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Systematic Review

Recognition, Triage, and treatment Strategies for the Preservation of Vertical Root Fractures: A systematic review

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Abstract

Introduction: Patients with dental pain and swelling frequently present to emergency departments (EDs), where emergency physicians must distinguish urgent dental conditions from non-urgent ones. Vertical root fracture (VRF) is a diagnostically challenging condition that is often misidentified as an acute apical abscess or periodontal abscess, leading to inappropriate antibiotic use or delayed referral. This review synthesizes evidence on recognizing, triaging, and referring VRF for emergency clinicians.

Method: This systematic review was conducted through a broad search of electronic databases, including MEDLINE, PubMed, BVS (LILACS and BBO), Scopus, Web of Science, Cochrane Library, and Embase, from 1990 to 2025. We applied no language restrictions and checked the reference lists of all related articles.

Result: The searches identified 1,927 records. After removing duplicates and screening, 37 full-text articles were assessed, and 15 studies met the predefined eligibility criteria. The included evidence consisted predominantly of case reports, case series, and other small clinical studies. Because study designs, treatment protocols, and outcomes varied substantially, the findings were synthesized narratively.

Conclusion : Suspect VRF in patients with a history of root canal treatment who present with localized pain on chewing, a deep isolated periodontal pocket, or a sinus tract near the gingival margin. Dental specialists perform definitive treatment (bonding, bioceramic sealing, or intentional replantation), which is not an emergency department procedure. Emergency physicians should provide analgesia, reserve antibiotics for systemic involvement, and refer to a dentist or endodontist within 24–48 hours. Large-scale studies on emergency department diagnosis of VRF are lacking.

Keywords: Vertical root fracture; tooth preservation; treatment; adhesive resin; 4-META/MMA-TBB; MTA; Biodentine; intentional replantation.

Introduction

VRF is an important endodontic complication that can lead to localized periodontal inflammation, bone loss, and eventual tooth loss. Its clinical presentation is variable, and no single clinical or radiographic finding is pathognomonic. Accurate diagnosis therefore remains challenging, particularly in previously endodontically treated teeth [1-5].

Historically, extraction has frequently been selected for teeth with VRF. However, conservative and surgical approaches have been investigated to preserve selected fractured teeth, including bonding of fracture fragments with adhesive resins, sealing with bioceramic materials, and intentional replantation. The clinical applicability of these approaches depends on fracture location, periodontal status, fracture accessibility, tooth anatomy, and the ability to achieve adequate adaptation and sealing.

Although VRFs occur primarily in endodontically treated teeth, they have also been described, albeit rarely, in vital teeth [5, 6]. Some evidence suggests that maxillary premolars and molars are more prone to develop VRFs than other teeth, probably because of root anatomy [7, 8].

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Clinical findings such as a deep and narrow periodontal pocket, localized swelling, sinus tract formation, and characteristic radiographic changes may raise suspicion of VRF. Still, definitive diagnosis may require direct visualization during surgical exploration. Recent treatment studies have therefore focused on whether selected fractured teeth can be preserved rather than routinely extracted.

This review summarizes clinical evidence on treatment strategies to preserve teeth affected by vertical root fracture and describes reported clinical outcomes, follow-up, and limitations of the available evidence.

Methods

Study design

This study was conducted as a structured narrative review using a predefined literature-search and study-selection process. The review was not prospectively registered, and no meta-analysis was planned because the identified studies were heterogeneous in design, treatment protocols, and outcome reporting.

Eligibility criteria

Population: Teeth diagnosed with vertical root fracture.

Intervention: Any clinical treatment intended to preserve a tooth affected by VRF, including adhesive bonding, resin-based repair, bioceramic sealing, surgical repair, and intentional replantation.

Comparison: Not applicable.

Outcomes: Tooth survival or retention, clinical and radiographic healing, periodontal status, symptoms, function, and reported treatment success or failure.

Study design: Clinical studies, case reports, case series, and other clinical reports that provided treatment outcomes relevant to tooth preservation.

Eligibility criteria

Studies were eligible when they reported a clinical treatment approach intended to preserve a tooth diagnosed with VRF and provided clinical, radiographic, periodontal, or survival-related outcomes.

Population: Teeth diagnosed with vertical root fracture.

Intervention: Treatments aimed at preserving the fractured tooth or root.

Comparison: Not applicable.

Primary outcomes were tooth retention and survival; secondary outcomes included functional status, periodontal healing, radiographic healing, symptoms, and treatment-related complications.

