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Preservation of Residual Radicular Pulp: A Biologically Guided Vital Pulp Therapy Protocol for Immature Teeth with Fractured Dens Evaginatus and Apical Periodontitis

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Abstract

Background

Immature permanent teeth with fractured dens evaginatus frequently develop apical periodontitis before completion of root formation. These teeth are commonly managed as completely necrotic, although viable radicular pulp may persist despite periapical disease. Recognition of residual radicular pulp may permit a more conservative biologically based treatment strategy.

Objective

To describe a biologically guided vital pulp therapy protocol based on preservation of residual radicular pulp and to evaluate its clinical application in a consecutive series of immature premolars with fractured dens evaginatus and apical periodontitis.

Methods

Clinical records of 14 immature premolars in 12 consecutive patients treated between 2003 and 2022 were retrospectively reviewed. Clinical findings, electric pulp test responses, root development, depth of tissue removal, and treatment outcomes were analyzed. The protocol aimed to identify viable radicular pulp during treatment, selectively remove necrotic or irreversibly inflamed tissue, and preserve the remaining healthy pulp whenever clinically feasible.

Results

Clinically identifiable vital radicular pulp was encountered in 12 of the 14 teeth (85.7%) despite clinical and radiographic findings commonly associated with complete pulp necrosis. These teeth were managed using the biologically guided vital pulp therapy protocol, whereas the remaining two teeth underwent conventional root canal treatment because complete pulp necrosis extended to the root apex. The mean depth of tissue removal was 8.3 mm. Clinical symptoms resolved in all patients, periapical healing was observed radiographically, and continued root development occurred with a mean increase in root length of 1.6 mm. Long-term follow-up demonstrated maintenance of clinical function without recurrence of apical disease.

Conclusions

Apical periodontitis associated with fractured dens evaginatus should not be regarded as unequivocal evidence of complete pulp necrosis in immature teeth. Recognition of residual radicular pulp may allow application of a biologically guided vital pulp therapy protocol that preserves the native pulp-dentin complex while promoting healing and continued root maturation in appropriately selected cases.

Key words: Dens evaginatus, Vital pulp therapy, Apical periodontitis, Immature permanent teeth, Residual radicular pulp, Pulp preservation

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Introduction

Immature permanent teeth that develop apical periodontitis before completion of root formation present a unique biological and therapeutic challenge. Successful management requires elimination of infection while preserving the biological potential for continued root maturation. Fractured dens evaginatus represents one of the most common causes of this clinical scenario because the accessory tubercle frequently contains an extension of the pulp that is vulnerable to fracture soon after eruption (Oehlers et al., 1967). Consequently, bacterial contamination may occur while root development is still incomplete, placing the clinician in the difficult position of controlling infection without unnecessarily sacrificing the remaining vital pulp tissue.

Dens evaginatus is a developmental dental anomaly characterized by an accessory tubercle projecting from the occlusal surface of the crown, most frequently affecting mandibular premolars. The anomaly occurs predominantly in individuals of Asian ancestry, as first documented by Sumiya (1959) and subsequently confirmed in more recent epidemiological studies (Lin et al., 2018; Naini et al., 2018). Histologic investigations demonstrated that the tubercle usually consists of enamel surrounding a dentin core containing an extension of the pulp (Oehlers et al., 1967). This anatomical feature explains the high risk of pulpal exposure following fracture or attrition of the tubercle and the frequent development of pulpal disease shortly after tooth eruption (Levitan & Himel, 2006; Chen et al., 2020).

Once bacterial contamination occurs, the inflammatory process may progress from reversible or irreversible pulpitis to pulp necrosis and apical periodontitis (Levitan & Himel, 2006; Lerdrungroj et al., 2023). Because these events usually occur before completion of root development, premature loss of pulp vitality may arrest root maturation, leaving the tooth with thin dentinal walls, an open apex, and increased susceptibility to fracture (Uyeno & Lugo, 1996; van der Vyver et al., 2023). Preservation of the native pulp-dentin complex remains the preferred biological objective because living pulp continues to provide immune surveillance, sensory function, dentin deposition, and defensive responses (Hargreaves et al., 2013).

Current management of fractured dens evaginatus is guided primarily by pulpal diagnosis (Lerdrungroj et al., 2023). Teeth with normal pulps or reversible pulpitis are generally managed conservatively to prevent pulpal exposure and permit continued root maturation (Sim, 1996; Lerdrungroj et al., 2022). When irreversible pulpitis is diagnosed and the radicular pulp is considered healthy, vital pulp therapy is recommended (European Society of Endodontology, 2019; American Association of Endodontists, 2021). In contrast, immature teeth presenting with apical periodontitis are commonly presumed to have complete pulp necrosis and are therefore treated by regenerative endodontic procedures, apexification, or conventional root canal treatment, depending on the stage of root development and restorability (Banchs & Trope, 2004; Tsukiboshi et al., 2017; Ricucci et al., 2019). This treatment paradigm is based on the assumption that apical periodontitis is synonymous with complete pulp necrosis. However, increasing histologic evidence indicates that pulpal inflammation and necrosis are frequently spatially heterogeneous rather than uniformly distributed throughout the root canal system (Ricucci et al., 2014). Consequently, the presence of periapical disease does not necessarily indicate complete loss of pulp tissue throughout the canal. Despite extensive coronal necrosis and apical inflammation, residual radicular pulp may remain viable in immature teeth, retaining the capacity for immune defense, dentin deposition, and continued root maturation. Recognition of residual radicular pulp has important therapeutic implications. If viable pulp tissue can be identified within the root canal during

treatment, clinical management should aim not only to eliminate infected tissue but also to preserve the remaining healthy pulp whenever possible. Such an approach differs fundamentally from treatment strategies for completely necrotic teeth because it seeks to maintain the native pulp-dentin complex rather than replace its function through regenerative procedures or artificial apical barriers.

The possibility that immature teeth with apical periodontitis may retain residual radicular pulp was first illustrated in a previous report describing three mandibular premolars with fractured dens evaginatus in which vital tissue was unexpectedly encountered during canal exploration (Tsukiboshi et al., 2017). Those observations challenged the traditional assumption that apical periodontitis necessarily reflects complete pulp necrosis. However, they were limited to a small number of cases and did not establish a reproducible clinical strategy for recognizing or preserving residual radicular pulp during treatment.

Accordingly, the present study was undertaken on the premise that viable residual radicular pulp should be preserved in immature teeth with fractured dens evaginatus. Clinical decision-making should therefore be guided by tissue viability instead of presumed complete pulp necrosis. The aim of this study was to describe a biologically guided vital pulp therapy protocol based on recognition and preservation of residual radicular pulp, and to evaluate its clinical application in a consecutive series of immature premolars with fractured dens evaginatus and apical periodontitis.

Materials and Methods

Study design

This retrospective observational study describes the development and clinical application of a biologically guided vital pulp therapy protocol based on recognition and preservation of residual radicular pulp in immature permanent premolars with pulpal disease associated with fractured dens evaginatus. Clinical outcomes were evaluated in a consecutive series of treated teeth.

The protocol evolved from repeated clinical observations that immature teeth with fractured dens evaginatus and apical periodontitis frequently retained residual radicular pulp despite clinical and radiographic findings commonly interpreted as evidence of complete pulp necrosis. Accordingly, treatment was directed toward identifying and preserving residual radicular pulp whenever clinically feasible.

Clinical records of patients treated by the author between 2003 and 2022 were reviewed. Only teeth managed according to the same biological treatment strategy and followed clinically and radiographically after treatment were included.

