Novel endodontic microsurgery treatment for maxillary premolar vertical root fracture based on 3D technology

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3D technology has been applied in both surgery simulation and guidance in endodontic microsurgery. Treatment options are still limited for vertical root fracture (VRF) in inaccessible areas that require accurate resection, especially in single-rooted teeth. This case illustrates successful treatment based on 3D technology. The literature on endodontic microsurgery of VRF is summarized. A 27-year-old woman presented with periapical lesions and apical root resorption of a maxillary premolar. After endodontic microsurgery was arranged, unexpected VRF was discovered through CBCT. Using a 3D-printed template, the root fracture was precisely removed with minimal damage. A literature review revealed a total of 12 articles published since 1946 on this topic. The 3D-printed template facilitated endodontic microsurgery, indicating reliable location of the root fracture and reduction in iatrogenic injury. (Quintessence Int 2021;52:666–674; doi: 10.3290/j.qi.b1701731)

Key words: 3D-printing technology, computer-guided surgery, endodontic microsurgery, external apical root resorption, vertical root fracture

Apical periodontitis, due to an infection of the root canal system, is treated by endodontic therapy. Nevertheless, primary and secondary root canal treatments (RCTs) do not always resolve the problem, and surgical intervention is required as the next approach. Endodontic microsurgery involves exposing and removing the periapical lesion, removing part of the root tip, and preparation and filling of the root tip.

Owing to advances in the development of equipment, novel nickel-titanium (NiTi) retreatment systems and root canal obturation techniques are extensively applied during endodontic procedures. Vertical root fracture (VRF) in root canal-treated teeth is sometimes concomitant, especially with external apical root resorption. VRF is a type of root fracture that follows the vertical axis, and may involve only a section or both sides of the root. VRF is an undesirable complication of RCT, and often results in extraction, especially in teeth with external apical root resorption that has occurred because of stress factors during filling procedures and sustained mastication forces. VRF is one of the most common reasons for tooth extraction after endodontic treatment.

The treatment of VRF requires locating the root fracture exactly and distinguishing it from the adjacent anatomical structures, which can be challenging. The adjacent tissues are often damaged when gaining sufficient access and ensuring good visibility for surgical resection. Although accurate removal of the VRF during surgery is essential, hitherto it has been unrealistic.

Computer-aided surgical simulation systems (CASS) have recently been developed. CASS include surgical simulation and operation assisted guiding templates manufactured by computer-aided design and computer-aided manufacturing (CAD/CAM) technology. CASS have been extensively used in oral and maxillofacial surgery, implant surgery, orthognathic surgery, orthodontic treatment, and prosthodontic treatment. By providing improved accuracy during surgery, CASS have brought about a paradigm shift in practice and provided the basis for new surgical techniques.
Table 1  Review of previous reports on clinical management of vertical root fracture