We conducted a structured search in MEDLINE/PubMed, BVS (LILACS and BBO), Scopus, Web of Science, Cochrane Library, and Embase for publications from January 1, 1990, through December 31, 2024. The broad date range was selected to capture the development of conservative VRF treatment approaches, including early laser and adhesive techniques and more recent bioceramic and replantation approaches.

The search combined terms related to vertical root fracture and treatment, including “vertical root fracture,” “management of vertical root fracture,” “dual-cure resin,” “4-META/MMA-TBB resin,” “MTA,” and “laser.” The database-specific search strategies are presented in Table 1. No language restrictions were applied.

Titles and abstracts retrieved from the electronic databases were screened for relevance to treatment and preservation of teeth affected by VRF. Reference lists of relevant articles were also screened manually to identify additional eligible studies.

Exclusion criteria included articles without accessible full text, publications that did not provide relevant information on treatment or preservation outcomes, and gray literature. Studies focused exclusively on diagnosis without a treatment or preservation outcome were not included.

We manually screened reference lists of eligible and relevant articles for additional studies. Records were managed using EndNote, and duplicate records were removed. Two researchers independently screened titles and abstracts and reviewed potentially eligible full texts. Disagreements were resolved by discussion and, when necessary, consultation with a third researcher.

Data extraction included study characteristics, number of teeth, fracture location, treatment modality, follow-up duration, and reported clinical or radiographic outcomes. The extracted information was compared between the two reviewers.

Because the included studies were predominantly case reports and case series with substantial clinical and methodological heterogeneity, we performed a narrative synthesis. Formal quantitative pooling was not considered appropriate.

Results

A total of 1,927 records were identified through the electronic databases and manual reference screening. After removal of 521 duplicates and subsequent screening, 37 full-text articles were assessed for eligibility. Fifteen studies met the inclusion criteria and were included in the narrative synthesis. Table 2 presents all 15 included studies, including their study characteristics, treatment approaches, follow-up periods, and reported outcomes.

The included studies comprised a heterogeneous body of clinical evidence, predominantly case reports and case series, with some prospective clinical series. The evidence was therefore summarized by treatment modality rather than quantitatively pooled.

All 15 included studies investigated treatment approaches intended to preserve teeth affected by vertical root fracture (Table 2).

The following treatments were used in the intervention group.

The included studies reported adhesive resin cement, dual-cure adhesive resin cement, 4-META/MMA-TBB dentin-bonded resin, mineral trioxide aggregate (MTA), Biodentine, and laser-assisted approaches.

Several treatment strategies have been reported for selected VRF cases, including laser-based approaches, removal and bonding of fracture fragments with adhesive resins, bioceramic sealing, and intentional replantation with root-fragment bonding.

Laser

Nd: YAG laser has been investigated in relation to VRF and dentin modification; however, the available evidence does not establish a predictable clinical protocol for laser treatment of fractured roots.

Experimental work on CO2 laser exposure has examined thermal effects on dentin and the potential to modify or seal fracture surfaces. These findings represent early or experimental evidence and should not be interpreted as establishing clinical superiority.

Adhesive resin cement

Dental adhesive materials have been used to repair fractured roots, including extraoral reattachment of root fragments with self-etching or dual-cure adhesive resins. These techniques are technically sensitive and require careful control of the bonding environment.

Biodentine

Biodentine is a calcium-silicate-based cement that has been reported as a conservative treatment option in selected VRF cases. Evidence in this review is limited, and long-term comparative clinical data remain insufficient.

4-META/MMA-TBB dentin-bonded resin

The 4-methacryloxyethyl trimellitate anhydride/methyl methacrylate-tri-n-butyl borane (4-META/MMA-TBB) dental adhesive resin has been used for bonding VRF teeth in several clinical reports and case series.

Reported outcomes include reductions in periodontal probing depth, gingival inflammation, and tooth mobility in selected cases; however, these findings largely come from small clinical studies and should be interpreted cautiously.

