		
Root development status					
	Very immature	3	3	0.025	0.58
	Immature	3	24		
Fracture end displacement					
	No obvious displacement	6	16	0.056	0.77
	Obvious displacement	0	11		

FIGURE 1. Calcified healing of horizontal root fracture in a young permanent tooth. (A) Initial X-ray. (B–F) correspond to 3 months, 6 months, 1 year, 1.5 years, and 2 years after the trauma, respectively.

FIGURE 2. A case of connective tissue healing of horizontal root fracture in the middle part of a young permanent tooth. (A) Initial X-ray. (B–F) correspond to 3 months, 6 months, 1 year, 1.5 years, and 2 years after the trauma, respectively.

socket. Diagnosis: Horizontal root fracture in the apical 1/3 of tooth 11; extrusive luxation of tooth 21. Treatment: Teeth 11 and 21 were repositioned under local infiltration anesthesia, followed by fiber splint elastic fixation for 4 weeks. Regular follow-up examinations were performed to monitor pulp vitality and root development. During the follow-up period, Fig. 3B–F correspond to 3 months, 6 months, 1 year, 1.5 years, and 2 years after the trauma, respectively. A distinct bone bridge separating the fractured fragments was observed in the horizontal root fracture line of tooth 11; the free apex continued to develop, and the apical hard bone plate remained continuous. During follow-up, we identified pulp necrosis and periapical infection in tooth number 21. Consequently, apexification was performed on tooth 21, followed by root canal filling with calcium hydroxide paste.

Typical Case 4: A case of inflammatory healing of horizontal root fracture in a young permanent tooth.

A 9-year-and-7-month-old male presented with maxillary anterior tooth trauma for 7 hours. Initial examination: Gingival laceration and bleeding were observed in the region of teeth 11 and 21; teeth 11 and 21 were intact, extruded, and inclined lingually, with grade III mobility. Initial CBCT (Fig. 4A): Root development of teeth 11 and 21 was nearly complete (Nolla stage 9); a horizontal root fracture line was seen in the middle part of the root, with crown displacement toward the lingual side. Diagnosis: Horizontal root fracture in the middle part of teeth 11 and 21. Treatment: Teeth 11 and 21 were repositioned under local infiltration anesthesia, followed by fiber splint elastic fixation for 4 weeks. Regular follow-up examinations were conducted to monitor pulp vitality and root development. Widening of the root fracture line was observed at 6 months (Fig. 4B), 1 year (Fig. 4C), 1.5 years (Fig. 4D), and 2 years (Fig. 4E) after the operation.

Special Case 5: A case of connective tissue healing of horizontal root fracture at the cervical part with displacement in a young permanent tooth.

An 8-year-and-3-month-old male presented with maxillary anterior tooth trauma for 1 day, who had undergone emergency repositioning and elastic fixation. Initial examination: Fixation wires were seen in the maxillary anterior region; no obvious defect was found in tooth 11. Post-repositioning and fixation X-ray (Fig. 5A): Root development of teeth 11 and 21 was 2/3 complete (Nolla stage 8); a horizontal root fracture line was seen at the cervical part of tooth 11; The crown and root were not completely repositioned, with mesiodistal displacement between the crown and root fragments. Diagnosis: Horizontal root fracture at the cervical part of tooth 11. Treatment: Regular follow-up examinations to monitor pulp vitality and root development. At 3 months after the operation (Fig. 5B), the fracture line became clear, showing connective tissue healing, with no obvious periapical shadow. At 1 year after the operation (Fig. 5C), root development persisted, accompanied by apical elongation. At 1.5 years after the operation (Fig. 5D), root development continued with further root elongation.

4. Discussion

This study retrospectively analyzed the clinical data of 33 cases of horizontal root fractures in young permanent teeth,

FIGURE 3. A case of bone and connective tissue healing of horizontal root fracture in a young permanent tooth. (A) Initial X-ray. (B–F) correspond to 3 months, 6 months, 1 year, 1.5 years, and 2 years after the trauma, respectively.

