Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

ROOT FRACTURES IN ENDODONTICS. PROGNOSIS AND TREATMENT. REVIEW OF LITERATURE.

Madrid, academic year 2022/2023

Identification number: 100

ABSTRACT

Introduction: Fractures are often encountered in the dental office, as their main etiology is dental trauma but they can also be caused by parafunctional habits, traumatic occlusion, deep caries or iatrogenic causes. Root fractures affect the dentin, the cementum and the pulp of the tooth. They are classified according to their location, direction and extent. For the correct management of such case, a complete investigation of the patient is mandatory in order to give the correct diagnosis and prognosis; **Objectives:** Aims for this study were to compare metal and fiber posts in the incidence of root fractures after endodontic treatment and to put in evidence the differences between calcium hydroxide (CaOH) and mineral trioxide aggregate (MTA) in the formation of dentin barrier; **Methodology:** A systematic review was made based on an electronic literature search in PubMed and Google Scholar. The studies ranged from 2012 to 2022. Publications were researched in English. Inclusion and exclusion criteria were established; **Results:** Once we applied the inclusion and exclusion criteria in our research and after a full-assessment of the articles, a total of 10 records were included in the review. The results were organized and presented in tables; **Conclusion:** All of our articles concluded that there were no significant differences in the clinical performance of fiber and metal posts but the failure pattern of fiber posts is more manageable. MTA and CaOH can both be used between appointments but calcium hydroxide takes more time to form the dentin barrier during healing and MTA has been shown to make teeth resist better to fracture.

KEYWORDS

Dentistry; root fracture; post; calcium hydroxide; MTA.

RESUMEN

Introducción: Las fracturas son comunes en la consulta dental, ya que su etiología principal es el traumatismo dental, pero también pueden ser causadas por hábitos parafuncionales, oclusión traumática, caries profundas o causas iatrogénicas. Las fracturas radiculares afectan la dentina, el cemento y la pulpa del diente. Se clasifican según su ubicación, dirección y extensión. Para el manejo correcto de estos casos, es obligatoria una investigación completa del paciente y así un diagnóstico y pronóstico correctos; **Objetivos:** Los objetivos de este estudio fueron comparar los postes de metal y de fibra en la incidencia de fracturas radiculares después del tratamiento endodóntico y evidenciar las diferencias entre el hidróxido de calcio (CaOH) y el agregado de trióxido mineral (MTA) en la formación de la barrera dentinaria; **Metodología:** Se realizó una revisión sistemática basada en una búsqueda electrónica de literatura en PubMed y Google Académico. Los estudios incluidos abarcaron el período de 2012 a 2022. Las publicaciones se investigaron en inglés. Se establecieron criterios de inclusión y exclusión; **Resultados:** Una vez que aplicamos los criterios de inclusión y exclusión en nuestra investigación y después de una evaluación completa de los artículos, un total de 10 registros se incluyeron en la revisión. Los resultados se organizaron y presentaron en tablas; **Conclusión:** Todos nuestros artículos concluyeron que no hubo diferencias significativas en el rendimiento clínico de los postes de fibra y metal, pero el patrón de falla de los postes de fibra es más manejable. Tanto CaOH como el MTA se pueden utilizar entre citas, pero el hidróxido de calcio tarda más tiempo en formar la barrera de dentina durante la curación, mientras que se ha demostrado que el MTA hace que los dientes sean más resistentes a la fractura.

PALABRAS CLAVE

Odontología; fractura radicular; poste; hidróxido de calcio; MTA.

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I. INTRODUCTION

Endodontics is the branch of dentistry that focuses on the diagnosis and treatment of dental pulp and periapical tissues. Root fractures are relatively common, they can occur due to various reasons and they have a significant influence on the prognosis of the tooth and the treatments available. As dentistry is trying to become a more conservative discipline, one of the challenges nowadays for endodontists is the management of such root fractures, to maintain them as long as possible and to avoid radical treatments such as extractions.

In endodontically treated teeth, are there any differences between metal posts and fiber posts in terms of root fractures?

In this study, we will talk about the different kinds of root fractures, go through the classification and etiologies as well as the method to diagnose them.

1. Root fractures

Dental trauma can vary from simple enamel infraction to complete tooth avulsion. Tooth fractures — in the crown, the root or in both — is known as the third most common cause for tooth loss(1).

In this review, we are going to focus on fractures including both the crown and the root of the teeth but also fractures exclusively happening in the root.

Crown root fractures are described as wounds that affect the cementum, dentin, and enamel. Due to injury, the pulp could be exposed or not. Concerning root fractures, which exclusively happen in the root, they affect the cementum, dentin, and the pulp and they may have secondary impacts on the periodontium. They represent

0,5% to 7% of the traumas concerning the permanent dentition, which mainly take place between 11 and 20 years old(1–3).

2. Types of fractures and their clinical management

To establish clarity, a classification and definition of cracks and fractures were developed in 2008 by the American Association of Endodontists (AAE), according to their location, direction and extent, along with suggestions for possible treatment methods for each case(4–8).

As craze lines only affect the enamel of the tooth and are asymptomatic, we will not go further about them in this review. On the other hand, fractured cusps, cracked and split teeth start in occlusal and continue until the root, affecting the enamel as well as the dentin and sometimes the pulp. Moreover, we call « vertical root fracture » (VRF) any fractures that find its origin in the apex of the tooth. All of them, except for craze lines, are most commonly found in posterior teeth(4–6,8,9).