Table 1. Search strategy

Database	Search Line	Search Strategy
Medline	#1	(vertical root fracture [Title/Abstract] OR management of vertical root fracture [Title/Abstract] OR dual-cure resin [Title/Abstract] OR 4-META/MMA-TBB resin [Title/Abstract] OR MTA [Title/Abstract] OR laser [Title/Abstract])
	#2	(Endodontic treatment [Title/Abstract] OR VRF [Title/Abstract] OR vertical root fracture [Title/Abstract] OR resin [Title/Abstract] OR resin cement [Title/Abstract] OR MTA [Title/Abstract] OR Biodentine [Title/Abstract] OR Bioceramic [Title/Abstract] OR laser [Title/Abstract] OR CO2 laser [Title/Abstract] OR endodontics [MeSH])
	#1 AND #2	
Scopus	#1	TITLE-ABS (vertical root fracture OR management of vertical root fracture OR dual-cure resin OR 4-META/MMA-TBB resin OR MTA OR laser)
	#2	TITLE-ABS ("Endodontic treatment" OR "VRF" OR "vertical root fracture" OR "resin" OR "resin cement" OR "MTA" OR "Biodentine" OR "Bioceramic" OR "laser" OR "CO2 laser" OR "endodontics")
	#1 AND #2	
Web of Science	#1	TS=(vertical root fracture OR management of vertical root fracture OR dual-cure resin OR 4-META/MMA-TBB resin OR MTA OR laser)
	#2	TS=("Endodontic treatment" OR "VRF" OR "vertical root fracture" OR "resin" OR "resin cement" OR "MTA" OR "Biodentine" OR "Bioceramic" OR "laser" OR "CO2 laser" OR "endodontics")
	#1 AND #2	
BVS (Lilacs/BBO)	#1	(tw:(vertical root fracture OR management of vertical root fracture OR dual-cure resin OR 4-META/MMA-TBB resin OR MTA OR laser))
	#2	(tw:("Endodontic treatment" OR "VRF" OR "vertical root fracture" OR "resin" OR "resin cement" OR "MTA" OR "Biodentine" OR "Bioceramic" OR "laser" OR "CO2 laser" OR "endodontics"))
	#1 AND #2	
Cochrane	#1	"vertical root fracture":ab,ti OR "management of vertical root fracture":ab,ti OR "dual-cure resin":ab,ti OR "4-META/MMA-TBB resin":ab,ti OR MTA:ab,ti OR laser:ab,ti
	#2	"Endodontic treatment" OR "VRF" OR "vertical root fracture" OR "resin" OR "resin cement" OR "MTA" OR "Biodentine" OR "Bioceramic" OR "laser" OR "CO2 laser" OR "endodontics"
	#1 AND #2	
Embase	#1	("vertical root fracture":ab,ti OR "management of vertical root fracture":ab,ti OR "dual-cure resin":ab,ti OR "4-META/MMA-TBB resin":ab,ti OR MTA:ab,ti OR laser:ab,ti)
	#2	'Endodontic treatment':ab,ti OR 'VRF':ab,ti OR 'vertical root fracture':ab,ti OR 'resin':ab,ti OR 'resin cement':ab,ti OR 'MTA':ab,ti OR 'Biodentine':ab,ti OR 'Bioceramic':ab,ti OR 'laser':ab,ti OR 'CO2 laser':ab,ti OR 'endodontics':ab,ti
	#1 AND #2	