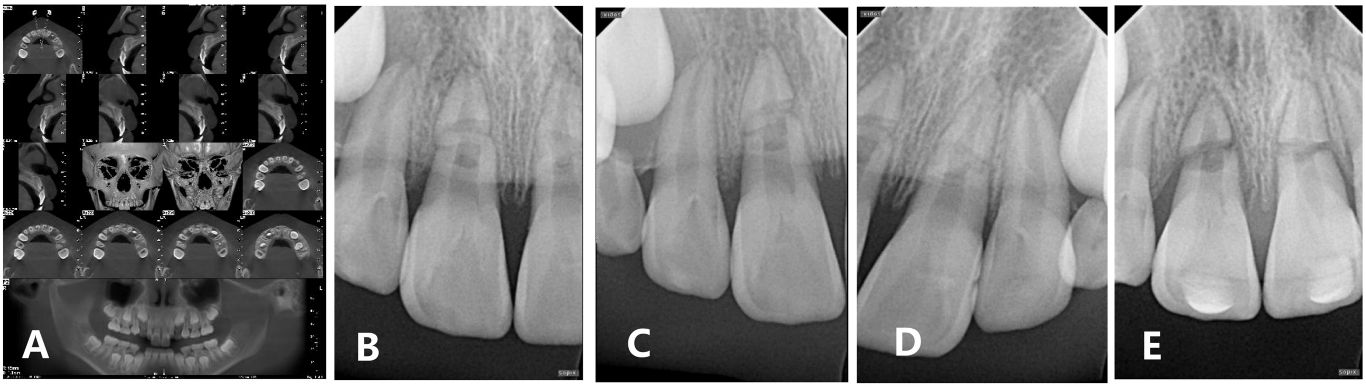

FIGURE 4. A case of inflammatory healing of horizontal root fracture in a young permanent tooth. (A) Initial CBCT examination. (B–E) correspond to 6 months, 1 year, 1.5 years, and 2 years after the trauma, respectively.

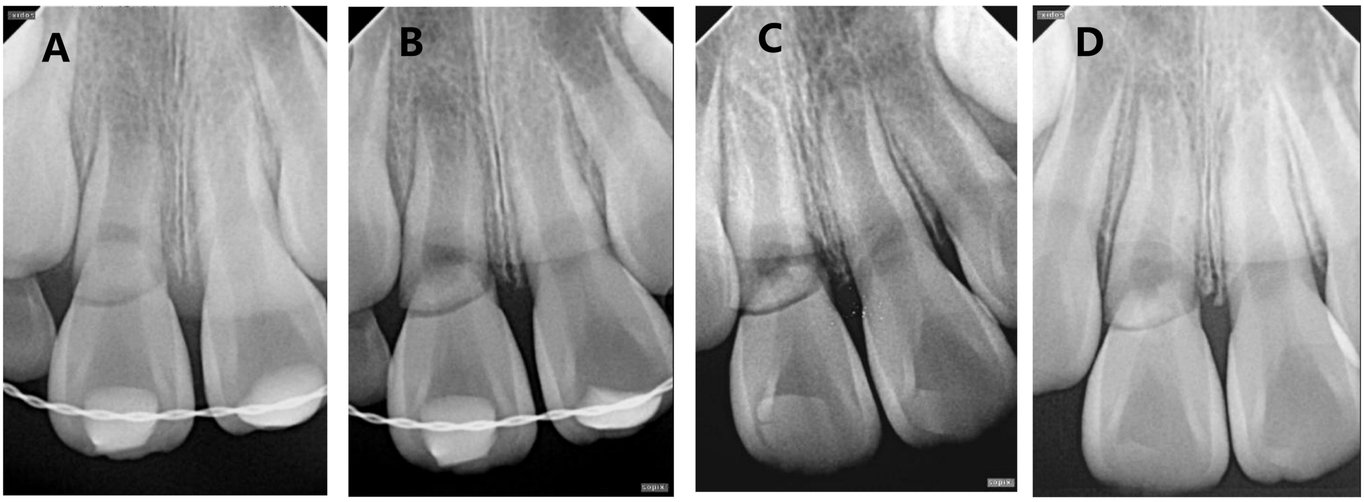

FIGURE 5. A case of connective tissue healing of horizontal root fracture at the cervical part with displacement in a young permanent tooth. (A) Post-repositioning and fixation X-ray. (B–D) correspond to 3 months, 1 year, 1.5 years, respectively.

investigating the healing status of root fractures and related influencing factors. The results showed that young permanent teeth with horizontal root fractures had a high healing rate after standardized treatment. Additionally, root fracture location, root development status, and fracture end displacement had no significant impact on overall healing, but root development status significantly influenced calcified healing. These findings provide a reference for clinical treatment.

