A vertical root fracture (VRF) is a complex condition in which the fracture lines can be partial or complete and extend along the long axis of the tooth. Considering the nature of the damage and the low likelihood of a successful outcome, such fractures can be difficult to manage. Their management typically involves complex endodontic or surgical procedures, which can be technically challenging for general dentists. Recent advancements introduce promising techniques, such as intentional replantation, adhesive methodologies, and regenerative procedures, showcasing potential in salvaging teeth affected by VRFs. Nonetheless, the imprecise nature of symptoms necessitates meticulous case evaluation by clinicians. Comprehensive patient counseling regarding diverse treatment options and potential ramifications remains crucial to preserving the affected tooth. Preserving a vertically fractured tooth aids in improving both function and aesthetics while safeguarding the arch’s integrity by maintaining the height of the alveolar bone. It is important to note that the success of the treatment procedures depends on the extent and location of the fracture, the condition of the tooth and fragment, and the skill of the dental professional performing the treatment.

This review highlights the complexity of VRF management, emphasizing the necessity for precise evaluation, patient education, and the exploration of innovative techniques. It aims to review the treatment of VRFs, ranging from classical to contemporary methods, with a focus on tooth preservation. The establishment of standardized protocols and conduct of further research to ascertain long-term efficacy are imperative in optimizing outcomes and retaining natural dentition in cases of VRFs.

**Keywords:** Fracture Healing • Tooth Replantation • Vertical Dimension

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Background

Among the 5 types of tooth fractures, a vertical root fracture (VRF) begins as a rupture in the root that extends coronally from the apex in an oblique or longitudinal manner [1,2]. This fracture can develop after root canal therapy, leading to tooth or root extraction [3,4]. Although VRFs have various etiologies, important clinical factors include the patient’s age and the type of tooth involved [5]. There are also known risk factors, such as excessive removal of healthy dentin during root canal treatment, prolonged contact with intracanal disinfectants and medicaments, and improper placement of post-endodontic restorations [6]. Among teeth that have undergone root canal treatment, the incidence of VRFs ranges from 4% to 32% [6], and 80% of VRFs are typically detected within 2 years after the onset of initial symptoms [7].

Significant symptoms associated with VRFs include the presence of a sinus tract, increased probing depth, swelling/abcess formation, and tenderness to percussion [8]. In addition to clinical assessments, radiographic methods can facilitate the diagnosis of VRFs, although some fractures may not be visible on radiographs. Periapical radiography is commonly used to diagnose root fractures, but its 2-dimensional nature can lead to anatomical noise and distortion. In contrast, cone-beam computed tomography provides 3-dimensional images with reduced noise and distortion, offering superior accuracy in the detection of VRFs, compared with periapical radiography [9].

Because VRFs constitute a major challenge for endodontists, there has been extensive debate regarding suitable treatment options. Although many studies have been conducted, the choice of VRF treatment method depends on the clinician’s experience and the clinical features in each case. Extraction is the typical course of action for teeth with VRFs; however, recent reports of alternative strategies have demonstrated short-term success regarding tooth preservation [10]. A multi-disciplinary approach involving endodontic, periodontic, orthodontic, prosthetic and surgical interventions can be required [1].

This article aims to review the treatment of VRFs, ranging from classical to contemporary methods, with a focus on tooth preservation. In many cases of VRFs, extraction is required; therefore, this too will be described.

VRF Treatment Approaches

There are diverse treatment approaches for VRFs. Table 1 describes these approaches, along with their advantages and disadvantages. In this review, we focus on 5 key aspects of the treatment approaches listed in Table 1: root amputation, root resection, or hemisection [11,12]; laser-mediated VRF fusion [13,14]; whether calcium hydroxide dressing aids healing or causes damage [15]; fracture line bonding (with or without intentional replantation) [15-18]; and tooth extraction [6,19].

Treatment is intended to preserve the health and function of teeth with VRF, primarily in cases of partial VRF. Two goals of optimal treatment are eliminating microbial invasion at the fracture line and preventing periodontal tissue loss [6]. However, the treatment of VRFs can be challenging, as shown in Figure 1.

Root Amputation, Root Resection, or Hemisection

Root amputation, usually involving maxillary molars, comprises removal of the root at its furcation or apex, without removing the crown. Root resection is generally regarded as removal of the root, regardless of crown treatment [20]. A multi-rooted tooth requires surgical division up to the furcation, which allows removal of the root and overlying anatomic crown. This procedure, known as root hemisection, is intended to preserve as much of the original tooth anatomy as possible [21].