Patient selection

The study included 14 premolars in 12 consecutive patients presenting with pulpal disease following fracture of a dens evaginatus tubercle.

Inclusion criteria were:

- immature permanent premolars with fractured dens evaginatus;
- clinical signs and/or symptoms consistent with pulpitis or pulp necrosis;
- availability of pretreatment clinical and radiographic records;
- minimum clinical follow-up after treatment.

Teeth with complete destruction precluding conservative treatment or with insufficient clinical documentation were excluded.

Patient age, sex, tooth location, presenting symptoms, clinical findings, radiographic appearance, treatment procedures, and follow-up examinations were obtained from the clinical records.

Clinical examination

At the initial examination, each tooth underwent routine clinical and radiographic assessment.

Clinical examination included:

• electric pulp testing (EPT);
• cold sensitivity testing when indicated;
• percussion testing;
•evaluation for gingival swelling or sinus tract formation;
•assessment of tenderness to biting.

Periapical radiographs were obtained in all cases. Cone-beam computed tomography (CBCT) was performed when clinically indicated to evaluate the extent of periapical bone destruction, root development, and root canal anatomy. Root developmental stage was assessed according to the classification of Moorrees et al. (1963).

Recognition and preservation of residual radicular pulp

The biologically guided treatment strategy was founded on the premise that pulpal inflammation or necrosis associated with fractured dens evaginatus is frequently confined to the coronal portion of the pulp space, whereas residual radicular pulp may remain viable despite the presence of apical periodontitis. Consequently, treatment was directed toward identifying the apical extent of necrotic or irreversibly inflamed tissue while preserving the maximum amount of healthy radicular pulp capable of supporting healing and continued root maturation (Fig. 1).

Cases with limited coronal involvement

When clinical findings suggested that fracture had occurred recently and inflammation was presumed to be limited predominantly to the coronal pulp, local anesthesia was administered before treatment. Access was prepared through the fractured dens evaginatus using a high-speed diamond bur under rubber dam isolation. Inflamed pulp tissue was removed until healthy tissue demonstrating controlled bleeding was identified under the operating microscope. The depth of tissue removal varied according to the extent of inflammation and was typically between approximately 3 and 6 mm.

Cases with suspected deeper pulpal involvement

When clinical findings suggested that necrosis extended further into the root canal, the initial exploration was performed without local anesthesia in selected patients. Access was prepared using a long-shank round diamond bur in a high-speed handpiece. Pulp removal was continued until the patient reported the first perception of discomfort or slight pain accompanied by the onset of bleeding. This transition was interpreted clinically as indicating contact with innervated viable pulp. Tissue removal was terminated immediately to maximize preservation of residual radicular pulp.

This author-specific approach was intended solely as a clinical aid for identifying the transition between insensitive necrotic tissue and viable pulp. It should not be interpreted as a routine alternative to contemporary pain-control protocols. Appropriate patient selection, informed consent, and operator experience were considered essential.

Intracoronal dressing and definitive restoration

After hemostasis, the wound surface was irrigated with sterile saline. Calcium hydroxide/iodoform paste (Vitapex; Shofu, Tokyo, Japan) was placed directly over the preserved pulp tissue, and the remaining pulp chamber was temporarily restored with glass ionomer cement. Patients were reviewed clinically and radiographically. Following resolution of symptoms and evidence of periapical healing, re-entry was performed when indicated. The calcium hydroxide/iodoform dressing was removed, the presence of a hard tissue barrier was evaluated clinically, and MTA cement (BioMTA; Morita, Tokyo, Japan) was placed over the pulp wound before definitive restoration with resin composite.

When exploration demonstrated complete pulp necrosis extending to the root apex, preservation of residual radicular pulp was no longer biologically possible. The tooth was managed by conventional root canal treatment rather than the biologically guided protocol.

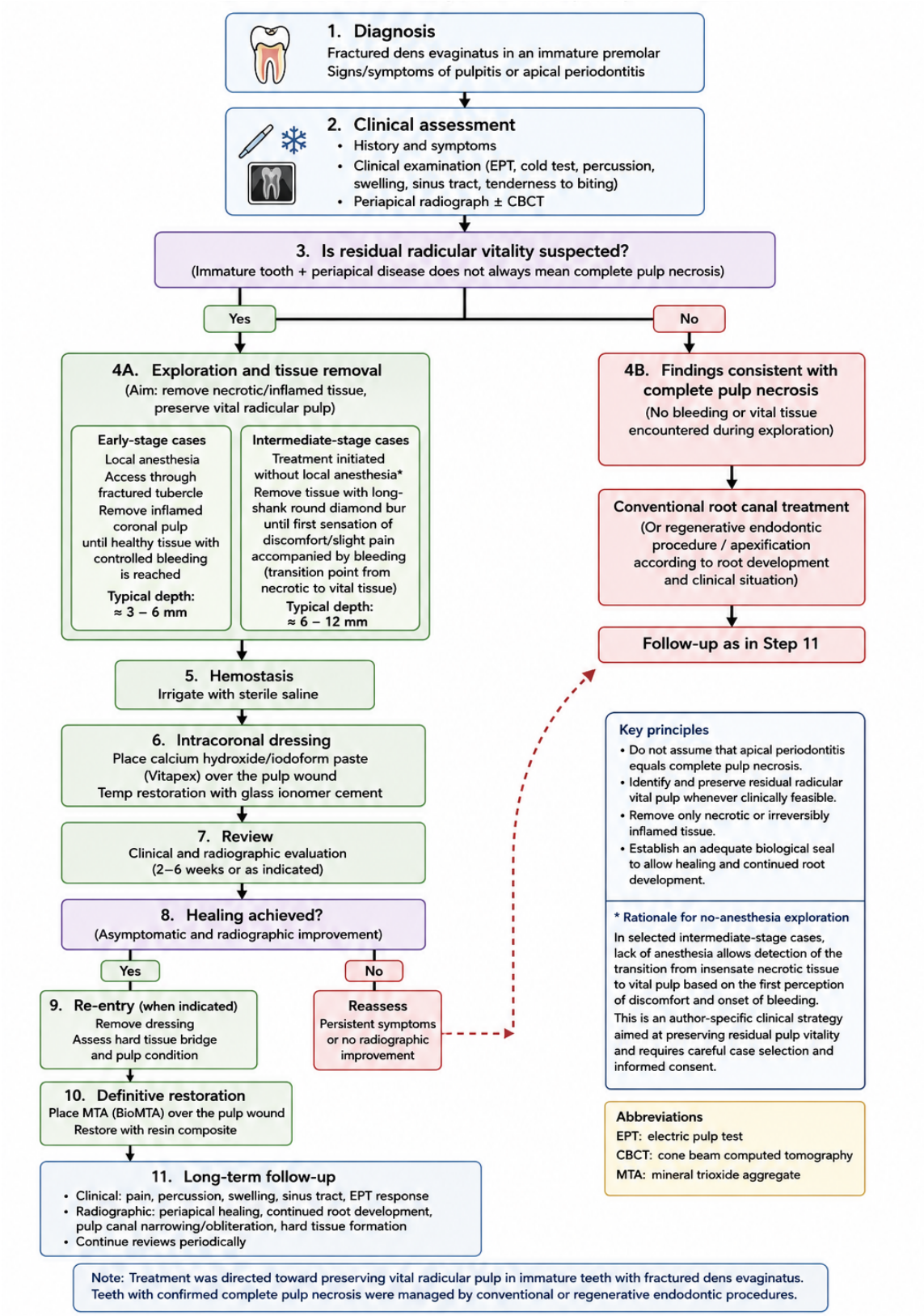


Fig. 1. Biologically guided treatment algorithm for immature teeth with fractured dens evaginatus and apical periodontitis. The algorithm illustrates the proposed clinical decision-making pathway. Instead of assuming complete pulp necrosis solely on the basis of apical periodontitis, treatment is directed toward identifying residual radicular pulp whenever clinically feasible. When viable pulp is encountered, selective removal of necrotic or irreversibly inflamed tissue is followed by placement of calcium hydroxide/iodoform paste, subsequent MTA cement after hard tissue barrier formation, and definitive restoration. Teeth in which no viable pulp is identified are managed by conventional root canal treatment.