2.1. Longitudinal fracture

2.1.1. Fractured cusps

A fractured cusp is usually described as a total or partial fracture that starts at the crown and spreads beyond the gingiva, directed mainly mesiodistally and buccolingually. The crack frequently reaches the marginal ridge and spreads along a buccal or lingual groove, reaching the cervical part of the crown or the root. (**Figure 1**)(5,6,10).

Figure 1. Cuspal fracture of a lower molar(10).

Depending on how much tooth structure is still present, the damaged cusp is removed, and the tooth is then rebuilt with a direct restoration, an onlay or a crown. When adequately applied, dentin and enamel bonding with adhesive resins has been found to protect and strengthen the tooth. We only perform root canal treatment (RCT) when the fracture reaches the pulp(5).

2.1.2. Cracked tooth

A partial breakage that originates coronally, extends beyond the gingiva, and mesiodistally, is referred to as a cracked tooth. Both the proximal surfaces and one or both of the marginal ridges could be affected by the fracture. The fracture only occurs in the tooth's crown section, or it also extends to the proximal root (**Figure 2A**). As it extends apically, the crack is more centralized and closer to the apex than a fractured cusp, which increases its probability of causing pulpal and periapical pathology(5–7).

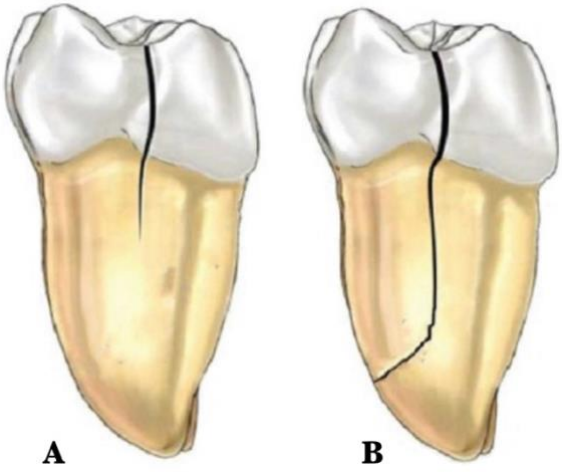


Figure 2. Cracked tooth of a lower molar affecting the crown and the coronal third of the root (A). The crack propagates deeper in the root and creates a split tooth (B)(10).

The fractured tooth therapeutic approach will change depending on where and how severe the crack is, which can be challenging to evaluate. Pulpal and periapical diagnosis must be established before beginning RCT. A tooth with a little crack may still need a root canal, but only if the situation requires it. A tooth with a large crack will have more chance of pulp affectation and thus will probably need root canal treatment. Consequently, the treatment plan is mainly determined by pulpal and periapical diagnosis rather than just crack discovery(5).

If the crown is evident on the cavity floor, we should remove the visible fracture with a bur, initiating an endodontic aperture and allowing to see the extent of the fracture. However, even after staining, a fracture is minor and imperceptible at its most extreme point, and it likely extends further into the dentin than what can be seen. If the fracture extends toward the proximal surfaces, the removal of the fracture below the cemento-enamel junction (CEJ) is not recommended because the tooth will most likely be unrestorable, and the removal of sound tooth structure decreases the resistance of the dental piece. Nevertheless, if the break on the proximal surface is not treated, bacteria may continue to infiltrate the tooth, necessitating either root canal therapy or extraction in the future. One of the hardest situations to treat is a crack that cannot be separated, that spreads far into the root, and/or includes the furcation.

Unless the tooth needs to be extracted, a fixed restoration is recommended to maintain the fragments together. Before beginning treatment, radiographic examination and periodontal probing must be carefully taken into account. Dentists should share with the patient the results of their findings and every available treatment options(5,11).

2.1.3. Split tooth

A split tooth is described as a full rupture that starts at the crown and extends subgingivally before frequently moving mesio-distally across the proximal surfaces and marginal ridges. The fracture initiates in the crown until the root (**Figure 2B**). A crack centered in the occlusal surface will spread more apically. Although it could develop suddenly, a split tooth is usually the consequence of a non-treated cracked tooth. The middle or apical third of the root is affected and extends toward lingual. Teeth segments are completely independent with no dentin connections(5,6).

Split teeth can hardly be preserved completely; however, the prognosis and course of treatment depend on the crack's location and extent. In a situation of a deep fracture, the entire tooth must be extracted whereas when the fracture splits the root surface in the middle or cervical third of the root, the coronal fragment will be mobile and extracted. Then, the remaining portion of the tooth could be saved(5).

2.1.4. Vertical root fracture

A « real » vertical root fracture (VRF) is considered as a total or partial fracture that originates from the root and is typically directed buccolingually (**Figure 3**). Both buccal and lingual proximal surfaces may be affected by the fracture, or it could simply affect one of them. Only the tooth's root section is fractured, and it may spread coronally, towards mesial and distal, in the direction of the cervical periodontal attachment. Recently, it has been found that a VRF can develop at any point along the root's length. VRFs are more commonly found in posterior teeth. They are less common than transverse root fractures with a prevalence from 2 to 5% of crown/root fractures(1,5,12).

Figure 3. Vertical root fracture initiating from the mesial root of a lower molar(10).

VRFs can be classified according to the separation of the tooth pieces, which can be complete with a total separation of mobile fragments, or incomplete, when the fragments are not separated and can't be moved. Furthermore, the position of the fracture in relation to the alveolar crest divides the fractures in two categories. They are supraosseous, when they terminate above the bone and do not create

complications, or they are intraosseous, when the bone is also involved in the fracture, which creates periodontal defects (**Table 1**)(1).