4.1 Overall healing effect of horizontal root fracture in young permanent teeth

Andreasen studied the healing of 400 teeth with horizontal root fractures, reporting an overall healing rate of 78%, including 30% with calcified tissue healing, 43% with connective tissue healing, 5% with combined bone and connective tissue healing, and 22% with non-healing [10]. In this study, the overall healing rate of 33 young permanent teeth with horizontal root fractures was 93.9% (31/33), with only 2 cases showing inflammatory healing (non-healing), suggesting a favorable prognosis for young permanent teeth with horizontal root fractures after standardized treatment. The relatively high healing rate (93.9%) may be attributed to the fact that all the teeth in this study were young permanent teeth with strong growth potential, whereas most previous studies focused on mature permanent teeth. This result is consistent with the view emphasized in the IADT guidelines that "the pulp and periodontal tissues of young permanent teeth have strong regenerative potential" [1]. The present study strictly followed the IADT guidelines for treatment, including timely repositioning of displaced fracture ends, use of elastic fixation (4–8 weeks, extended if necessary), long-term follow-up (24 months), and prompt apexification for pulp infection. These standardized procedures likely contributed to the high healing rate.

In this study, six teeth have exhibited pulp issues, in which 5 teeth underwent apexification due to pulp infection or periapical inflammation, and 1 tooth developed diffuse pulp canal calcification. This indicates that despite the overall good healing, pulp status remains a key indicator requiring close monitoring. Studies have reported that the incidence of pulp necrosis in teeth with intra-alveolar horizontal root fractures ranges from 22% to 26% [10–14]. Cvek found that the survival rate of 534 horizontally fractured teeth in patients aged 7–17 years was 80%, with a 69% healing rate after root canal treatment [15]. Wölner-Hanssen AB and von Arx T conducted a retrospective study of 32 cases of horizontal root fractures and reported a 91% survival rate, with vital pulps accounting for 31% [16]. The relatively low pulp infection rate and the higher proportion of viable pulp in this study may be attributed to the small sample size. Additionally, the young permanent teeth exhibit rich blood supply to the pulp and possess strong growth potential, which may also be a potential reason for their higher rate of pulp preservation.

Electric pulp testing remains controversial in the diagnosis of dental trauma. The IADT recommends that in clinical assessment of pulp status, a lack of response to sensibility tests may indicate temporary pulp non-response. Evaluation of pulp status requires regular follow-up, with a minimum monitoring period of 1 year suggested to determine pulp viability [1, 17]. Monitoring root development in young permanent teeth is a reliable indicator of pulp status: normal root development observed during follow-up imaging suggests healthy pulp, whereas arrested root development indicates pulp necrosis and/or infection. Regular pulp sensibility tests and imaging during long-term follow-up (1–24 months) enable early detection and intervention of pulp infection, preventing inflammatory progression from affecting healing. This underscores the critical role of follow-up in the treatment of young permanent tooth trauma.

4.2 Analysis of factors influencing root fracture healing

4.2.1 Impact of root fracture location and fracture end displacement on overall healing

Studies have shown that the closer the root fracture line is to the root apex, the better the prognosis [8]. Some studies suggest that horizontal root fractures in the coronal third, which communicate with the gingival sulcus, have a poorer prognosis due to bacterial infection [18]. Teeth with coronal fractures without hard tissue healing are prone to secondary trauma due to excessive mobility, increasing the risk of tooth loss [15]. However, other studies do not support this view, noting that splinted coronal fragments of horizontal fractures in the coronal 1/3 have a similar cure rate to fractures in the middle 1/3 or apical region [16, 17]. Fractures in the apical or middle 1/3 can achieve a favorable prognosis if pulp vitality is preserved [18]. Cvek analyzed 94 teeth with horizontal fractures in the coronal 1/3, reporting an overall healing rate of 84%, including 18% with calcified tissue healing, 66% with connective tissue or combined bone and connective tissue healing, and 16% with non-healing [19]. Since horizontal root fractures account for only 0.5%–7% of dental trauma cases, there is limited research literature on this condition, with most studies being case reports and few systematic reviews or Meta-analyses. Most studies on horizontal root fractures suffer from insufficient sample sizes. Consequently, conclusions from different studies are somewhat controversial, which may be related to factors such as the samples selected, follow-up duration, and treatment protocols employed.