For molars with periodontal, endodontic, restorative, or prosthetic problems, root resection therapy is a possible treatment option. Although the most common indications for root resection are periodontal-based, our discussion focuses on endodontic indications, such as an unfillable canal, root fracture, root perforation, root resorption, and root decay [22]. Root resection therapy can provide good outcomes in cases of incomplete fracture [23]. In a protocol for the treatment of incomplete VRFs, Taschieri [24] proposed removing the fractured apical segment of the root via resection. The residual fracture groove can then be prepared using a bur and sealed with mineral trioxide aggregate (MTA) [23,24]. According to Anitha and Rao [12], root resection involving removal of the entire fractured root fragment can facilitate retention of the remaining tooth. However, they note that long-term success requires careful case selection to ensure that the remaining root exhibits a robust periodontal status and can be sufficiently restored [12]. Other case selection approaches, based on a strict set of criteria [25], such as surgical performance, periodontal disease, endodontic therapy, oral hygiene, and high patient motivation, can ensure treatment success [12,21].

The surgical method of Anitha and Rao [12] led to a successful outcome in a patient with pain caused by vertical fracture of the mesial root in the lower right first molar. This result demonstrates that hemisection is an effective method of VRF treatment. In this instance, the 3-year follow-up visit revealed good oral hygiene and no patient concerns, indicating that hemisection can be an alternative to extraction for some patients with VRF who exhibit a suitable oral environment, along with the ability and desire to practice good oral hygiene.
Table 1. Treatment approaches for vertical root fractures.

<table>
<thead>
<tr>
<th>Treatment modality</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>No treatment, just observation with monitoring</td>
<td>Following the actual clinical condition without taking any step in the treatment</td>
<td>Least invasive option, allows assessment of the fracture’s stability</td>
<td>Tooth may become symptomatic or fail. Typically leads to tooth loss due to infection or complications</td>
</tr>
<tr>
<td>Root resection and root amputation</td>
<td>Removing apex of a tooth’s root, or the whole root of multi-rooted teeth</td>
<td>Tooth preservation, maintains the bone density, restores the function and is an alternative to extraction</td>
<td>Complex procedure, risk of residual infection which leads to limited success. Requires surgical skills</td>
</tr>
<tr>
<td>Hemisection</td>
<td>The surgical removal of one-half of a tooth, typically in multi-rooted teeth</td>
<td>Can save one portion of the tooth, cost-effective, conservation of healthy roots</td>
<td>May result in a gap if one portion is extracted, also it is a complex procedure</td>
</tr>
<tr>
<td>Laser fusion of vertical root fracture</td>
<td>Sealing the fracture line while generating thermal energy</td>
<td>Better alternative than extraction and no treatment</td>
<td>Is not a widely recognized or established dental procedure</td>
</tr>
<tr>
<td>Re-cementing, bonding or sealing the fractured fragment</td>
<td>Closing the fracture line with different approaches, with the aim of saving the tooth and sealing the fracture line so the bacteria does not enter</td>
<td>Minimally invasive, compared with resection and hemisection, even though it is often combined with these procedures. Cost-effective and preserves the tooth</td>
<td>Complex procedure, Requires good surgical skills and healthy periradicular tissues, some bacteria can remain within the fracture lines</td>
</tr>
<tr>
<td>Intentional replantation</td>
<td>Tooth is intentionally removed from its socket, treated or repaired, and then replanted back into its original position in the patient’s mouth</td>
<td>Preservation of natural tooth, less invasive than dental implants and requires fewer dental appointments</td>
<td>Risk of complications, success rates vary, potential for reinfection, risk of root resorption, not suitable for all cases</td>
</tr>
<tr>
<td>Prosthodontic rehabilitation (partial denture or bridge)</td>
<td>Focused on restoring or replacing missing teeth and associated oral structures to enhance oral function, aesthetics, and overall well-being</td>
<td>Provides a functional and aesthetic replacement of the lost tooth as a result of vertical root fracture</td>
<td>Alteration of adjacent healthy teeth, not suitable for single-tooth replacements, potential for discomfort or instability</td>
</tr>
<tr>
<td>Tooth extraction and implant placement</td>
<td>The most common treatment in vertical root fracture cases</td>
<td>Removes the source of infection and brings back the tooth function</td>
<td>Loss of the natural tooth and extra cost for the implant</td>
</tr>
</tbody>
</table>

It is important to consider the risk of surgical treatment for VRFs. After resection or hemisection of a fractured root, especially a resected root without root-end filling [26], the affected tooth may not tolerate pressure, leading to vertical fracture of the remaining root. Ayrancı et al [27] reported that apical resection does not reduce the fracture resistance of a tooth. However, the current literature supports the approach of allowing each patient to select the desired treatment option after they have received information regarding the advantages and disadvantages of surgical treatment for VRFs.