Vertical root fractures are localized in a longitudinal plane but they can also expand sideways towards the periphery of the root, in an incomplete or total way, just like horizontal root fractures (**Figures 4 and 5**)(13).

The only foreseeable option for treatment is either tooth extraction or root canal treatment. When a tooth presents multiple roots, the fragmented root may be removed through hemisection or root amputation. Although innovative therapies are being investigated, there is currently no practical or efficient way to save a cracked root(5).

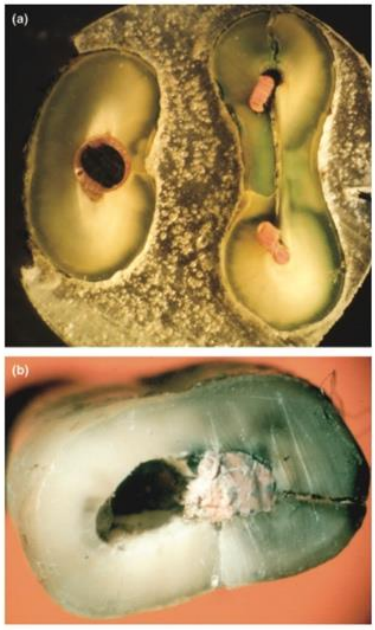


Figure 4. (A) Cross-section of a lower molar and (B) an upper premolar with an incomplete VRF(13).

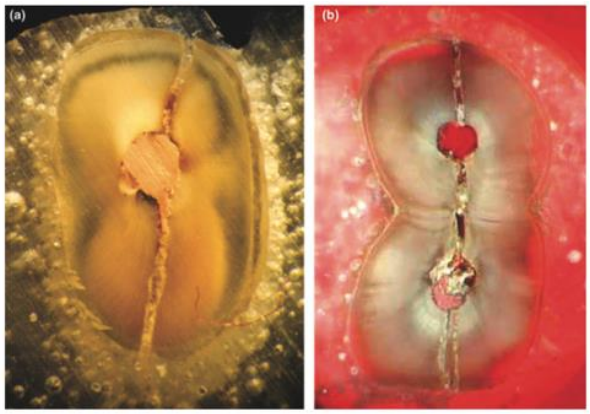
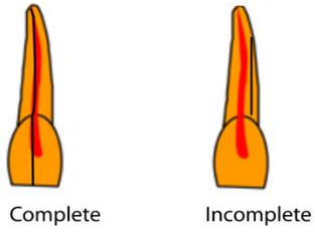
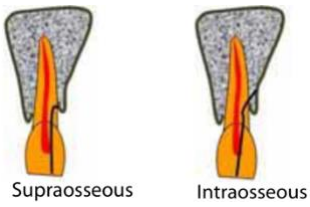


Figure 5. (A) Cross section of an upper premolar with one canal and (B) two canals showing complete VRF(13).

Table 1. Vertical root fractures classification(1).

Separation of the tooth fragments	
Position of the fracture in relation to the alveolar crest	

2.2. Horizontal fracture

Concerning exclusive root fractures, we can distinguish two main types; horizontal and vertical(1).

Horizontal root fractures mainly occur on the maxillary central incisor region due to frontal trauma, which explains why they are more commonly seen in young adults. They can be organized according to the extent of the fracture, the number of fractures, the position of the coronal segment and the location of the fracture line (**Figure 6 and Table 2**) :

- Cervical: not reaching the alveolar bone crest
- Middle: in the first 5 mm in the alveolar bone
- Apical: deeper than 5 mm below the alveolar bone crest(1,2,9).

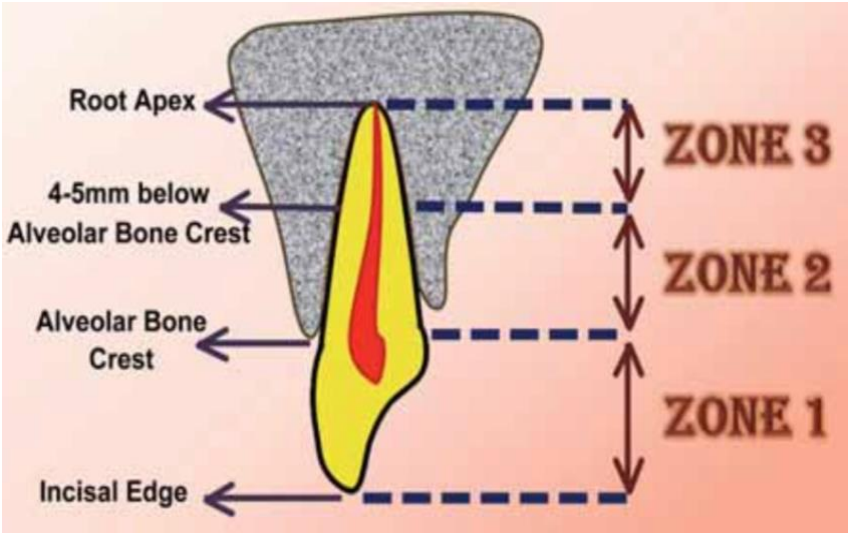
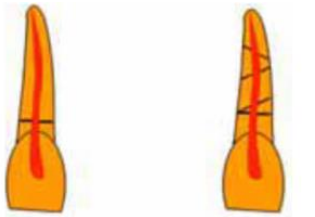
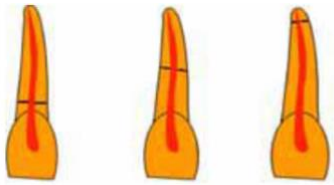
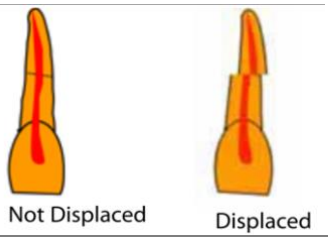
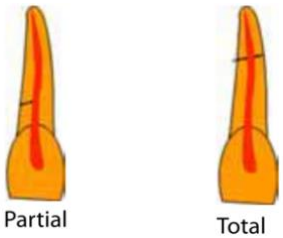