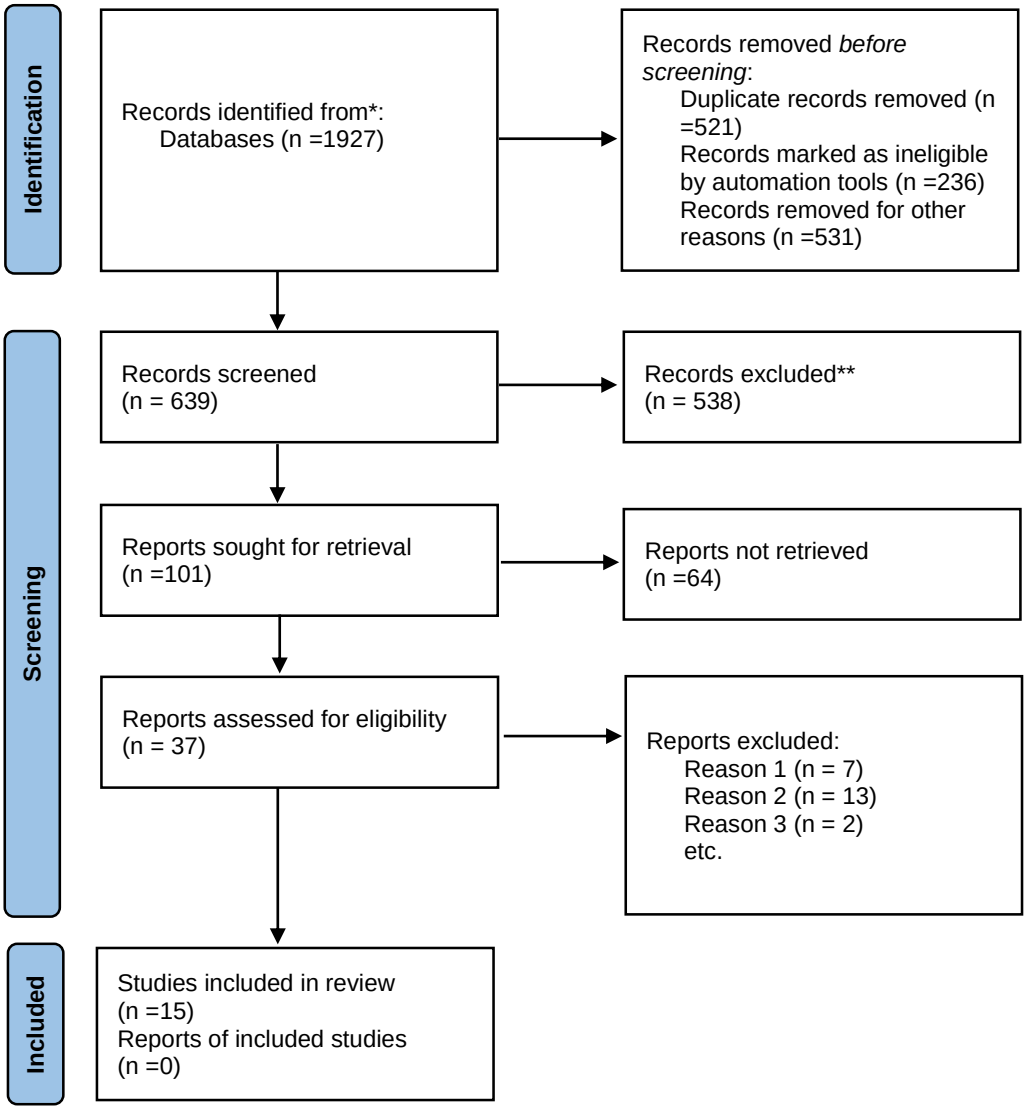


Figure1. PRISMA flow diagram

Table 2: List of available studies for the treatment of vertical root fractures

Items	AUTHORS	YEARS	TOOTH NUM	METHOD	TREATMENT	FOLLOW UP	CONCLUSION
1	Dederich et al. [5]	1999	1	Intraoral	CO2 laser	12m	No inflammation, pocket reduction and increased radiodensity at the osseous defect.
2	Funato et al., [23]	1999	1	Intraoral	4-META/MMA-TBB dentin-bonded resin	6m	The tooth was asymptomatic and showed reduced radiolucent area.
3	sugaya et al.,[12]	2001	12	Extraoral and intentional replantation	4-META/MMA-TBB dentin-bonded resin	22m	Out of 12 cases, 3 extracted,9were successful
4	Hayashi et al.[19],	2002	20	Extraoral and intentional replantation	4-META/MMA-TBB dentin-bonded resin	4-45m	Survival rates were 83.3% at 12 months and 36.3% at 24 months.
5	Kawai et al., [17]	2002	2	Extraoral and intentional replantation	adhesive resin cement	3 years	The teeth were asymptomatic and displayed bone regeneration.
6	Hayashi et al.,[13]	2004	26	Extraoral and intentional replantation	4-META/MMA-TBB dentin-bonded resin	76M	Out of 18 cases, 6were asymptomatic with healthy pdl, 8 cases failed
7	arikan et al., [31]	2008	11	Extraoral and intentional replantation	Dual cure resin cement	72m	Healthy pdl
8	Öztürk and Ünal, [20]	2008	1	Extraoral and intentional replantation	self-etching dual-cured adhesive resin cement	4 years	The tooth was asymptomatic and bone regeneration was observed.
9	taschieri et al., [7]	2010	10	Intraoral	MTA	33m	Out of 10 cases, 2 extracted, others were successful
10	ozer et al., [30]	2011	23	Extraoral and intentional replantation	self-etching dual-cured adhesive resin cement	24m	The teeth were asymptomatic and showed reduced periapical radiolucency.
11	Moradi majd et al., [9]	2012	9	Extraoral and intentional replantation	Dual-cure resin cement	12m	The tooth was asymptomatic, and the apical radiolucency reduced in size.
12	Floratos and Kratchman,[16]	2012	4	Intraoral	MTA	8-24m	The teeth were asymptomatic. Periapical healing with periodontal ligament re-formation was noted.
13	Hadrossek and Dammaschke [17],	2014	1	Extraoral and intentional replantation	Biodentinee	24m	The tooth was asymptomatic, and the periodontal pocket returned to normal.
14	nizam et al., [29]	2015	21	Extraoral and intentional replantation	4-META/MMA-TBB dentin-bonded resin	12m	No pathosis
15	Okaguchi et al., [21]	2019	6	Extraoral and intentional replantation	4-META/MMA-TBB dentin-bonded resin	33-74m	Tooth function was normal with successful clinical outcome and healing of radiolucent lesions.