Outcome assessment

Clinical follow-up included evaluation of:

- pain;
- percussion sensitivity;
- presence or absence of swelling;
- sinus tract resolution;
- electric pulp test response.

Radiographic follow-up evaluated:

- healing of periapical radiolucencies;
- continued root development;
- hard tissue barrier formation;
- pulp canal narrowing or obliteration.

Radiographic measurements

Whenever CBCT images were available, pulp resection depth was measured as the distance from the cusp tip to the resected pulp surface. Continued root development was measured as the increase in root length between pretreatment and follow-up CBCT examinations using standardized linear measurements. When CBCT was unavailable, measurements were estimated from calibrated periapical radiographs.

Statistical analysis

Because of the descriptive nature of this retrospective observational study and the limited sample size, only descriptive statistics were calculated. Continuous variables were presented as means, whereas categorical variables were presented as frequencies.

Results

Identification of residual radicular pulp

Application of the biologically guided protocol identified clinically detectable residual radicular pulp in 12 of 14 immature premolars (85.7%) despite clinical and radiographic findings commonly associated with complete pulp necrosis (Table 1). The remaining two teeth exhibited complete pulp necrosis extending to the root apex and were therefore managed by conventional root canal treatment rather than the biologically guided protocol.

These findings indicate that apical periodontitis associated with fractured dens evaginatus did not necessarily correspond to complete pulp necrosis in this consecutive series of immature premolars.

Patient characteristics

Fourteen immature premolars from 12 consecutive patients fulfilled the inclusion criteria and were treated between 2003 and 2022 (Table 1). Patient age at presentation ranged from 10 years 0 months to 13 years 10 months (mean, 11 years 1 month). The patient cohort comprised five boys and nine girls. Thirteen teeth were mandibular premolars (#35, n = 8; #45, n = 5), and one tooth was a maxillary premolar (#15).

Most teeth exhibited advanced but incomplete root formation (Stages 4–6), reflecting the characteristic timing of dens evaginatus fracture shortly after eruption. Eight teeth were classified as Stage 5, three as Stage 4–5, one as Stage 4, and two as Stage 6 (Table 1).

Pretreatment clinical findings

Clinical signs traditionally interpreted as indicating complete pulp necrosis—including negative electric pulp test responses, sinus tract formation, gingival swelling, and periapical radiolucencies—were frequently observed in teeth that nevertheless retained residual radicular pulp identified during treatment.

Electric pulp testing was positive in seven teeth, negative in six, and one tooth responded only to cold testing. Four teeth presented with buccal sinus tracts, and two exhibited localized gingival swelling at the initial examination (Table 1).

Periapical radiolucencies were present in most cases and, when CBCT was performed, demonstrated varying degrees of periapical bone destruction while confirming extension of the pulp horn into the fractured dens evaginatus.

Table 1. Clinical characteristics, treatment variables, and outcomes of immature premolars with fractured dens evaginatus

Patient characteristics					Treatment variables					Outcomes			
Patient	Age (years, months)	Sex	Tooth	Root stage*	EPT†	Sinus tract	Swelling	Vital radicular pulp identified during treatment	Treatment‡	Depth of tissue removal (mm)	Root length before (mm)	Root length after (mm)	Root development§ (mm)
K.L.	12 y 3 m	M	#35	5	(+)	–	–	Yes	BG-VPT	8.0	21.0	22.0	**1.0**
A.D.	12 y 8 m	F	#45	5	(–)	–	Yes	Yes	BG-VPT	8.0	18.0	19.3	**1.3**
K.M.	10 y 0 m	M	#35	4–5	Cold (+)	–	–	Yes	BG-VPT	2.5	17.0	20.0	**3.0**
M.H.	11 y 3 m	F	#35	5	(+)	–	–	Yes	BG-VPT	3.5	21.0	21.8	**0.8**
H.Y.	11 y 6 m	M	#35	4–5	(–)	Yes	–	Yes	BG-VPT	10.5	18.6	21.3	**2.7**
S.S.	11 y 9 m	F	#35	6	(+)	–	–	Yes	BG-VPT	5.0	17.5	17.6	**0.1**
A.M.	11 y 4 m	F	#15	4–5	(–)	–	–	No	RCT	13.5	15.5	18.8	**3.3**
A.M.	11 y 4 m	F	#45	5	(–)	Yes	–	Yes	BG-VPT	12.5	17.9	19.1	**1.2**
K.T.	13 y 1 m	M	#45	5	(+)	Yes	–	Yes	BG-VPT	7.0	20.6	20.9	**0.3**
K.O.	13 y 10 m	F	#35	4	(–)	–	Yes	Yes	BG-VPT	8.0	17.0	22.6	**5.6**
K.S.	11 y 1 m	F	#35	4–5	(+)	–	–	Yes	BG-VPT	6.5	19.0	21.1	**2.1**
T.K.	13 y 1 m	F	#35	5	(–)	Yes	–	No	RCT	18.0	19.5	19.9	**0.4**
T.K.	13 y 1 m	F	#45	5	(+)	–	–	Yes	BG-VPT	7.0	19.2	20.2	**1.0**
R.O.	12 y 9 m	M	#45	6	(+)	–	–	Yes	BG-VPT	6.0	21.8	21.8	**0.0**
Summary	Mean 11 y 1 m	M: 5 F: 9	#35: 8 #45: 5 #15: 1	–	–	4 teeth	2 teeth	12/14 (85.7%)	BG-VPT: 12 RCT: 2	Mean 8.3	Mean 18.8	Mean 20.5	Mean 1.6

BG-VPT, biologically guided vital pulp therapy; RCT, conventional root canal treatment; EPT, electric pulp test.

* Root stage was classified according to Moorrees et al., 1963.

+ EPT: (+) = positive response; (-) = no response; Cold (+) = positive response to cold test only.

‡ Treatment performed: BG-VPT = biologically guided vital pulp therapy; RCT = conventional root canal treatment.

§ Root development (mm) = root length after treatment - root length before treatment.

Treatment characteristics

The depth at which viable radicular pulp was identified varied considerably among teeth. In the 12 teeth managed by the biologically guided protocol, the depth of tissue removal ranged from 2.5 to 12.5 mm, reflecting substantial variation in the corono-apical extent of pulpal involvement (Table 1).

In each of these teeth, tissue removal was terminated immediately after clinically identifiable viable pulp was encountered. Following hemostasis, calcium hydroxide/iodoform paste was placed over the preserved pulp, and the teeth subsequently underwent re-entry for placement of MTA cement after clinical and radiographic evidence of healing.

In contrast, the two teeth with complete pulp necrosis required tissue removal to depths of 13.5 mm and 18.0 mm, respectively, before confirming absence of viable pulp. These teeth were subsequently managed by conventional root canal treatment.

