Introduction
Fractures of endodontically treated teeth are commonly referred to as vertical root fractures (VRFs) (1). VRFs usually present with a poor prognosis for tooth survival and generally result in extraction. VRFs, especially those occurring in short time spans after root canal therapy, can be disheartening to patients and the treating clinician, especially when analysing clinical outcomes in terms of cost-benefit and cost-effectiveness (2). VRFs are different to cracked tooth syndrome (CTS), which usually presents in vital teeth with symptoms of pain to biting and thermal sensitivity. Typically, these fractures run in a mesial to distal orientation along the occlusal surface of the crown (3) in varying degrees of proximity towards the pulp with a higher incidence in upper first premolars (4) and lower second molars (5) (Figure 1). VRFs are initiated within the root and are almost exclusively located along the buccal and/or lingual aspects of the affected root. The aim of this review is to provide a concise summary on VRFs and possible insights towards their prevention through better clinical decision making.

Prevalence
Prevalence refers to the proportions of people who have a disease in a given population at a given time. The true extent of a particular disease within a population may be difficult if not impossible to accurately quantify and estimates from sampled populations may provide varying base rates. Thus, studies in endodontics have reported ranges of two to 20 per cent for VRFs. Vire (6) reported a prevalence of four percent (116 teeth), Fuss (7) reported 10 percent (147 teeth) and Zadik (8) reported eight percent (547 teeth). However, in all three studies, restorative failures were the dominant reason for tooth extraction at 60, 50 and 61 percent, respectively. Also, common to most studies, is a higher prevalence of VRFs for ribbon shaped root canal configurations in the mesial roots of molars, followed by upper first premolars and lower incisors (9).

Etiology
The etiology of VRFs in endodontically treated teeth is complex and multifactorial with various predisposing factors for its initiation and propagation by inherent (non-modifiable) and/or operator induced (modifiable) factors.

Inherent Factors: One of the main inherent factors for the initiation of VRFs is the amount of residual tooth structure remaining from previous caries and restorative treatments (12). VRFs can start apically and propagate coronally or start coronally and propagate apically along the affected root, possibly also through extensions of mesial and/or distal marginal ridge fractures especially in cases previously treated for CTS. Anatomical factors that are also inherent to the mesial roots of mandibular molars include the presence of the isthmus, which may present as a natural weak plane for VRF initiation (13) and the butterfly effect in ribbon shaped roots as a possible phenomenon for VRFs occurring in a buccal-lingual direction (14). Parafunctional habits, terminal teeth and malocclusion with poorly placed restoratives may also contribute to a higher incidence of VRF.

Operator factors: These are usually modifiable factors which can include overzealous access and root canal preparations (15), heavy condensation forces (16), overzealous preparation of post spaces (17), and overzealous crown preparations in conjunction with loss of peri-cervical dentin (17). VRFs of non-endodontically treated teeth have also been reported in the endodontic literature, specifically in the Chinese population (10,11). Common to most of these patients was increasing age, loss of dentition, severe attrition and bruxism possibly related to dietary habits (11).

Diagnosis
Formulating a diagnosis of VRF starts with an accurate history taking (subjective analysis). History taking should include the reasons for the initial root canal therapy and possibly the chronological sequence of events that
has lead the patient to see the dentist. Teeth that have had root canal therapy as an end stage to CTS provides the clinician with an estimate of a prior probability for decision making before utilising any clinical testing for the likelihood of a VRF or split tooth. Interestingly, patient symptoms for a VRF are very mild to sometimes none and few patients may mention a bad taste that may be associated with a draining sinus tract. Clinical presentations can be a marginal sinus tract and/or an isolated deep probing along the buccal or lingual aspects of the affected root (9). Probing under local anesthesia may be needed for some patients. Radiographic findings are usually adjacent areas of bone loss around the associated root(s), however, on a few occasions, this can be pathognomonic for a VRF but it may be associated with apical disease extending towards the alveolar crest mimicking the characteristics of a VRF for an anatomically failing root canal therapy. There is also an increasing demand and use of cone beam computed tomography (CBCT) for VRF diagnosis, however, there are limitations for the use of CBCT with root filled teeth, as they are subject to beam hardening, producing artifacts into the imaging that can bring false positives into the decision making (18), thus labelling some cases as VRF when in fact these may be failing anatomically and retreatment may allow for successful regeneration of adjacent bone.
Figure 5.
Internal visualisation of a VRF along the corono-buccal aspect of the mesial root after staining with methylene blue dye.