4-META/MMA-TBB: 4-methacryloxyethyl trimellitate anhydride/methyl methacrylate-tri-n-butyl borane.

Discussion

The research presents a new strategy for managing teeth with VRF. In the past, the typical treatment for these cases involved extracting the tooth, followed by dental implant placement. Emergency physicians are trained to identify and manage acute, life-threatening conditions.

Dental emergencies, however, represent a unique challenge: they are rarely life-threatening but cause significant morbidity, and their management requires knowledge that is often not included in medical school curricula. Studies show that emergency physicians have low confidence in diagnosing dental conditions and frequently overprescribe antibiotics for dental pain. VRF exemplifies this diagnostic gap. Unlike acute apical abscess—which presents with clear systemic signs and radiographic findings—VRF is a chronic, insidious condition. Patients may present to the ED after weeks or months of intermittent discomfort, often after multiple dental visits. The absence of fever or facial swelling may falsely reassure the emergency physician, leading to inadequate referral. Nevertheless, the research advocates for conserving the original tooth by using a method that focuses on reconstructing root fractures.[4, 15]

The CO2 laser was previously investigated for treating vertical root fracture (VRF) as a potential conservative alternative to tooth extraction, but it is not standard clinical practice today. The initial interest in using the CO2 laser for VRF focused on its ability to generate high heat to achieve a hermetic seal.[5]

The CO2 laser was proposed to treat VRFs via a technique known as Laser Fusion or Laser Glazing. This concept involved :

•Dentin Surface Modification: Irradiating the dentin walls of the fracture line with the CO2 laser. The laser's high energy, which is well absorbed by water and hydroxyapatite, was intended to cause superficial melting and recrystallization of the dentin[22].

•Sealing with Bioceramics/Composites: In some studies, the laser was used to fuse a filling material, such as bioactive glass paste or composite resin, into the fracture line, aiming to create a monolithic, impenetrable barrier against bacterial ingress from the oral cavity .

Early research and case reports suggested potential benefits, including:

•Sterilization: The high temperature generated by the laser could sterilize the fracture surface, which is often contaminated with bacteria.

•Improved Sealing: Initial in vitro studies sometimes showed that laser-treated or laser-fused fracture lines exhibited reduced dye leakage compared to controls.

Despite early optimistic reports, clinical implementation of the CO2 laser for VRF largely failed to achieve reliable, long-term success. Contemporary management of VRF considers the technique obsolete due to significant technical and biological limitations.

.1Risk of Thermal Damage and Irreversible Injury

This is the primary reason for discontinuation. The CO2 laser's high absorption by dental hard tissue generates intense, rapid heat .

•Dentin Carbonization: Excessive temperature often resulted in carbonization (burning) or the formation of a brittle, non-adhesive glaze layer on the fracture surface, which could crack and fail over time.

•Pulp and Periodontal Damage: The thermal effect can extend through the root wall, potentially causing irreversible damage to the surrounding periodontal ligament (PDL) and crestal bone, thus hindering healing and promoting necrosis.

2. Failure to Achieve a Reliable Seal

VRFs are complex, non-linear cracks that are rarely completely clean.

•Lack of Adhesion: The laser-created glaze layer often failed to provide the reliable bond strength or hermetic seal required to withstand masticatory forces and prevent bacterial leakage in the long term. Any residual bacteria, particularly those introduced through the fracture or present in the canal, would quickly recolonize the area, leading to progressive bone loss and treatment failure .

In essence, the CO2 laser proved to be too aggressive for the delicate biological structures surrounding the tooth root, making it a high-risk, low-prognosis technique that has been superseded by more biocompatible and predictable adhesive and surgical approaches [5, 22].