The results of this study showed that root fracture location (coronal 1/3, middle 1/3, apical 1/3), presence or absence of fracture end displacement, and displacement direction had no significant impact on overall healing ($p > 0.05$). This is consistent with some previous studies [15], likely due to the biological characteristics of young permanent teeth: their roots are incompletely developed, with rich blood supply to the periodontal ligament and pulp, granting strong regenerative and repair capacity. Even if fractures are near the crown or accompanied by end displacement, healing via connective tissue, bone tissue, or calcified tissue can still be achieved with timely repositioning and fixation. Notably, all 5 teeth with fractures in the coronal 1/3 in this study healed, suggesting that favorable outcomes can be achieved with stable fixation and timely follow-up, even for fractures near the gingival margin. In case 5, the root development of the upper right central incisor was in Nolla 8 stage. Even though a horizontal root fracture occurred at the neck of the tooth and the fracture end was significantly displaced, the pulp remained viable and normal growth and development of the root could be observed during follow-up. This supports active treatment for coronal 1/3 fractures in clinical practice.

4.2.2 Impact of root development status on overall healing and calcified healing

Numerous studies on root fractures indicate that the degree of root development significantly affects pulp healing capacity [7, 20, 21]. Young permanent teeth have large root canals and abundant blood supply, with strong healing capacity in both pulp and periodontal tissues [22, 23], resulting in significantly higher rates of calcified and connective tissue healing compared with fully developed teeth. In this study, focusing on young permanent teeth, root development status was categorized as "very immature (Nolla stages 5–8, open apical foramen)" and "immature (Nolla stage 9, wide apical foramen)". Results showed no significant impact on overall healing (p

= 0.229), but in the chi-square test a significant impact on calcified healing (p = 0.025): the calcified healing rate was significantly higher in "very immature" teeth (3/6, 50%) than in "immature" teeth (3/27, 11.1%). However, in the Fisher's test, it did not have statistical significance. It must be noted that the current study had a limited sample size of only 33 cases. When performing subgroup analyses, the number of cases in each subgroup was even smaller, thereby reducing statistical power. In future studies, we will include more cases for analysis to enhance statistical significance.

This difference may be related to variations in blood supply during root development stages: Nolla stages 5–8 are characterized by an open apical foramen, allowing more direct blood supply between pulp and periodontal tissues, sufficient nutrient delivery, and favorable conditions for calcified tissue formation. In contrast, Nolla stage 9 teeth have a nearly closed apical foramen, with relatively reduced pulp blood supply, making connective tissue healing more likely than calcified healing [24, 25]. This suggests that in clinical practice, preserving pulp vitality should be prioritized for "very immature" teeth to promote more stable calcified healing, while for "immature" teeth, clinicians should accept connective tissue healing as the primary mode without excessive concern about overall prognosis.

4.2.3 Limitations of the study

This study has certain limitations: (1) Since horizontal root fractures represent a relatively unique type of dental trauma, collecting case data is challenging, and clinical cases also exhibit a certain rate of loss to follow-up. Meeting all three criteria simultaneously—young permanent teeth, horizontal root fractures, and an observation period exceeding 24 months—makes the task even more difficult. The 33 affected teeth represent the maximum number of cases the author could collect during the study period. Although the small sample size and its division into multiple subgroups limited the statistical power of this study, it is considered to still hold clinical significance. The small sample size (33 affected teeth) and single-center retrospective design may introduce selection bias, requiring caution when extrapolating results; (2) The observation period was 24 months, and long-term healing stability (*e.g.*, fracture site resistance in adulthood) remains unknown; (3) Potential influencing factors, such as "time interval from trauma to treatment" and "differences in fixation methods", were not included. Future studies should expand the sample size and include more variables to refine conclusions. (4) In this study, there also exists variability in radiographic method, operator assessment and splinting method. These factors also exert a certain influence on the outcomes.