<table>
<thead>
<tr>
<th>Study</th>
<th>Tooth/teeth*</th>
<th>Treatment</th>
<th>Follow-up period</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ollet(^{27})</td>
<td>3, 9, 19</td>
<td>Intentional replantation of fractured segments with cyanoacrylate.</td>
<td>16 mo, 15 mo, 3 mo</td>
<td>Poor prognosis</td>
</tr>
<tr>
<td>Vertucci(^{28})</td>
<td>13</td>
<td>Removal of the half of the root at the buccal aspect, followed by 20% citric acid application.</td>
<td>36 mo</td>
<td>No pathosis</td>
</tr>
<tr>
<td>Trope and Rosenberg(^{29})</td>
<td>15</td>
<td>Intentional replantation of fractured segments with glass-ionomer bone cement.</td>
<td>12 mo</td>
<td>No pathosis</td>
</tr>
<tr>
<td>Selden(^{30})</td>
<td>12, 19, 30</td>
<td>Fracture line was prepared and filled with 4-META, then packed with silver glass-ionomer cement. Bone grafting and guided tissue regeneration were placed.</td>
<td>2–12 mo</td>
<td>Poor prognosis</td>
</tr>
<tr>
<td></td>
<td>2, 13</td>
<td>The same as previous, but the filling material was white glass-ionomer cement only.</td>
<td>11 mo, 5 mo</td>
<td>Poor prognosis</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>The same as previous, but the filling material was 4-META only, and there was no bone grafting.</td>
<td>3 mo</td>
<td>Poor prognosis</td>
</tr>
<tr>
<td>Dederich(^{31})</td>
<td>20</td>
<td>CO(_2) laser.</td>
<td>12 mo</td>
<td>No pathosis</td>
</tr>
<tr>
<td>Kawai and Masaka(^{32})</td>
<td>4, 13</td>
<td>The tooth was extracted; fracture line was bonded with resin cement and then replanted with 180-degree rotation.</td>
<td>36 mo, 33 mo</td>
<td>No pathosis</td>
</tr>
<tr>
<td>Kudou and Kubota(^{33})</td>
<td>13</td>
<td>Fragments were bonded with resin adhesive, and replanted with rotation.</td>
<td>18 mo</td>
<td>No pathosis</td>
</tr>
<tr>
<td>Fidel et al(^{34})</td>
<td>8</td>
<td>Orthodontic extrusion and fiber-glass post and light-cured resin.</td>
<td>13 mo</td>
<td>No pathosis</td>
</tr>
<tr>
<td>Ozturk and Unal(^{35})</td>
<td>8</td>
<td>Replantation after intentional replantation of fractured segments with dual-cured adhesive cement.</td>
<td>48 mo</td>
<td>No pathosis</td>
</tr>
<tr>
<td>Arkan et al(^{36})</td>
<td>8</td>
<td>Intentional replantation of fractured segments with dual-cured adhesive cement.</td>
<td>18 mo</td>
<td>No pathosis</td>
</tr>
<tr>
<td>Natu et al(^{37})</td>
<td>19</td>
<td>Hemisection.</td>
<td>24 mo</td>
<td>No pathosis</td>
</tr>
<tr>
<td>Hadrossek and Dammerschke(^{38})</td>
<td>8</td>
<td>Calcium-silicate-cement was used to fill the fracture line preparation and also as a retrograde filling. Then, the tooth was replanted.</td>
<td>24 mo</td>
<td>No pathosis</td>
</tr>
</tbody>
</table>

* Tooth numbering according to FDI notation.
4-META, 4-methacycloxyethyl trimellitate anhydride.

The present article describes a novel method for treatment of a maxillary premolar with VRF during endodontic microsurgery, in which the VRF and the overlying cortical bone was removed precisely with the guidance of a template fabricated using 3D technology.

Method and materials

Literature search

The literature regarding the treatment of VRF during endodontic microsurgery was reviewed. A search of the following online databases was performed, for articles published since 1946: Ovid Medline, PubMed, EMBASE, Web of Science, and Google Scholar. The search keywords were “vertical root fracture” and “endodontic microsurgery or treatment” or “surgery.” Table 1 presents the aggregated data from the articles about the treatment of VRF during endodontic microsurgery since 1946. The information of those cases in which patients’ information was complete and available were summarized.

Case presentation

A 27-year-old woman presented with discomfort in the maxillary right premolar due to chronic apical periodontitis (Fig 1). The maxillary right premolar was tender to percussion and showed a negative response to the electric pulp test. Radiography showed open apices, external resorption of the root, and a large periapical radiolucency (Fig 2). The patient was clinically diagnosed with external resorption of the root, open apices, and chronic periapical periodontitis.

In view of the large size of the periapical lesion, external resorption of root, and the open apices, an apical barrier was performed and endodontic microsurgery was recommended (Fig 3). However, an unexpected VRF was discovered on a pre-operative diagnostic CBCT scan. After discussion about the sur-
Figs 1a to 1d  Clinical photographs showing chronic apical periodontitis of the maxillary right premolar. (a) Anterior view. (b) Right buccal view. (c) Occlusal view. (d) Left buccal view.

Figs 2a to 2d  CBCT images and 3D reconstruction of the maxillary right premolar showing periapical radiolucency, external root resorption, and open apices. (a to c) Sagittal, coronal, and horizontal CBCT images. (d) 3D reconstruction.