Clinical and radiographic outcomes

Preservation of residual radicular pulp was associated with favorable clinical and radiographic healing in all teeth managed according to the biologically guided protocol.

Pain resolved after treatment, buccal sinus tracts disappeared, and gingival swelling subsided without recurrence.

Radiographic examination demonstrated progressive resolution of periapical radiolucencies, formation of hard tissue beneath the pulp dressing, and continued root maturation in most teeth.

Mean root length increased from 18.8 mm before treatment to 20.5 mm at the final examination, corresponding to a mean increase of approximately

1.6 mm (Table 1). Although additional root elongation was generally modest, many teeth were already approaching completion of root formation at presentation.

At re-entry, a hard tissue barrier was observed on the pulp wound surface in all teeth treated by the biologically guided protocol. Teeth that retained residual radicular pulp remained clinically functional throughout follow-up, and electric pulp testing remained positive or became positive in those teeth in which sensibility could be evaluated. Long-term follow-up, extending to more than seven years in several patients, demonstrated sustained clinical and radiographic success without recurrence of

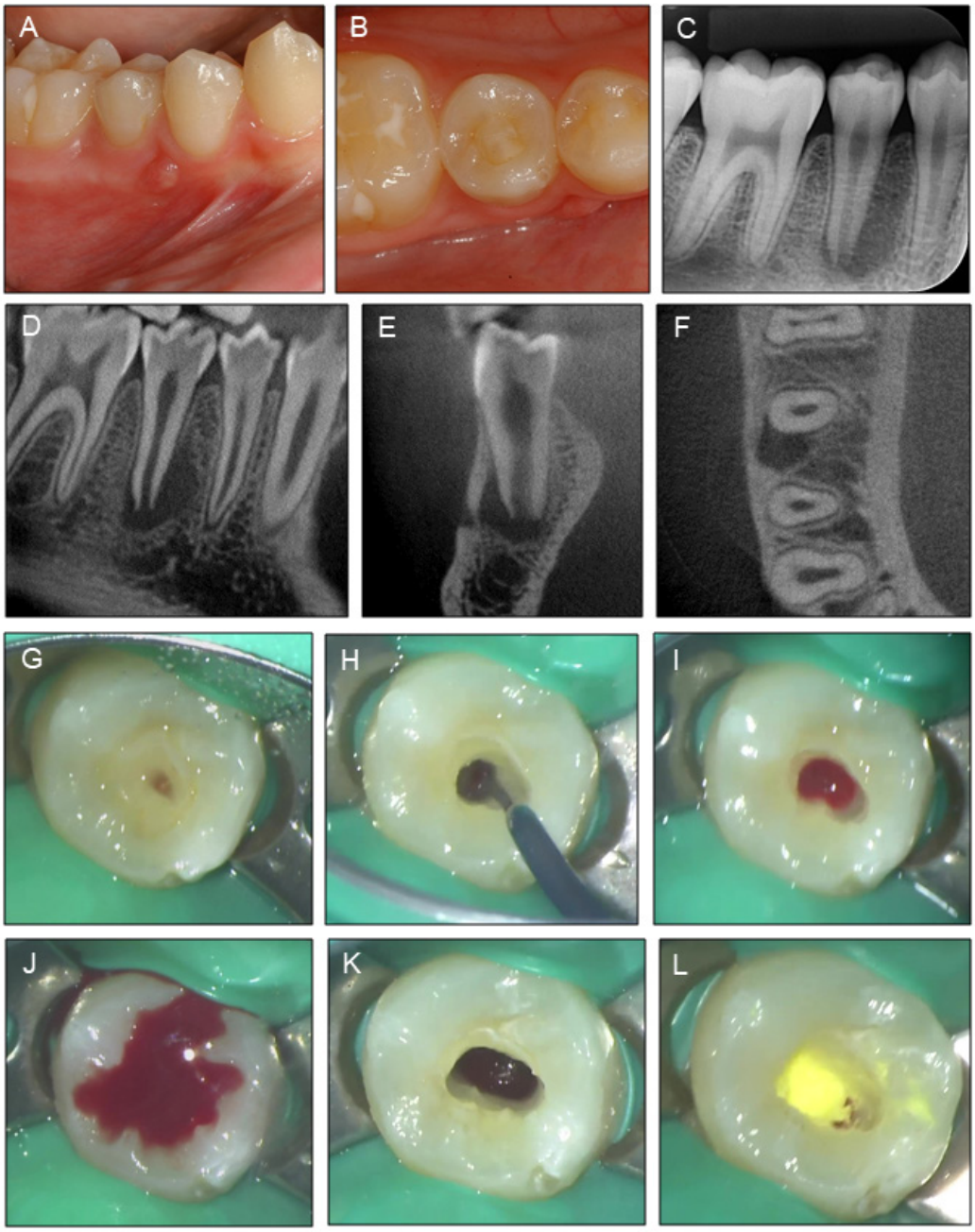


Fig. 2. Case 1. Advanced coronal necrosis with preservation of residual radicular pulp.
(A–B) Initial clinical photographs showing sinus tract and fracture of dens evaginatus. (C) Preoperative periapical radiograph demonstrating a large periapical radiolucency and incomplete root development. (D–F) Preoperative CBCT images confirming an immature root. (G) Purulent exudate following enlargement of the fractured dens evaginatus. (H) Exploration of the pulp space revealing necrotic tissue. (I–J) Profuse bleeding from the apical pulp indicating the presence of viable radicular pulp tissue. (K) Microscopic view of the pulpotomy wound. (L) Placement of Vitapex over the pulp wound.

apical disease.

Illustrative Clinical Applications of the Biologically Guided Protocol

The following five representative cases illustrate application of the biologically guided vital pulp therapy protocol across the spectrum of clinical presentations encountered in this series. They were selected to demonstrate the principal biological decision points of the protocol rather than to represent the overall study outcomes, which are summarized in Table 1. The first case is presented in greater detail to illustrate the clinical steps and biological rationale of the protocol.