Figure 6. Classification of horizontal root fracture according to the alveolar crest(1).

Table 2. Horizontal root fractures classification(1).

Number of fractures	
Location of the fracture line	
Position of the cervical fragment	
Extent of the fracture	

Horizontal root fractures are more commonly found in the central part of the root. They also present the best chance of pulp survival in comparison to other type of trauma injuries(1).

3. Etiology

The reason why transverse root fractures appear more before the second decade of life (11-22 years old) is because they are caused during sporting events, fights or falls. Usually, they occur after direct trauma in anterior teeth and indirect trauma in premolars and molars. When the impact is directed towards the root, a fracture at that place will probably occur. On the contrary, if the shock happens on the crown, the strength of the impact is passed on the root and a cervical root fracture will possibly follow(1,2).

In addition to trauma, horizontal root fractures could be produced by parafunctional habits, traumatic occlusion, deep caries or iatrogenic causes(1).

Several predisposing factors of vertical root fractures have been identified. Among them we can find the loss of healthy tissue, which appear during carious process, indeed, it increases the risk of crack propagation along the tooth. Furthermore, the reduction of alveolar bone and the existence of fissures that diminishes the strength of the dentin are both recognized as underlying causes for VRFs. More simply, the anatomy of the roots alone makes these teeth more susceptible to fracture. Indeed, the risk of VRFs increases as the mesio-distal diameter of the root diminishes(1,9,13).

Set aside those considerations, iatrogenic factors that can induce fractures also exist. The most common one being RCT. In fact, the extensive instrumentation of the coronal third diminishes the amount of dentin and weakens the radicular structures. Thus, it is important to have a balance between removing infected tissue and maintaining sufficient amount of dentin to support masticatory forces(5,13,14).

Concerning the obturation of pulp treatment, it has been shown by studies that condensation with gutta percha is one of the most common risk factors for VRFs. More precisely, more pressure is applied at the tip of the root during vertical condensation compared to lateral technique. When measuring with Instrom machine, it is shown that 15 to 16 kg needs to be applied on the root in order to produce a fracture. In practice, only 3 kg is usually sufficient to obtain space for additional gutta-percha cones(4,13–15).

In addition to the root canal treatment itself, if an intra-radicular post needs to be placed, it decreases even more the resistance of the tooth, and the risk of fracture increases. Nowadays, it is recommended to use posts only when it is necessary to retain a foundation and, in these cases, use preferably prefabricated posts with round edges that we insert in a passive way and with parallel sided walls. On the contrary, more fractures are observed with the use of conical and threaded posts. Posts made of fiber-reinforced-composite are of good use because they have an elasticity modulus similar to the one of the dentin(1,4,5,13–15).

VRFs are also observed in teeth with extensive restorative treatments, such as crowns or inlays because of the wedging effect(1,4,5).

Just like horizontal root fractures, healthy teeth (meaning, non-carious and non-endodontically treated teeth) can also suffer fractures because of parafunctional habits or strong masticatory muscles, which applies too much forces on the dentition(1,9).

Although the various risk factors for a fracture are well established, the precise etiology for the tissue destruction that goes with it is still unclear(14).

4. Diagnosis

4.1. Anamnesis

The first thing to do when there is suspicion of fracture after a trauma is asking the patient for the cause of the injury, when and where the trauma took place and if there is any spontaneous symptom. It is fundamental to ask the patient if he suffers from any other symptoms such as vomiting, drowsiness or headache as injuries in the head and neck may have neurological consequences(1).

4.2. Clinical examination (signs and symptoms)

4.2.1. Horizontal root fracture

When the fracture is horizontal, the apical portion is not displaced nor mobile. Middle third fractures usually present lateral luxation of the coronal fragment, displacement in the lingual direction, and a minor extrusion. When the fracture happens in the cervical part of the root inside the bone, the mobile fragment will usually still be attached to the periodontal fibers. For fractures above the crestal bone, the whole crown of anterior teeth is typically very mobile. On the other hand, posterior teeth will present one movable cusp compared to the rest of the crown. The tooth could present temporary crown discoloration and be responsive to percussion and/or palpation. It's crucial to carefully examine the subgingival region to identify any fracture lines(1).

Due to temporary or permanent pulpal damage caused by trauma, sensitivity and vitality testing may initially produce negative results and a frequent follow-up is needed. Lately, it was advised to use a pulse-oximeter to assess the pulpal condition

of a newly injured tooth (**Figure 7**). Indeed, it gives a reliable positive vitality analysis over time and has greater specificity and sensitivity than electrical and thermal testing(1).

Figure 7. Pulse oximeter(1).