Figs 3a to 3c  Clinical photographs and periapical radiograph of the maxillary right premolar after apical barrier formation.

Figs 4a to 4d  Preoperative CBCT images show a radiolucent lesion with an approximate size of 8.3 × 6.2 × 5.6 mm at the apices of the maxillary right premolar, and the exact location of the root fracture (red arrow). (a to c) Sagittal, coronal, and horizontal CBCT. (d) 3D reconstruction.
gery and prognosis, the patient showed a strong desire for preservation of the tooth, so it was decided to treat the tooth with a microsurgical approach using 3D technology to remove the VRF. There were no contraindications for the procedure. The treatment plan was approved by the institutional review board.

A radiolucent lesion (8.3 × 6.2 × 5.6 mm) at the apices of the maxillary right premolar and the exact location of root fracture were observed on the CBCT scan (Fig 4). The CBCT scan data were exported as a DICOM file and imported to 3D software to locate the root fracture and the area of the periapical lesion (Fig 5) to design the template.

Figs 5a to 5c  3D reconstruction of the maxillary right premolar and the adjacent anatomical structures showing position of the lesion area and the root fracture.  

(a and b) Buccal lateral and palatal view of the 3D reconstruction (blue indicates the fracture area).  

(c) Position of the lesion area.

Figs 6a to 6e  The template was designed to be supported by the teeth. The lesion and root fracture area were located, and the outline was confirmed.  

(a) Reconstruction of the maxillary right premolar and the adjacent anatomical structures.  

(b) The hollow part of the template followed the outline of the lesion to avoid excessive removal of the cortical bone, locating the lesion precisely.  

(c) The track of the inner part guided the removal of the root fracture.  

(d and e) Removal of the root fracture was designed to be perpendicular to the long axis of the root and approximate the fracture with the diameter of the fissure bur.
**Surgical planning and simulation**

All DICOM data and the digital impression acquired via an intraoral scanner were imported to 3D software to generate virtual models of the VRF and the chronic periapical periodontitis. Subsequently, virtual surgical simulation, in accordance with the treatment objective, was completed. The position and area of the root fracture and periapical lesion were expressed on the templates, and the distance from the template to the margin of the root fracture was measured.

The template was designed to be supported by teeth. The lesion and root fracture area were located, and the outline was confirmed. The working area of the template was designed to follow the border of the lesion to avoid removing excessive cortical bone. To preserve more root length, the track of the inner part guiding the removal of the root fracture was designed to approximate the fracture with the diameter of the fissure bur, perpendicular to the long axis of the tooth (Fig 6). The template was manufactured in MED610 using a 3D printer (3510SD, 3D Systems) (Fig 7).
Transfer of virtual plan to the operating room

The template was positioned on the teeth, and the hollow part delineated the boundary of the cortical bone covering the root fracture and lesion exactly. Following the outline, a minimal amount of cortical bone was removed. As root fractures are usually located on the mesial and palatal side, they cannot be clearly observed without damage to the adjacent tissues. The other part of the template was important to prevent this damage; the inner part was positioned in the hollow space of the template, and the inferior margin indicated the position, direction, and angle of the root fracture. With the assistance of the template, the fractured part of the root could be removed, thereby preserving more root length. The affected tissues were completely removed and sent fresh for histopathologic examination.

The root-end filling (iRoot-BP, Innovative Bioceramix), which formed an apical barrier before the surgery, was checked via methylene blue staining. Guided bone regeneration (GBR) was performed using xenogeneic bone (Heal-All) and collagen membrane (Heal-All). The flap was carefully sutured (Fig 8).

Results

Histopathologic examination

Histopathologic evaluation revealed periapical granuloma with the presence of eosinophils, plasma cells, lymphocytes, and foam cells (Fig 9).

Comparison of simulated model and actual postoperative outcome

To evaluate the accuracy, the simulated models and actual postoperative outcome were compared in Geomagic Studio (3D Systems) via the 3D deviation function. Based on other teeth and regions of the models that were not altered during surgery, simulated and actual postoperative CBCT reconstruction models were overlapped to generate color distance maps to evaluate the displacements. The mean displacement was calculated.