**Laser-Mediated VRF Fusion**

The effectiveness of laser treatment for VRFs has been investigated since the 1980s. Although successful outcomes have been reported, there are doubts about the efficiency of this technique and its influencing factors. Because the working principle of the carbon dioxide (CO₂) laser is based on the short-term generation of intense heat, such a laser can sterilize and seal a vertical fracture that is a serious threat to the tooth. However, it remains unclear whether treatment success is the result of sterilization or the sealing effect [14]. There is some concern about the use of intense heat in pulp tissue [28]. In most cases, vertical fractures occur in non-vital teeth that have undergone endodontic treatment [29]. However, exposure of the vital pulp to intense heat should not be problematic if the remaining dentin thickness is at least 1 mm [30].

Factors that contribute to the success of this technique include a full-coverage cast crown restoration, which can promote mechanical stabilization of the fracture. Additionally, fractures...
that appear thin and well-approximated are more likely to be successfully fused with a CO₂ laser, compared with fractures that exhibit large gaps [14]. Fractures with perpendicular access for the entire length are preferred [14], because proper laser beam exposure requires this type of access to the root surface [31]. Radiographic evidence of periapical bone loss is not required in endodontically treated teeth, implying the success of previous endodontic therapy [14].

Despite the questionable effect of the CO₂ laser in VRF treatment, a 1996 study of the effects of CO₂ and neodymium-doped yttrium aluminum garnet (Nd: YAG) lasers on 81 single-rooted teeth with induced root fracture revealed that the Nd: YAG laser was not effective in terms of fracture line fusion. The main finding in teeth treated with this laser was surface ablation, whereas the CO₂ laser demonstrated greater effectiveness [32].

**Whether Calcium Hydroxide Dressing Aids Healing or Causes Damage**

A 1988 study by Stewart indicated that the intracanalicular use of calcium hydroxide dressing facilitates successful treatment of VRF over 9 to 12 months [33]. However, the results of in vitro studies suggested that teeth with long-term dressings can demonstrate an increased predisposition to root fracture [34]. For example, a 2006 study by Rosenberg et al revealed that dentin was weakened by 23% to 43.9% after root canal filling with calcium hydroxide [35]. Conversely, more recent studies have shown that calcium hydroxide products do not increase the predisposition to root fracture [36], and that thin and fragile roots can contribute to fracture [34]. Notably, calcium hydroxide dressings are effective in the management of horizontal root fractures [37], although such fractures are outside the scope of this review.

**Fracture Line Bonding (With or Without Intentional Replantation)**

There are several options for joining fractured fragments: solely inside the canal (intracanalicular); with external flap elevation; and through a combination of internal root canal preparation plus tooth extraction to allow external fracture line bonding and sealing, followed by intentional replantation [38]. Each bonding and sealing method requires various materials, including 4-methacyloyethyl trimellitate anhydride in methyl methacrylate initiated by tri-n-butyl borane (4-META/MMA-TBB) resin cements [38,39], dual-curing resin cements [16], amalgam, ethoxy benzoic acid cement, MTA [40], and biodentine [41,42].

The intracanalicular approach of vertical fracture bonding is supported by many authors [43,44]. However, these authors have consistently stated that the entire fracture line cannot be reached; therefore, some bacteria can persist within the fracture line, leading to treatment failure [38]. There have been various reports of successful VRF treatment with 4-META/MMA-TBB resin bonding through the root canal [43]. It is important to note that the prognosis of VRF treatment with intracanal access is better for vertical fractures detected at an early stage, prior to periodontal status disruption [38]. In a case report by Baranwal et al [44], the authors used universal dentin bonding and flowable composite to join the separated fragments in the crown region. After chemical and mechanical preparation of the canal, followed by drying, they placed biodentine in the apical part of the canal using a Lentulo spiral filler, then continued with other restorative procedures. The 24-month follow-up examination showed signs of successful treatment [44].

Regarding external treatment of fractured teeth, flap elevation without tooth extraction results in the inability to reach some
fracture lines, leading to bacterial colonization in those lines [38]. Additionally, some portions of alveolar bone must be removed to access the fracture lines. Therefore, this removal of hard and soft periodontal tissues, which exposes the support apparatus of the fractured tooth, can reduce treatment success [45]. Intentional replantation is an ideal alternative treatment option that rarely compromises periodontal bone architecture [46].

The remaining option for vertical fracture management consists of tooth extraction, followed by external repair, and then intentional replantation. This method is advantageous in that it provides a 3-dimensional approach to the fractured tooth, enabling the removal of contaminated dentin and cement; all fractured surfaces can be cleaned and sealed with the selected material [38]. There have been multiple reports of successful VRF treatment with bonding and replantation involving frontal teeth [16,39,47]. Good results have also been achieved in posterior teeth, especially molars with 2 or more roots [38]. Substantial success was reported in the treatment of 6 teeth with VRFs (1 incisor, 1 canine, 1 premolar, and 3 molars) in 6 patients. In those teeth, the fracture lines were prepared and sealed with 4-META/MMA-TBB resin; the apical third was filled with MTA if necessary. When the fractured teeth exhibited roots that had been split in half, both fragments were extracted and carefully cleaned. The contaminated cement and dentin were removed with high-speed round burs or ultrasonic equipment with a water spraying system under a stereomicroscope. Subsequently, the root segments were cemented with 4-META/MMA-TBB resin. The attached tooth was then cleaned with saline. After removal of the periradicular granulation tissue, the tooth was carefully replanted into the alveolus [38].