4.2.4 Clinical significance

The findings of this study suggest that in the clinical management of horizontal root fractures in young permanent teeth, treatment decisions need not to be overly constrained by root fracture location, fracture end displacement, or root development stage. Instead, emphasis should be placed on: (1) timely and standardized repositioning and elastic fixation; (2) long-term follow-up (at least 24 months) to monitor pulp status and healing; and (3) prioritizing pulp-preserving measures for "very immature" teeth to increase the probability of calcified healing. These insights provide practical guidance for optimizing the clinical management of horizontal root fractures in young permanent teeth.

5. Conclusions

Standardized treatment per IADT guidelines achieves a high overall healing rate for horizontal root fractures in young permanent teeth. Fracture location and fragment displacement show no significant influence on total healing, whereas root development stage determines calcified healing likelihood. Very immature teeth (Nolla 5–8) present a much higher calcified healing rate than Nolla stage 9 teeth, attributed to abundant apical blood supply for mineralized tissue regeneration.

Clinically, timely repositioning and flexible splinting within 24 hours plus ≥24-month follow-ups are critical to track pulp status. Apexification is required once pulp infection occurs. Pulp preservation should be prioritized for very immature teeth to promote calcified union. Cervical fractures and displaced fragments can still gain favorable prognosis with proper fixation, so premature extraction should be avoided. Restricted by small single-center samples, larger multicenter trials are needed to validate these results. Standardized emergency care, long-term monitoring and stratified pulp-protective strategies greatly improve long-term outcomes.

AVAILABILITY OF DATA AND MATERIALS

The experimental data generated in this study contain confidential patient demographic and clinical information, which are restricted by ethical guidelines and privacy protection regulations to safeguard patient interests. Therefore, the full dataset is not publicly accessible. Researchers interested in accessing specific data may contact the corresponding author with a formal request, including a brief description of the intended research use. Data sharing will be facilitated following review of the request and compliance with relevant ethical and legal requirements.

AUTHOR CONTRIBUTIONS

MG and JYQ—Data collection, statistical analysis, and initial manuscript drafting. CXC—Study design, supervision, and critical revision (corresponding author). SYG—Radiographic assessment and technical support. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was approved by the Institutional Review Board (PJ2023-161-001). Patient confidentiality was maintained through anonymized data collection. The parents or guardians of the patients signed a broad informed consent form at the time of their first visit. They were fully informed that their child's biological samples, clinical data, and related information would be used anonymously for this current study as well as for future ethically approved medical research purposes.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Bourguignon C, Cohenca N, Lauridsen E, Flores MT, O'Connell AC, Day PF, *et al*. International Association of Dental Traumatology guidelines for the management of traumatic dental injuries: 1. fractures and luxations. Dental Traumatology. 2020; 36: 314–330.

[2] Sheikhnezami M, Shahmohammadi R, Jafarzadeh H, Azarpazhooh A. Long-term outcome of horizontal root fractures in permanent teeth: a retrospective cohort study. Journal of Endodontics. 2024; 50: 579–589.

[3] Haghdadi F, Mokabberi A, Rad SAB. Conservative management of horizontal root fracture: a case report. Clinical Case Reports. 2024; 12: e9625.

[4] Dhindsa A, Garg S, Poddar P, Singla S, Saraf BG, Shetty JA. Management of root fractures in young immature permanent teeth: three case reports. International Journal of Clinical Pediatric Dentistry. 2024; 17: 352–356.

[5] International Association of Dental Traumatology (IADT). Guidelines for the management of traumatic dental injuries: 2020 update. Dental Traumatology. 2020; 36: 278–297.

[6] Lu J, Kahler B. Regenerative endodontic procedures for two traumatized mature anterior teeth with transverse root fractures. BMC Oral Health. 2022; 22: 124.

[7] Atsumi K, Tanoue N. Treatment of horizontal root fractures in traumatized maxillary central incisors using minimally invasive surgical and prosthodontic foundation techniques. Case Reports in Dentistry. 2025; 2025: 9791300.