4.2.2. Vertical root fracture

It can be difficult to establish a firm diagnosis of VRF in teeth that have undergone endodontic treatment. Intraosseous root fracture produces deep, narrow and clearly defined pockets called « precipitous pockets ». Thus, clinical symptoms and radiographic characteristics commonly mimic those related to non-healing root canal procedures and specific periodontal disease manifestations(1,5,6,8,13).

Patients typically have an extended background of inconsistent pain or discomfort and describe pain while chewing. Other symptoms include gum inflammation, bad taste, fragment movement, and the existence of a sinus fistula(1,7,8,11,12,15)

From the perspective of doing a differential diagnosis, it seems relevant to note that the probing in VRF pockets is narrow and in an isolated point around the tooth, whereas the presence of pockets in patients with periodontal disease cis more

generalized (**Figure 8**). Therefore, the clinician must be able to make a distinction between bone resorption in VRF situations and bone losses due to periodontal disease. Even though resorption in both situations starts at the gingivally and progresses apically, in the periodontal process, it is delayed, with the exception of periodontal abscess(8,12,13,15).

Rivera et al. suggests that having an isolated periodontal defect with a fistula in an endodontically treated tooth (ETT), with or without a post, is a pathognomonic situation for the diagnostic of a VRF (**Figure 9**). In failed RCTs, fistulas are frequently localized at the apex, whereas in VRFs the sinus tract is typically closer to the crown in both buccal and lingual plates (**Figure 10**)(5,8,12).

Figure 8. Collaboration images of a VRF case from Dr. Dallo. (A) Indirect view of a superior first premolar, fracture line is visible from mesial to distal. (B) Localized probing at the mesial aspect of the tooth. (C) On the radiograph, a large bone loss is observed where the deep probing occurred.

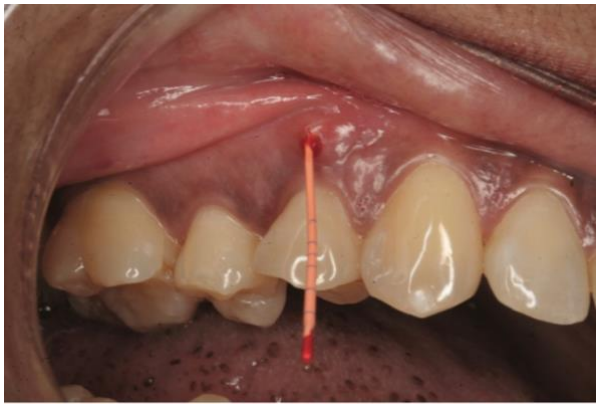


Figure 9. Abscess located near the cervical margin on a superior first premolar and sinus tracing with gutta-percha(8).

Figure 10. Deep localized periodontal probing in mesial of a lower first molar and sinus tract on the attached gingiva, near the crown(8).

The best way to diagnose VRF clearly is by performing an exploratory flap (**Figure 11**). If during the surgery, dehiscence, fenestration or fracture are not observed, an apicectomy may be performed. Nonetheless, the tooth's prognosis may remain uncertain as the fracture could be located at the lingual side(12,13,15).

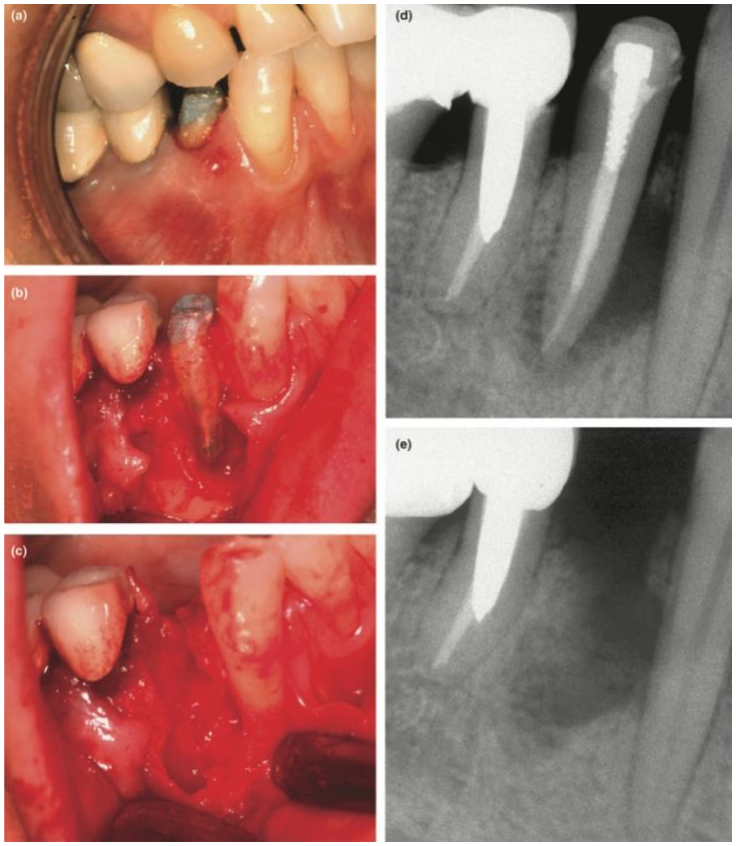


Figure 11. (A) Mandibular first premolar with VRF seen after the restoration. (B) We notice a large resorption of the buccal plate after surgery. (C) After extraction, granulation tissue filled the defect. (D) X-Ray before the extraction. (E) X-Ray after the extraction, we can see the amount of bone loss(13).