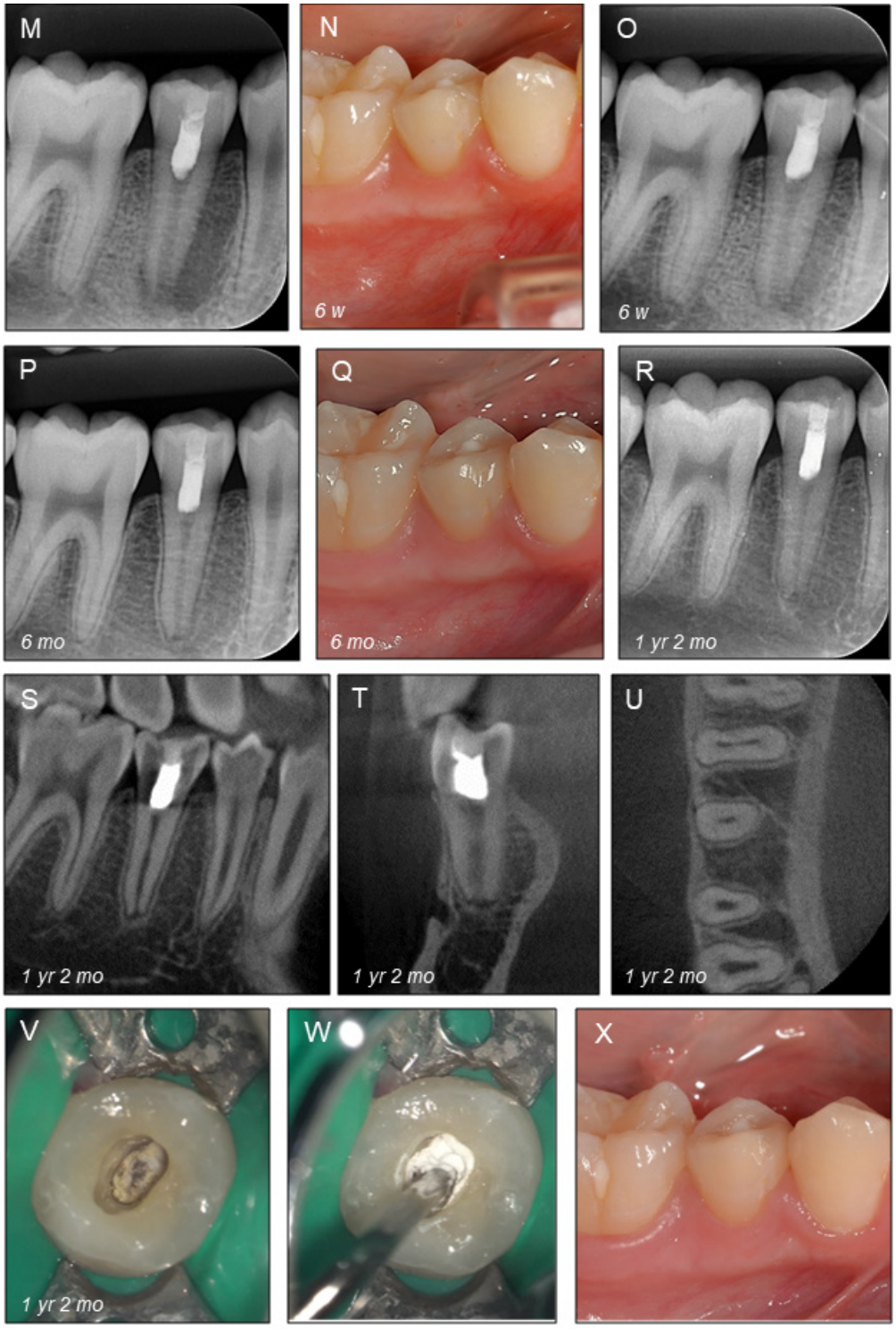


Fig. 2. Case 1. Advanced coronal necrosis with preservation of residual radicular pulp (continued)

(M) Immediate postoperative radiograph. (N) Resolution of the sinus tract after 6 weeks. (O) Reduction of the periapical radiolucency after 6 weeks. (P) Complete resolution of the periapical radiolucency and narrowing of the pulp canal space after 6 months. (Q) Clinical appearance at 6 months showing resolution of the sinus tract. (R–U) Periapical radiographs and CBCT images obtained 1 year and 2 months after treatment demonstrating hard tissue formation beneath the Vitapex, slight root development, and healing of the periapical tissues. (V) Hard tissue formation on the wound surface at re-entry. (W) Placement of MTA cement over the newly formed hard tissue. (X) Final restoration with composite resin.

Case 1. Advanced coronal necrosis with preservation of residual radicular pulp (Figure 2)

A 13-year-1-month-old boy (case K.T., Table 1) presented with pain, swelling, and a buccal sinus tract associated with the mandibular right second premolar following fracture of the dens evaginatus tubercle (Fig. 2A-B). A periapical radiograph revealed a large periapical radiolucency and incomplete root development (Fig. 2C). CBCT confirmed the presence of an immature root with incomplete root maturation (Fig. 2D–F).

Without local anesthesia, the center of the fractured dens evaginatus was enlarged using a long-shank diamond bur in a high-speed handpiece under water irrigation. A small amount of purulent exudate was observed (Fig. 2G). Access to the pulp space was then prepared, and exploration revealed necrotic tissue extending approximately 7 mm apically (Fig. 2H). At this depth, the patient reported discomfort and profuse bleeding was encountered, confirming the presence of viable radicular pulp tissue (Fig. 2I-J). The canal was irrigated with sterile saline, and hemostasis was achieved after approximately 15 minutes. Microscopic examination confirmed the presence of viable radicular pulp tissue at the pulpotomy wound (Fig. 2K). Vitapex was placed directly over the pulp wound (Fig. 2L), and the remaining pulp space and access cavity were sealed with glass ionomer cement (Base Cement; Shofu, Tokyo, Japan). A postoperative periapical radiograph was then obtained (Fig. 2M). The sinus tract resolved within 6 weeks (Fig. 2N), and a periapical radiograph demonstrated a reduction in the periapical radiolucency (Fig. 2O). At the 6-month follow-up, the periapical radiolucency had completely resolved, and narrowing of the pulp canal space was evident (Fig. 2P). No clinical evidence of the previous sinus tract remained (Fig. 2Q). Periapical radiographs and CBCT images obtained 1 year and 2 months after treatment demonstrated hard tissue formation immediately beneath the Vitapex, accompanied by slight root development. The periapical tissues appeared healthy (Fig. 2R–U). At this time, re-entry was performed. After careful removal of the glass ionomer cement and Vitapex, hard tissue formation was observed on the wound surface (Fig. 2V), and the tooth exhibited a positive response to electric pulp testing (EPT). MTA cement (BioMTA) was placed over the newly formed hard tissue (Fig. 2W), and the access cavity was permanently restored with composite resin (Fig. 2X).

This case illustrates that extensive coronal necrosis and apical periodontitis do not necessarily indicate complete pulp necrosis.

Case 2. Early pulpal involvement managed conservatively (Figure 3)

An 11-year-1-month-old girl (case K.S., Table 1) presented with discomfort associated with the mandibular left second premolar following fracture of the dens evaginatus tubercle. Clinical examination revealed a positive response to EPT and tenderness to percussion, consistent with a diagnosis of pulpitis. During access preparation, severe pain was elicited while excavating the fractured dens evaginatus, indicating the presence of viable pulp tissue. After administration of local anesthesia, pulpotomy was performed to a depth of approximately 6 mm. Following hemostasis, Vitapex was placed over the pulp wound, and the access cavity was temporarily sealed with glass ionomer cement. At the 1-year-11-month follow-up, radiographic and CBCT examinations demonstrated complete resolution of the periapical lesion and formation of a hard tissue barrier beneath the Vitapex. The tooth responded positively to EPT. At re-entry, the hard tissue barrier was preserved and covered with BioMTA, followed by permanent restoration with composite resin. Follow-up examinations at 3 years 3 months and 6 years 6 months confirmed continued clinical and radiographic success.