[8] Kowaltschuk TC, Gonçalves FM, de Araujo BMM, da Silva Cruz NT, Schroder AGD, Antoniazzi BB, *et al*. Splinting in horizontal root fractures: a Bayesian network meta-analysis. PLOS ONE. 2025; 20: e0326979.

[9] Taori P, Nikhade P, Chandak M, Ikhar A, Mahapatra J. Management of untreated horizontal root fracture: a case report. Cureus. 2022; 14: e28133.

[10] Andreasen JO, Andreasen FM, Mejàre I, Cvek M. Healing of 400 intra-alveolar root fractures. 1. Effect of pre-injury and injury factors such as sex, age, stage of root development, fracture type, location of fracture and severity of dislocation. Dental Traumatology. 2004; 20: 192–202.

[11] Andreasen JO, Andreasen FM, Mejàre I, Cvek M. Healing of 400 intra-alveolar root fractures. 2. Effect of treatment factors such as treatment delay, repositioning, splinting type and period and antibiotics. Dental Traumatology. 2004; 20: 203–211.

[12] Andreasen FM, Andreasen JO, Bayer T. Prognosis of root-fractured permanent incisors–prediction of healing modalities. Endodontics & Dental Traumatology. 1989; 5: 11–22.

[13] Choi Y, Hong SO, Lee SR, Min KS, Park SJ. Healing after horizontal root fractures: 3 cases with 2-year follow-up. Restorative Dentistry and Endodontics. 2014; 39: 126–131.

[14] Mane NA, Shetty P, Borkar AC, Mujumdar SV, Mujawar A. Healing after horizontal root fracture of maxillary central incisor: a case report with 24-month follow-up. Cureus. 2023; 15: e43373.

[15] Cvek M, Tsilingaridis G, Andreasen JO. Survival of 534 incisors after intra-alveolar root fracture in patients aged 7–17 years. Dental Traumatology. 2008; 24: 379–387.

[16] Wölner-Hanssen AB, von Arx T. Permanent teeth with horizontal root fractures after dental trauma. A retrospective study. Schweizer Monatsschrift für Zahnmedizin. 2010; 120: 200–212.

[17] Diangelis AJ, Andreasen JO, Ebeleseder KA, Kenny DJ, Trope M, Sigurdsson A, *et al*. Guidelines for the management of traumatic dental injuries: 1. fractures and luxations of permanent teeth. Pediatric Dentistry. 2017; 39: 401–411.

[18] Özler CÖ, Cehreli ZC. Conservative management of a cervical horizontal root fracture by long-term stabilisation: a case report. Australian Endodontic Journal. 2022; 48: 338–341.

[19] Chute AK, Toshniwal A, Gade V, Chute M. Repair of incomplete horizontal mid-root fracture of maxillary central incisor with mineral trioxide aggregate: a follow up report. Journal of Conservative Dentistry. 2014; 17: 393–395.

[20] Sancas MC, Pires PM, Primo LG. Conservative management of a horizontal root fracture in a primary maxillary central incisor: case report. Dental Traumatology. 2023; 39: 82–87.

[21] Gharechahi M. Horizontal root fracture accompanied by luxation of coronal fragment in a maxillary central incisor: a case report. Journal of Dental Research, Dental Clinics, Dental Prospects. 2013; 7: 244–247.

[22] Estefan BS, El Batouty KM, Nagy MM, Diogenes A. Influence of age and apical diameter on the success of endodontic regeneration procedures. Journal of Endodontics. 2016; 42: 1620–1625.

[23] Sabeti M, Ghobrial D, Zanjir M, da Costa BR, Young Y, Azarpazhooh A. Treatment outcomes of regenerative endodontic therapy in immature permanent teeth with pulpal necrosis: a systematic review and network meta-analysis. International Endodontic Journal. 2024; 57: 238–255.

[24] Takahara S, Ohkura N, Yoshiba N, Baldeon-Gutierrez R, Gomez-Kasimoto S, Edanami N, *et al*. Influence of tooth maturity on healing outcomes in regenerative endodontics. Journal of Dental Research. 2025; 104: 1147–1157.

[25] Lu G, Wang X, Hu J, Chen Y, Huang X. Two horizontal root fractures of a permanent central incisor tooth: a case report. Heliyon. 2024; 10: e39640.

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