4.2.3. Fractured cusp, cracked and split tooth

To distinguish these three types of fractures, wedging can be used to test the mobility of the fragments. If there is not any movement, it suggests a cracked tooth while a split tooth will show mobility. Finally, a fractured cusp will simply break off when subjected to modest pressure(5).

4.3. Radiological signs

4.3.1. Horizontal root fractures

For the identification of root fractures, radiographic images are essential. Horizontal root fractures occurring in the apical and middle third are more oblique, this is why occlusal radiographs are commonly used to diagnose them. On the other hand, to detect root fractures in the cervical part, which are more horizontal, you may need a periapical radiograph taken at 15°-20° from the fracture plane. Another recommended protocol is the following:

- One standard periapical radiograph with two more periapical radiographs at +15° and -15° from the fracture line.
- Or three periapical radiographs at 45°, 90° and 110°.

A study made by Kambugton et al. showed that root fractures were generally better diagnosed when three angulations beam were used rather than only one(1–3,16).

Despite their shortcomings, periapical radiographs in conjunction with clinical examinations continue to be the gold standard and must always be taken into account during the patient's initial evaluation. In cases of root fractures, the information collected will establish the necessity and the need for the use of 3D imaging for monitoring of healing and complications(3).

In traumatic injuries, it is important to know the relation between the roots and the location of the anatomical structures adjacent to the teeth. However, conventional periapical radiographs don’t give us these information but different 3-D imaging methods are available with a wide range of clinical uses. Among them, we can find the Cone Beam Computed Tomography (CBCT), also called Digital Volume Tomography (DVT)(3).

In 2007, the first description of CBCT in dental traumatology was published. In contrast to the conventional periapical radiograph, 3-D imaging is cheaper, produces less radiation and eliminates superimpositions giving a realistic picture of the anatomy which may reveal a more difficult situation than expected. Indeed, according to a retrospective study, the detection of root fractures was multiplied by three with CBCT compared to convention periapical radiograph (**Figure 12 and 13**)(3).

In addition, CBCT imaging is able to detect a bone fracture happening alongside with a root fracture, particularly at the labial cortical plate which is not uncommon given the thin bone wall at this location(1,2).

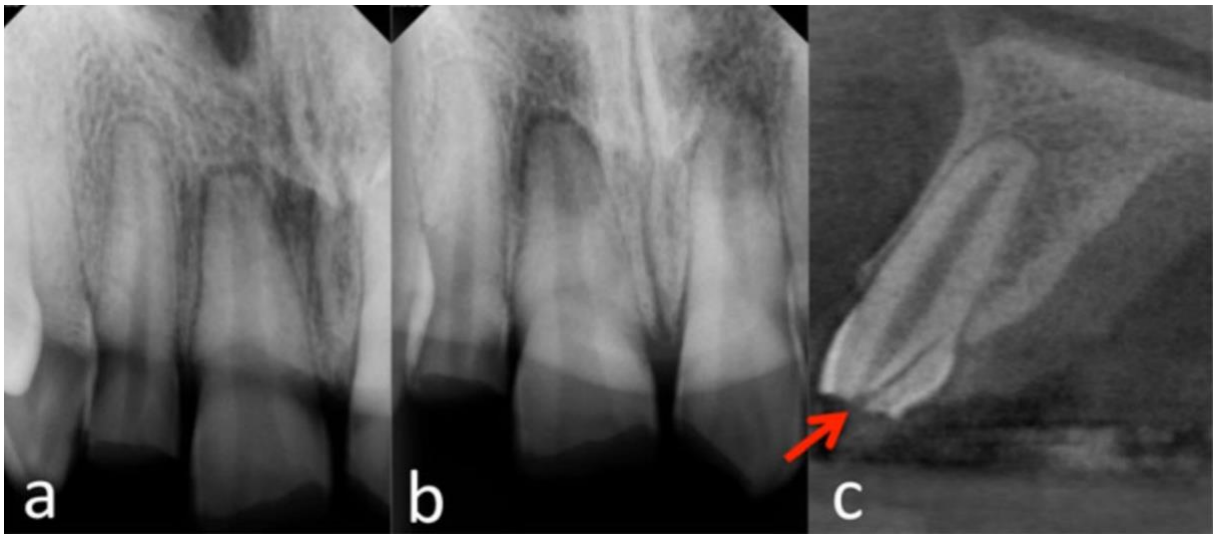


Figure 12. Periapical radiographs (A and B) of superior central incisors where no apparent fracture is detected. CBCT of an upper central incisor where the crown root fracture can be seen (C)(3).

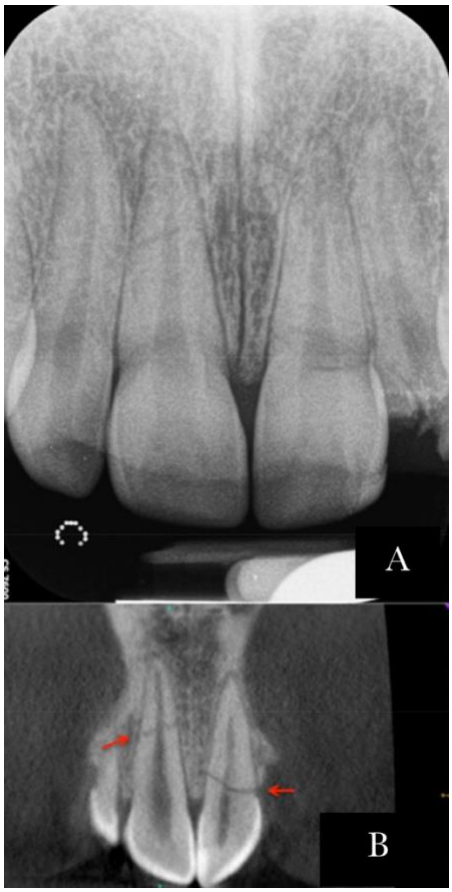


Figure 13. (A) Periapical radiograph of superior central incisors with an apparent horizontal fracture of 11. (B) CBCT scan of the same teeth where the horizontal fractures of both teeth are clearly visible(3).