This case demonstrates application of the protocol when pulpal involvement is limited predominantly

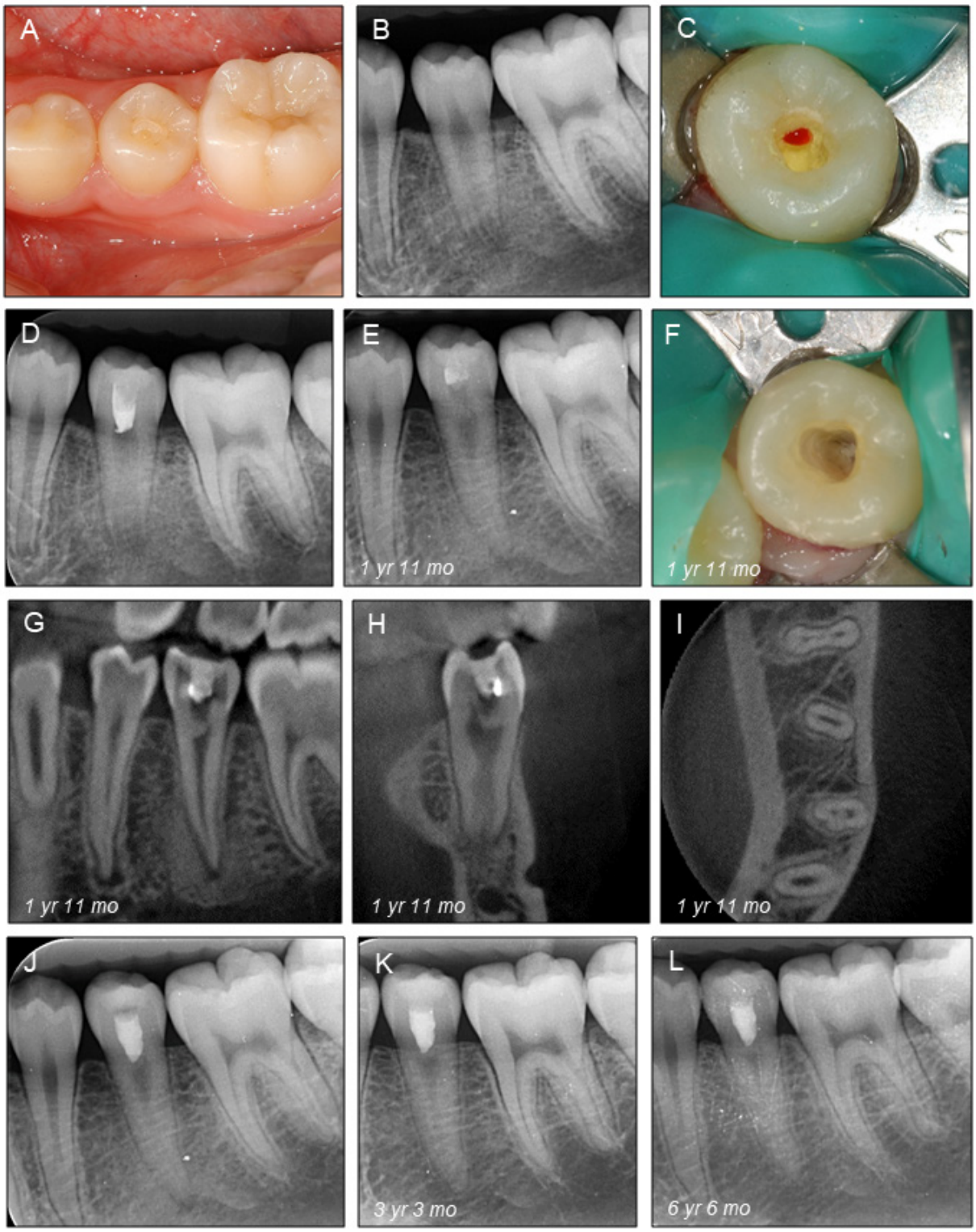


Fig. 3. Case 2. Early pulpal involvement managed by biologically guided vital pulp therapy.
(A–B) Initial clinical and radiographic examination. (C) Access preparation demonstrating bleeding from the pulp. (D) Immediate postoperative radiograph after biologically guided vital pulp therapy with Vitapex placement. (E) Pre-re-entry radiograph obtained 1 year and 11 months after treatment. Partial resorption of the capping material. (F) Hard tissue barrier observed at re-entry. (G–I) CBCT images demonstrating resolution of the periapical lesion and hard tissue barrier formation. (J) Placement of MTA cement over the hard tissue barrier. (K–L) Periapical radiographs obtained 3 years 3 months and 6 years 6 months after treatment showing normal periapical tissues.
This case demonstrates preservation of residual radicular pulp when inflammation is confined predominantly to the coronal pulp.