It is important to mention the successful outcomes reported by Moradi Majd et al [16] during the treatment of vertical fracture in an upper left central incisor, with the aid of intentional replantation. Those authors performed careful tooth extraction, followed by minimal preparation of the fracture line and filling with dual-curing resin; next, they conducted root-end resection and prepared a retrograde cavity, which was then filled with calcium-enriched mixture cement. After this treatment, the tooth was replanted in its original position. The procedure duration was 18 min. After replantation, the tooth was immobilized for 10 days using a semirigid splint. At the 12-month follow-up visit, the tooth was asymptomatic, and periapical radiolucency was reduced [16].

Despite the reported success of intentional replantation in cases of VRF, many clinicians support extraction and subsequent replacement with an implant. Although the rate of implant survival is increasing, intentional replantation remains a more economical treatment approach. Therefore, intentional replantation should be the initial treatment option; if replantation fails, implant placement remains possible [48]. There is evidence that intentional replantation can preserve a fractured tooth through the incorporation of biomaterials, such as MTA and leukocyte-platelet rich fibrin [49]. However, root resorption is a persistent problem after intentional replantation [50].

Tooth Extraction

Discussion related to VRF refers to a crack that starts in the root of the tooth (Figure 2).

In most cases, extraction remains the treatment of choice for VRF, especially in the context of complete fractures [6]. An intrasosseous fracture with periodontal pain, often involving the mesial and distal aspects of the tooth, is an indication for extraction [1]. This treatment option is intended to prevent the destruction of the bone and periradicular tissue, which would hinder prosthetic or implant-based replacement of the lost tooth [6]. In some cases, VRF-induced periodontal bone destruction leads to the formation of a deep bone dehiscence. This situation is an indication for extraction and replacement with an implant, with increasing assistance from connective tissue grafts, which have demonstrated promising results in terms of periodontal defect replacement and implant therapy [51]. Because tooth extraction is the final treatment option, a correct diagnosis is essential before selecting this option. Vertical fractures are often included in the differential diagnosis for cemental tears; however, both of these conditions can cause extensive periodontal bone loss and serve as an indication for extraction [52].

Future Directions

Management of a tooth fracture requires an accurate diagnosis, treatment planning, and regular follow-up visits [53].
Therefore, preventing VRF of a tooth requires carefully assessing the occlusal scheme, avoiding deflective contacts, and determining parafunctional habits, as well as giving importance to access cavity design and endodontic and post-endodontic procedures [54]. Clinical detection of this condition by endodontists is becoming more common, whereas it is rather underestimated by general practitioners [55]. The future of VRF treatment is poised for advancements driven by technological innovations and a deeper understanding of dental biomechanics. However, more studies are required for exact VRF diagnosis and management.

Conclusions

Teeth with VRFs require treatments to alleviate pain, prevent infection, preserve function, maintain aesthetics, protect overall oral health, prevent complications, facilitate future alternative therapeutic options, and improve patient comfort and confidence. Individuals with such fractures should seek timely dental care to effectively address these concerns. Depending on the clinical picture, the management of VRFs can involve both options (treatment and no treatment), as discussed below.

Treatment can be considered in cases of incomplete fracture, involving cooperative patients who desire to preserve the natural tooth. A key consideration regarding the decision to treat VRFs is the patient’s periodontal status. Therefore, it is appropriate to treat VRFs in cases of intact periodontal status, in which the bone is preserved and the overall prognosis is good.

Extraction is suitable in cases of VRFs that approach a diagnosis of a split tooth, in which the bone and periodontal tissues do not suggest the natural tooth can be preserved, and no other treatment methods would lead to a good overall prognosis. Additionally, VRFs associated with severe chronic infections can be challenging to treat because of their tendency to erode bone surrounding the tooth, decreasing support for future dental implants. For patients with systemic health problems, considering the complexity of other surgical and nonsurgical methods, along with their risk of infection, extraction remains the simplest choice.

Overall, the best treatment is prevention. Root fractures can be avoided by identifying susceptible teeth and roots, choosing appropriate dowels and cementing them properly, and avoiding the use of excessive force when removing tooth structures in endodontic and prosthetic procedures, as well as during gutta-percha condensation.

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