4.3.2. Crown root fractures

The diagnosis of a crown-root fracture is done by performing a detailed assessment of the tooth and its periodontium, the periodontal fibers could still be bound to the coronal fragment. It is highly recommended to use CBCT for evaluating the position and size of the crack since relying solely on periapical radiography may not always provide the adequate information. The crown-root proportion and the capacity of the dental structures left to be restored are the most essential aspects to take into account(3).

All professionals should follow the ALARA (As Low As Reasonably Achievable) recommendations regarding radiologic exposures when utilizing CBCT or any other imaging technology. CBCT should only be considered in situations where

conventional dental radiography fails to provide sufficient information. The shortest field of view (FOV) possible will be used as it provides higher resolution images with a reduced radiation dose(3).

4.3.3. Vertical root fractures

VRF diagnosis with radiographic evidence can be made by observing a fine line as wide as a hair in the dentin body, they are hardly visible in conventional periapical radiographs and could be noticed when soft tissue develops in the breach, making the radiolucency more visible, but this process takes time. Nonetheless, when the radiographic appearance is a clear root segment separation accompanied by a significant bone loss around the root, it is a clear indication of fracture but is rarely seen (**Figures 14 and 15**)(1,12,13,15).

Due to root superimposition, it is challenging to identify associated radiolucencies in root fractures since they often spread in a bucco-lingual direction. Nevertheless, if the resorption extends laterally, it can be visible with two periapical radiographs taken from different angles (**Figure 16**)(12,13).

Figure 14. Periapical radiograph of a superior premolar with a clearly VRF, and a large radiolucency involving the whole root(4).

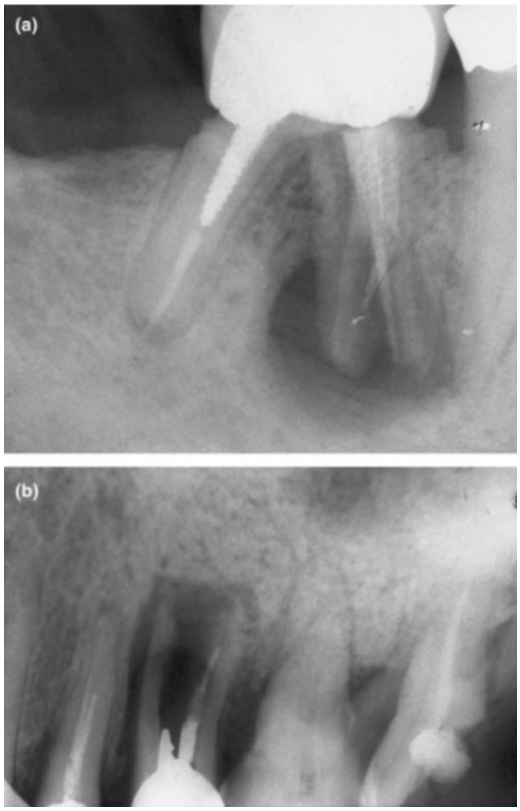


Figure 15. Large bone defects of a VRF in an inferior molar (A) and superior premolar (B)(13).

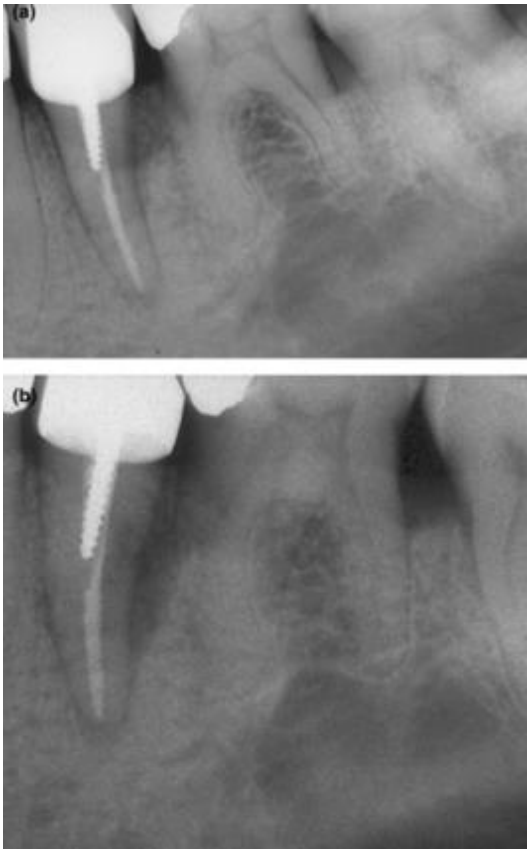


Figure 16. Bone loss distal to an inferior premolar root (A). Different angulation of the same tooth showing a deeper defect until two thirds of the root (B)(13).