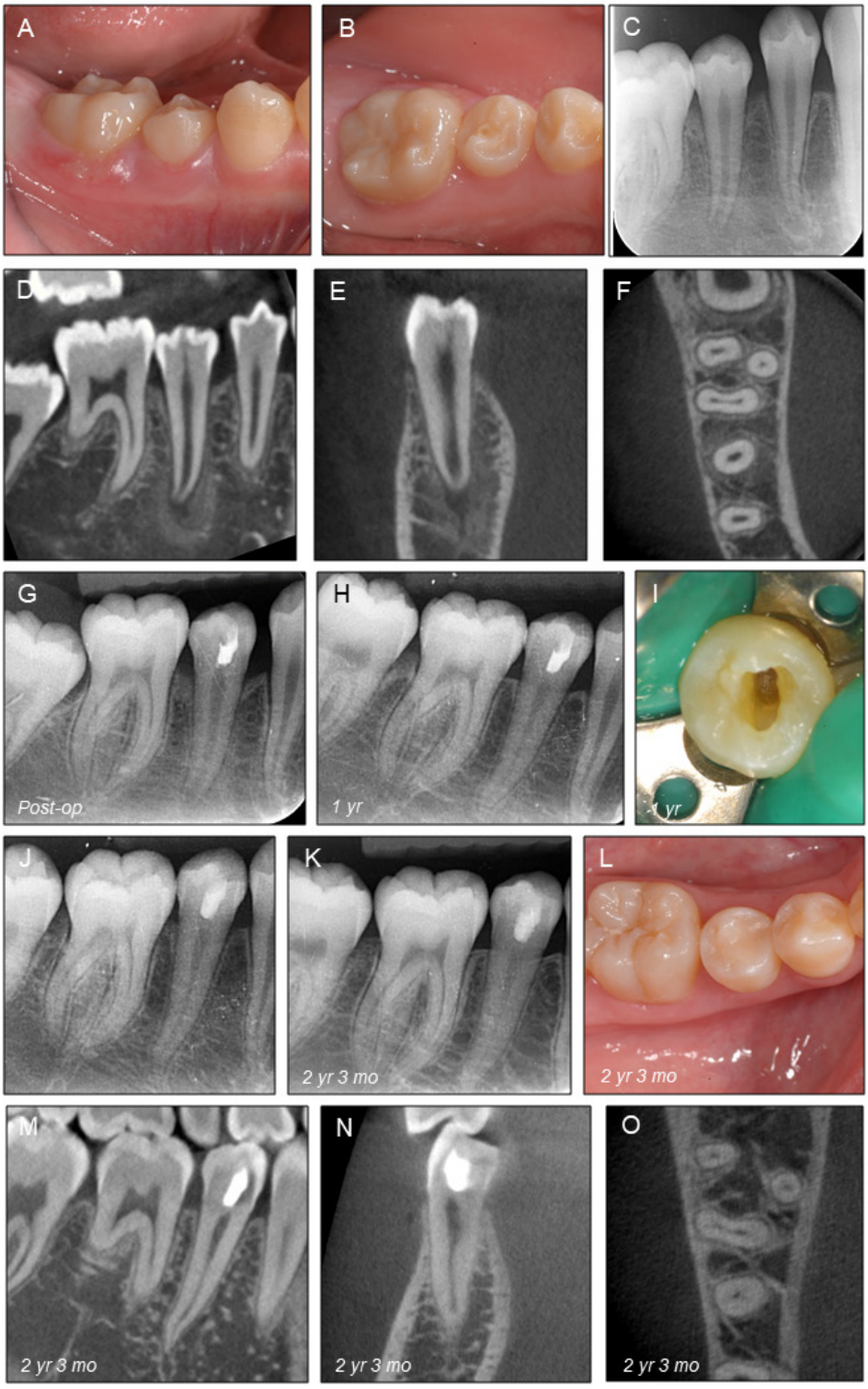


Fig. 4. Case 3. Irreversible pulpitis with apical inflammatory changes successfully managed by preservation of residual radicular pulp.
(A–C) Initial clinical and radiographic examination. (D–F) Preoperative CBCT images demonstrating condensing osteitis, pulp extension into the dens evaginatus, and lingual displacement of the tubercle. (G) Immediate postoperative radiograph after biologically guided vital pulp therapy with Vitapex placement. (H) Pre-re-entry radiograph obtained 1 year after treatment. (I) Hard tissue barrier observed at re-entry. (J) Placement of MTA cement over the hard tissue barrier. (K–L) Periapical radiograph and clinical photograph obtained 2 years 3 months after treatment showing normal clinical and radiographic findings. (M–O) CBCT images demonstrating resolution of the apical lesion and preservation of the pulp canal space without canal obliteration.
This case illustrates that residual radicular pulp may remain biologically functional despite apical inflammatory changes.

to the coronal portion of the pulp space.

Case 3. Irreversible pulpitis with apical inflammatory changes (Figure 4)

A 12-year-9-month-old boy (case R.O., Table 1) presented with spontaneous pain associated with the mandibular right second premolar following fracture of the dens evaginatus tubercle. Clinical examination revealed an equivocal response to EPT, prolonged pain to cold, and tenderness to percussion, consistent with a diagnosis of pulpitis. CBCT demonstrated condensing osteitis at the root apex and extension of the pulp into the dens evaginatus, which was displaced lingually. Under local anesthesia, pulpotomy was performed to a depth of approximately 6 mm. Following hemostasis, Vitapex was placed over the pulp wound, and the access cavity was temporarily sealed with glass ionomer cement. At the 1-year follow-up, the tooth responded positively to EPT, and re-entry revealed a well-formed hard tissue barrier, which was covered with BioMTA. Follow-up examinations at 2 years 3 months demonstrated normal periapical tissues without pulp canal obliteration, confirming successful healing.

Case 4. Deep coronal necrosis requiring extended exploration (Figure 5)

An 11-year-4-month-old girl (Case A.M., Table 1) presented with slight pain associated with the mandibular right second premolar following fracture of the dens evaginatus tubercle. Clinical examination revealed a negative response to EPT, tenderness to percussion, and no response to cold testing. Radiographic and CBCT examinations demonstrated a periapical radiolucency and extension of the pulp into the dens evaginatus. During access preparation without local anesthesia, the patient experienced discomfort when excavation reached approximately 12 mm from the buccal cusp, indicating the presence of viable radicular pulp tissue. Pulpotomy was performed to this level, followed by placement of Vitapex over the pulp wound and temporary restoration with glass ionomer cement. The sinus tract resolved within 1 month. At the 1-year-2-month follow-up, Vitapex was replaced with BioMTA, and the tooth was permanently restored with composite resin. Follow-up examinations up to 7 years 7 months demonstrated complete periapical healing and preservation of the pulp canal space without canal obliteration.

Case 5. Complete pulp necrosis requiring conventional root canal treatment (Figure 6)

An 11-year-4-month-old girl (Case A.M., Table 1) presented with slight pain associated with the maxillary right second premolar following fracture of the dens evaginatus tubercle. This patient was the same as in Case 4 but involved a different tooth. Clinical examination revealed a negative response to EPT, tenderness to percussion, and no response to cold testing. Although no definite periapical radiolucency was evident radiographically, the tooth was diagnosed with pulpitis associated with a fractured dens evaginatus. During access preparation without local anesthesia, the pulp was found to be necrotic to the root apex. Conventional root canal treatment was therefore performed, including canal debridement and placement of calcium hydroxide. Seven months later, slight continued root development was observed. Approximately 1 year after treatment, the calcium hydroxide was replaced with BioMTA, and the tooth was restored with a fiber post and composite resin. Follow-up examinations at 7 years 7 months demonstrated complete periapical healing and approximately 3 mm of continued root development.

Discussion

The principal finding of this study is that apical periodontitis associated with fractured dens evaginatus did not necessarily indicate complete