Figure 6.
Lower second molar with cracked tooth syndrome. Notice the deep isolated probing along the distal aspect together with a shallow restoration.

Figure 7.
Excessive shaping within the mesial root has most likely contributed to the VRF on this #46.

Figure 8.
Conservative shaping and placement of an immediate core in a case that presented with cracked tooth syndrome without an isolated deep probing. A conservative onlay is advised.
Another treatment modality to diagnose a VRF is through surgical exploration with a typical representation of a VRF along the buccal or lingual aspect of the affected root (Figure 3) and sometimes the extent can be seen travelling to the coronal aspect of the crown (Figure 4). Internal exploration can also be helpful for definitive diagnosis after staining with methylene blue dye to visualise VRFs (Figure 5).

Treatment
Treatment for VRFs is usually tooth extraction. Other options can include root amputation of the affected root; however, this technique is becoming less popular due to the wider availability of dental implants, which may provide better long-term outcomes compared to the alternative of root amputation. Root amputations are also notorious for patient management, as the amputated site can be a bothersome food trap especially in the early stages of healing. On the contrary, there are few case reports on successful root amputations and tooth survivability.

Prevention
Prevention of VRFs starts with an accurate history taking. In the presence of CTS that has a deep isolated periodontal pocketing, the choice for extraction and placement of an implant may be a better solution for long-term function and quality of life (Figure 6). Cases of CTS that also have pulpal floor fractures may also present with a poor long-term prognosis regardless of full coverage restorations (10). A cost-benefit analysis is an important outcome measure in monetary terms (2). For example, the investment for a patient to root canal treat a tooth with CTS with an isolated deep periodontal pocketing and/or pulpal floor fracture may provide benefit for the short term through reduction of symptoms and tooth retention when taking into account the cost returned to the patient through insurance payments and/or continual income. Cost-effectiveness analysis does not use monetary inputs to measure outcomes, rather it’s a measure of health-care outcomes for patients compared to the alternative suggested treatment (2). This would mean that the choice of an alternative (dental implant) may provide a better long-term health-care outcome for the patient compared to root canal treatment of a cracked tooth that has an isolated periodontal pocketing defect and/or pulpal floor fracture even though the initial cost of an implant may be superior to that of root canal treatment and restorative care alone. Preventative modifiable measures in general for all teeth receiving root canal therapy would be to minimise on the dentin footprint, both restoratively and endodontically (Figure 7). This concept may seem even more prudent in cases that have become symptomatic from fracture necrosis in an attempt to save residual tooth structure possibly influencing fracture resistance (Figure 8). Other modifiable factors include minimising condensation forces and minimising the amount of dentin removed during post space preparation. With the current availability of surgical operating microscopes, smaller burs and newer smaller tapered root canal instruments, more conservative root canal preparations and access designs should be exercised and engineered in a way to maximise on the amount of residual dentin in the pulp chamber and root canals, coupled with the placement of immediate restorations by the general dentist and the endodontist. It has also been suggested that the maintenance of thickness of peri-cervical dentin (20), which is about 2-3mm coronal and apical to the cemento-enamel junction may improve on structural outcomes of root canal treated teeth together with careful judicial reduction of cervical dentin during placement of crown margins. Considerations should also be given to the final occlusion. Poor or malocclusions may also increase the likelihood of a future VRF, especially in cases that have been treated for CTS without any significant deep periodontal pocketing suggestive of root fracture propagation at the time of treatment. Finally, patients should be educated on the expectations of probable outcomes especially in cases that present with a multitude of inherent etiological factors.

Conclusion
The prevalence of VRFs is lower than that of tooth restorative failures as a reason for post-endodontic tooth extraction, however VRFs present with an undesirable outcome as an end stage to endodontic therapy. Best practices would be to establish a definitive diagnosis of a VRF before deciding extraction and to be aware and realise the potential unmodifiable and modifiable etiological factors that can accelerate VRF leading to early tooth loss for all teeth receiving endodontic therapy.

REFERENCES


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