According to the color map (Fig 10), the deviation between the simulated plans and the postoperative result was less than 0.5 mm.

Clinical outcome

There were no intraoperative or postoperative complications, and the recovery was uneventful.

After 6 months, no discomfort was reported by the patient, and CBCT imaging revealed a functional postoperative recovery as well as bone healing (Fig 11). The crown-to-root ratio is the ratio of the length of the part of a tooth that appears above the alveolar bone versus what lies below it. It is an important consideration in the restoration of teeth, therefore it was applied as an evaluation index. The ratio of the crown/root of the maxillary right premolar reached the limit (1:1), and was a little better than the second maxillary premolar on the CBCT scan. No significant loosening of the maxillary second premolar was detected. Accordingly, the remaining root of the maxillary right premolar after surgery was adequate to withstand the occlusal force. After 1 year of follow-up, complete bony healing was observed.

Discussion

VRF is one of the most difficult complications of RCT and often leads to tooth extraction. It is a considerable challenge for clinicians. Given that more people want to retain their teeth, clinicians wish to provide a wide range of treatment options with...
the best available clinical evidence for success. Endodontic surgery with accurate section of the fractured root allows for the preservation of the remaining tooth structure when the fracture has occurred at the apical third. The success of the present study is encouraging for patients who wish to have their teeth preserved as an alternative treatment to tooth extraction. It is of vital importance that the remaining root is sufficiently able to withstand the occlusal force. Endodontic surgery is an alternative to tooth extraction for VRF in patients willing and able to carry out proper oral hygiene measures.

The literature regarding the treatment of VRF during endodontic microsurgery was reviewed (Table 1). It has been indicated that the bonding of the root fragments in posterior teeth has a low success rate.\textsuperscript{19} It can be tentatively inferred that the occlusal forces are more challenging in posterior teeth. Hemisection and replantation have been suggested as alternative treatments for multi-rooted teeth. However, there are few reported cases and the success rates for hemisection and replantation are low.

When a VRF is located in an accessible area, a more conservative method of surgery can be used. According to previous studies, when the fracture occurred in the buccal side and the lesion area was limited, preparation of the fracture line and bonding of the root fragments was associated with considerable success.\textsuperscript{40} In contrast, when the fracture line is located in an inaccessible area, such as the palatal side, it is difficult to prepare the full depth of the fracture line precisely, and, consequently, the treatment would often be unsuccessful due to remaining bacteria in the fracture gap. When a VRF occurs in a multirooted tooth, hemisection could be an appropriate treat-
ment. However, there is a dilemma when a VRF is located in an inaccessible area of a single-rooted tooth.\(^4\)

Endodontic surgery is an alternative to extraction for root fracture at the apical third; it is crucial to locate the fracture precisely in order to identify the part for resection.\(^4\) Even though the prescribed length to remove can be acquired from the CBCT scan, freehand removal in the operating room can be difficult for the surgeon due to various factors, such as bleeding and viewing angle. The 3D-printed template can help to solve this problem, as it can be simply and stably oriented on the teeth and indicate the ideal position and angle for resection. In addition, with the assistance of the template, intuitive observation of the complete pathologic field is not needed, and this decreases bleeding, reduces iatrogenic injury, minimizes damage, and improves the prognosis after surgery.

Although in the present case the 3D-printed template provided the precise position of the fracture line, there are still limitations that should be resolved to ensure higher accuracy. First, the total distance requiring resection from the surface to the palatal side of the fracture was gauged and recorded. There is no guiding assistance in the template, which still demands manual control in the operation and may introduce a displacement error. Second, the fissure bur used in the root fracture resection should be altered with microprecision grinding tools. Furthermore, the border of the template guiding the root fracture resection should be fabricated with rigid materials, which can both reduce the wear while guiding the resection and increase accuracy.

**Conclusion**

Teeth with VRF could be preserved with minimal damage if endodontic microsurgery is performed with the assistance of a 3D-printed template that provides positional control with considerable surgical accuracy in locating and resecting the root fracture effectively.

**Acknowledgment**

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**Disclosure**

The authors declare there are no conflicts of interest.

**References**


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