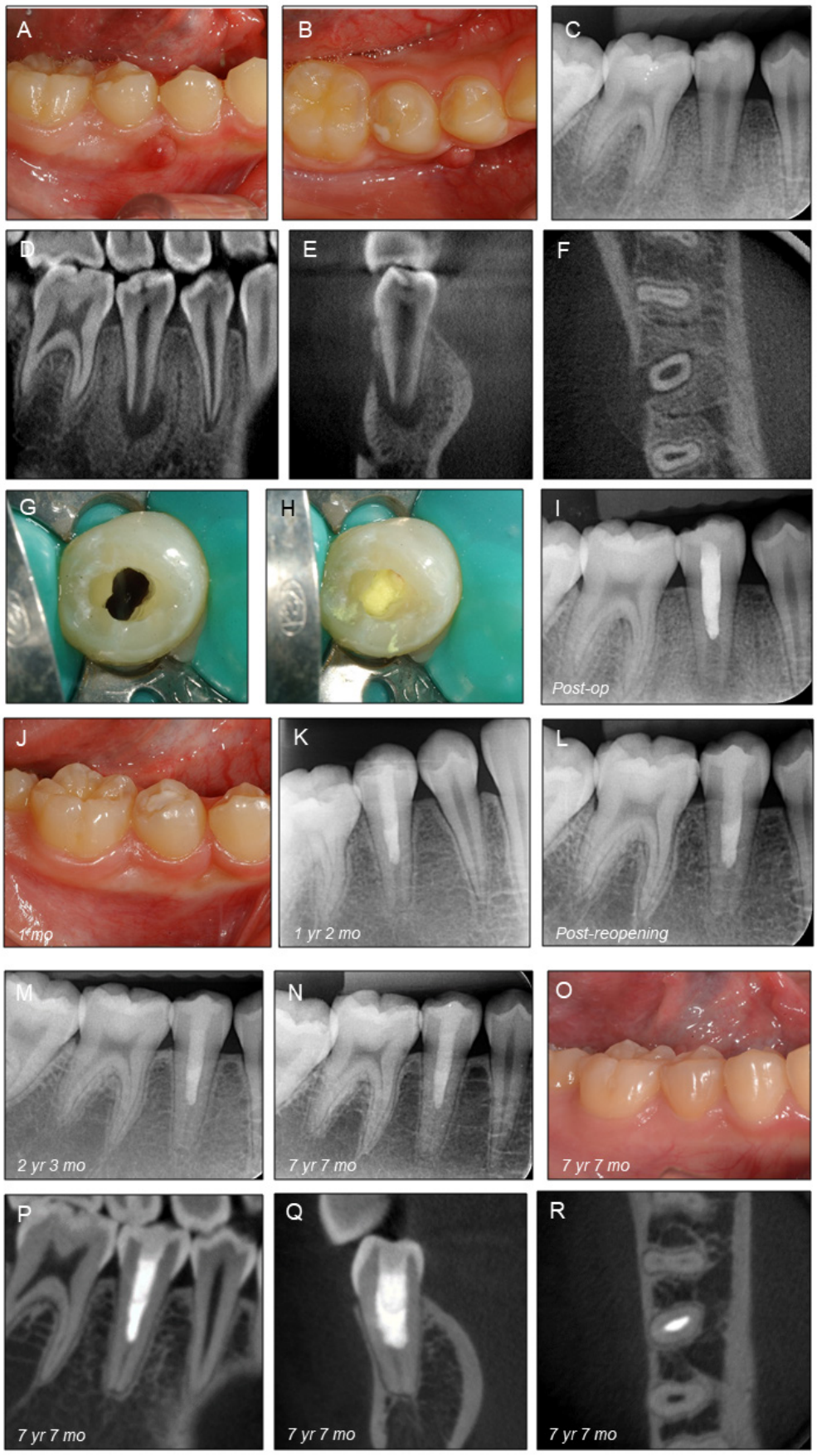


Fig. 5. Case 4. Advanced coronal necrosis requiring deeper exploration to identify viable radicular pulp.
(A–C) Initial clinical and radiographic examination. (D–F) Preoperative CBCT images demonstrating a periapical radiolucency and extension of the pulp into the dens evaginatus. (G) Access preparation without local anesthesia demonstrating the presence of viable radicular pulp tissue. (H) Placement of Vitapex over the pulp wound. (I) Immediate postoperative radiograph. (J) Resolution of the sinus tract after 1 month. (K) Pre-re-entry radiograph obtained 1 year and 2 months after treatment. (L) Placement of MTA cement and permanent composite resin restoration. (M, N) Periapical radiographs obtained 2 years 3 months and 7 years 7 months after treatment showing continued healing. (O) Clinical appearance at 7 years 7 months. (P–R) CBCT images demonstrating complete periapical healing and preservation of the pulp canal space without canal obliteration.
This case illustrates the importance of identifying the transition from necrotic to viable tissue rather than assuming complete pulp necrosis based on the presence of apical disease.

pulp necrosis. Clinically identifiable residual radicular pulp was present in 12 of the 14 immature premolars and could be preserved using a biologically guided treatment strategy. This observation supports the concept that in immature teeth, the presence of apical periodontitis should not automatically be equated with complete loss of pulpal vitality. Instead, treatment selection should be guided by the biological status of the remaining pulp whenever this can be assessed clinically. Importantly, the present findings should not be interpreted as suggesting that all immature teeth with apical periodontitis are candidates for vital pulp therapy. Rather, they emphasize that treatment selection should depend on the presence or absence of residual radicular pulp identified during clinical exploration.

The biological basis for this concept is consistent with current understanding of pulpal pathology. Histologic investigations have shown that inflammation and necrosis within the pulp are often spatially heterogeneous rather than uniformly distributed throughout the root canal system (Ricucci et al., 2014; Ricucci et al., 2019). In immature teeth, the abundant vascular supply through the wide apical foramen may permit



Fig. 6. Case 5. Complete pulp necrosis requiring conventional root canal treatment.
(A–B) Initial clinical and radiographic examination. (C) Immediate postoperative radiograph following conventional root canal treatment with calcium hydroxide placement. (D) Seven-month follow-up radiograph demonstrating slight continued root development. (E) Radiograph obtained 2 years 3 months after treatment following replacement of calcium hydroxide with MTA cement and definitive restoration. (F) Periapical radiograph obtained 7 years 7 months after treatment. (G–I) CBCT images demonstrating complete periapical healing and slight continued root development without evidence of apical radiolucency.
This case emphasizes that the proposed biological strategy includes recognition of teeth in which preservation of residual radicular pulp is no longer possible and conventional root canal treatment is therefore indicated.

survival of radicular pulp despite extensive coronal destruction. Consequently, bacterial contamination following fracture of a dens evaginatus tubercle may produce coronal necrosis while preserving apical pulp capable of maintaining immune defense, dentin deposition, and continued root maturation. The present clinical observations are consistent with this biological model.

The proposed management strategy therefore differs conceptually from conventional vital pulp therapy. Current guidelines recommend vital pulp therapy primarily for teeth with normal pulp, reversible pulpitis, or selected cases of irreversible pulpitis in which the remaining radicular pulp is presumed to be healthy (European Society of Endodontology, 2019; American Association of Endodontists, 2021; Duncan, 2022; Colloc & Tomson, 2025). By contrast, the teeth included in the present study frequently exhibited apical periodontitis, sinus tracts, swelling, or negative sensibility responses, findings that would ordinarily suggest complete pulp necrosis. Instead of relying exclusively on the preoperative diagnosis, the proposed biological strategy incorporates intraoperative assessment to determine whether residual radicular pulp remains present and can be preserved.

The present study extends the preliminary observations reported by Tsukiboshi et al. (2017), in which viable radicular pulp was unexpectedly encountered in three immature premolars with fractured dens evaginatus and apical periodontitis. The current series expands those observations by describing a reproducible clinical strategy and evaluating its application in a consecutive series with long-term follow-up. Rather than introducing a new operative technique, the present study proposes a refinement in biological diagnosis: apical periodontitis associated with fractured dens evaginatus should not automatically be interpreted as complete pulp necrosis because recognition of residual radicular pulp may fundamentally alter treatment selection. An important observation was the considerable variation in the depth at which viable radicular pulp was encountered, indicating substantial variability in the corono-apical extent of pulpal inflammation and necrosis. These findings reinforce the concept that pulpal disease represents a biological continuum rather than a simple dichotomy of vital versus necrotic pulp. Clinically, this suggests that treatment should be directed by the extent of remaining viable tissue rather than by radiographic evidence of apical disease alone.

Continued root development after treatment was modest, with a mean increase in root length of approximately 1.6 mm. This should be interpreted in light of the developmental stage of the treated teeth, most of which had already reached Stage 5 or Stage 6 root formation and therefore had limited remaining growth potential. Under these circumstances, the principal biological benefit of preserving residual radicular pulp is not extensive additional root elongation but maintenance of the native pulp-dentin complex, physiological dentin deposition, and resolution of apical inflammation.

One aspect of the proposed strategy that warrants discussion is the selective use of exploration without local anesthesia in carefully selected patients. This author-specific approach was intended solely as a clinical aid for identifying the transition between insensitive necrotic tissue and innervated viable pulp. It should not be regarded as a routine recommendation, nor does the present study establish its superiority over other methods of assessing pulp status. Appropriate patient selection, informed consent, and operator experience are essential, and further prospective investigation is required before broader clinical application can be recommended.

This study has several limitations. It represents a retrospective observational investigation conducted by a single operator, with a relatively small sample size and no comparison group. In addition, the

presence and extent of residual radicular pulp were determined clinically rather than histologically. Although histologic confirmation is inherently impossible in successfully treated teeth intended for long-term retention, this limitation should be acknowledged. Consequently, the proposed strategy should be regarded as a biologically plausible clinical approach supported by observational evidence rather than as definitive proof of a new diagnostic paradigm.

Despite these limitations, the study has important clinical implications. It does not propose replacing regenerative endodontic procedures, apexification, or conventional root canal treatment in teeth with complete pulp necrosis. Rather, it suggests that these procedures may not always be necessary when residual radicular pulp remains present. Recognition of this possibility broadens the therapeutic options available for immature teeth with fractured dens evaginatus and reinforces the importance of preserving the native pulp-dentin complex whenever biologically feasible.

In conclusion, the findings support a biologically guided approach in which recognition and preservation of residual radicular pulp become the principal determinants of treatment selection in immature teeth with fractured dens evaginatus and apical periodontitis. Prospective multicenter studies using standardized diagnostic criteria are now needed to validate this concept and define its indications, limitations, and long-term outcomes.

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