The optimal bonding and repair material for VRF should possess certain characteristics to promote periodontal tissue attachment: adequate fixation strength, short setting time, ease of application, hydrophilicity, bacteriostatic properties, and biocompatibility [24]. Recently, a self-curing adhesive resin cement known as 4-methacryloxyethyl trimellitate anhydride/methyl methacrylate-tri-n-butylborane (4-META/MMA-TBB) has been primarily utilized for stabilizing mobile teeth or treating fractured teeth, yielding successful reconstruction results [6, 23]. The compressive strength of MTA increases from 40 MPa after 24 hours to 67.3 MPa after three weeks [16].

As a result, roots strengthened with MTA showed fracture strengths nearly four times greater than those of

unfilled root canals and twice that of roots containing an apical MTA plug with a gutta-percha backfill [27].

In addition to its adhesive qualities to dentin, Tanaka et al. (24) reported that the 4-META/MMATBB resin bonds with cementum by promoting the formation of hybridized cementum in the short term, which can effectively seal vertically fractured roots. In contrast, Sugaya et al. [12] found no formation of cementum-like hard tissue on the surface of the 4-META/MMA-TBB resin, and controlling the material's polymerization proved challenging. Research concluded that using the 4META-MMA adhesive resin with replantation yields better outcomes than alternative modern treatments [10, 11].

Endodontic repair cements ProRoot MTA [7] and Biodentine [17,26] have been used to manage vertical root fractures (VRF). These materials demonstrated an effective seal against both dentin and cementum and can promote the biological repair and regeneration of periodontal tissues. Compared with MTA, Biodentine has a shorter setting time, is more resistant to hydrolysis during setting, and releases higher amounts of calcium and silica, which are advantageous for the mineralization of bone and dentin [26].

Advantages of Biodentine include biocompatibility and bioactivity, Excellent Healing Potential, and the release of calcium ions, which promote the differentiation of periodontal ligament cells and stimulate the formation of reparative dentin, bone, and cementum, which is crucial for healing the fractured site.

Fast Setting Time: Sets in approximately 10–12 minutes (significantly faster than MTA). This is critical for extra-oral procedures where minimizing the extra-oral time is paramount for PDL cell survival. Dentin-like strength: its mechanical properties, including compressive strength and modulus of elasticity (MOE), are very similar to natural dentin. This helps the repaired root behave more like the original structure, distributing stress evenly and increasing fracture resistance. Biodentine uses zirconium oxide as a radiopacifier, resulting in a much lower risk of visible coronal staining [17, 26].

Disadvantages of Biodentine: Technical sensitivity; difficult to Manipulate/consistency; difficult to handle and place precisely into the minute, complex contours of a fracture line, especially in the presence of moisture or blood. |Lower Radiopacity than MTA. (Biodentine's radiopacity (due to zirconium oxide) is generally lower than the ISO standard for root canal filling materials. This can make it challenging to evaluate its precise placement and marginal seal on routine radiographs.) Lack of Long-Term Clinical Data and no large-scale randomized controlled trials [17].

Strengthening fixation of the vertical fracture line during VRF treatment is essential to minimize the risk of future refracture. However, although composite resin has stronger bonding strength than bioceramic materials [28], fixation strength is also closely related to defect shape. Studies have confirmed that retention form is necessary to improve fixation strength, and that retention-form design can increase contact area and enhance the retention force of the repair materials [25].

The objectives of this approach are to maintain the natural tooth and possibly increase patient satisfaction while minimizing total treatment duration. This procedure is especially advantageous for children, as it retains the width and height of the bone surrounding the natural tooth in the aesthetic zone [1, 4].

Conclusion

The available clinical literature describes several tooth-preserving approaches for selected cases of vertical root fracture, including 4-META/MMA-TBB adhesive bonding, dual-cure resin cement, bioceramic materials, and intentional replantation with root-fragment bonding. However, the evidence is heterogeneous and is dominated by case reports and small case series. The findings should therefore be interpreted cautiously, and they do not establish a single preferred treatment strategy. Prospective comparative studies with standardized outcomes and long-term follow-up are needed to determine which clinical and fracture-related factors are associated with successful preservation.

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Conflict of Interest Disclosures

There is no conflict of interest in this study.

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Authors' Contributions

All authors contributed equally in this study.

Ethical Statement

Not applicable.

Declaration of Generative AI and AI-assisted technologies

We used Deep Seek AI platform for English edition.

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