Recently, a review of the latest radiographic methods to help in endodontic diagnosis was conducted. The micro-CT system, the flat panel volume detector CT, and the tuned aperture CT may offer hints to a quick recognition of VRF. Moreover, it is known that transillumination with a fiber optic light and use of magnification can allow visualizing root fracture. Sometimes, the longitudinal extension of the fracture is only evaluated after extraction because those imaging tools can't always provide clear images to visualize these fractures. In order to develop a proper diagnosis and treatment plan, it is essential for the clinician to make a "prediction" of the depth of the fracture using both subjective and objective information available(4,9,13).

Another classification according to CBCT diagnosis was proposed by Gao et al.; we can distinguish displaced, subtle and hidden VRFs. Displaced VRFs can be easily identified on CBCT as complete fractures with a clear split of the segments (**Figure 17**)(6).

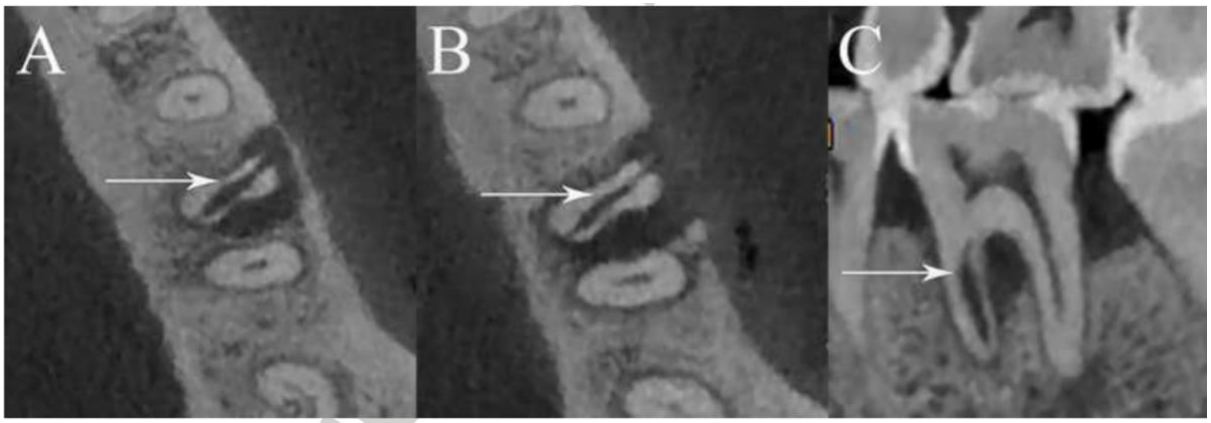


Figure 17. Displaced vertical root fractures observed in a CBCT scan. We can clearly see the separation of fragments in a transverse view (A and B) as well as in the frontal plane (C)(6).

On the other hand, subtle VRFs only shows incomplete, thin, fractures line, the diagnosis is more challenging and the evaluator's experience has a significant impact on the reliability of the diagnosis (**Figure 18**). Finally, hidden VRFs are the most complicated to diagnose with CBCT because of two reasons. First, the fracture line is smaller than the voxel size of the scanner; and secondly, as the presence of endodontic

filling artefacts imitate or overlap root fracture lines, CBCT has difficulty to capture this kind of VRF, however they can serve as a diagnostic tool (**Figure 19**)(6).

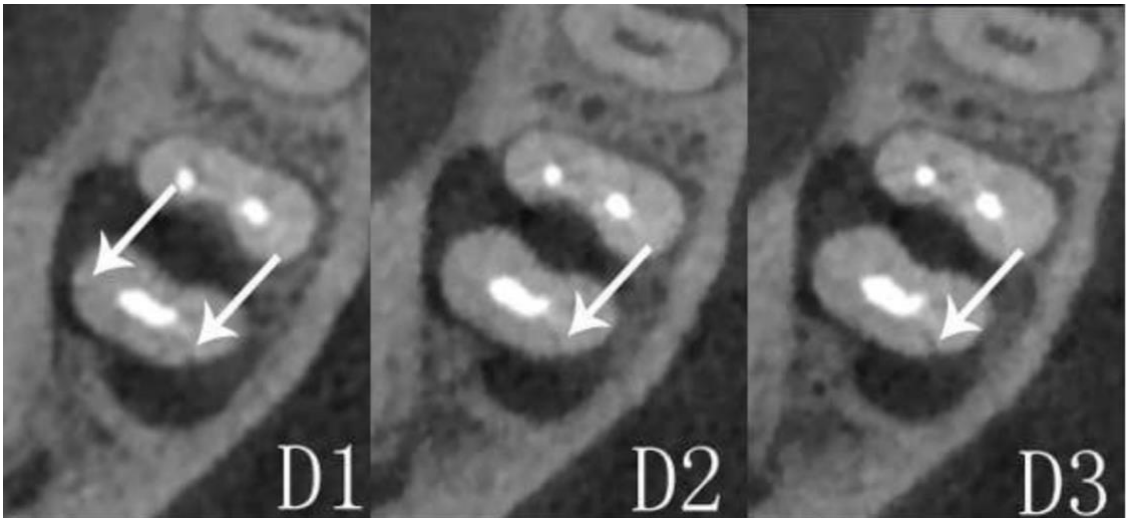


Figure 18. Subtle VRFs seen on a CBCT scan. We can only see a thin radiolucent line corresponding to a fracture (D1, D2, D3)(6).

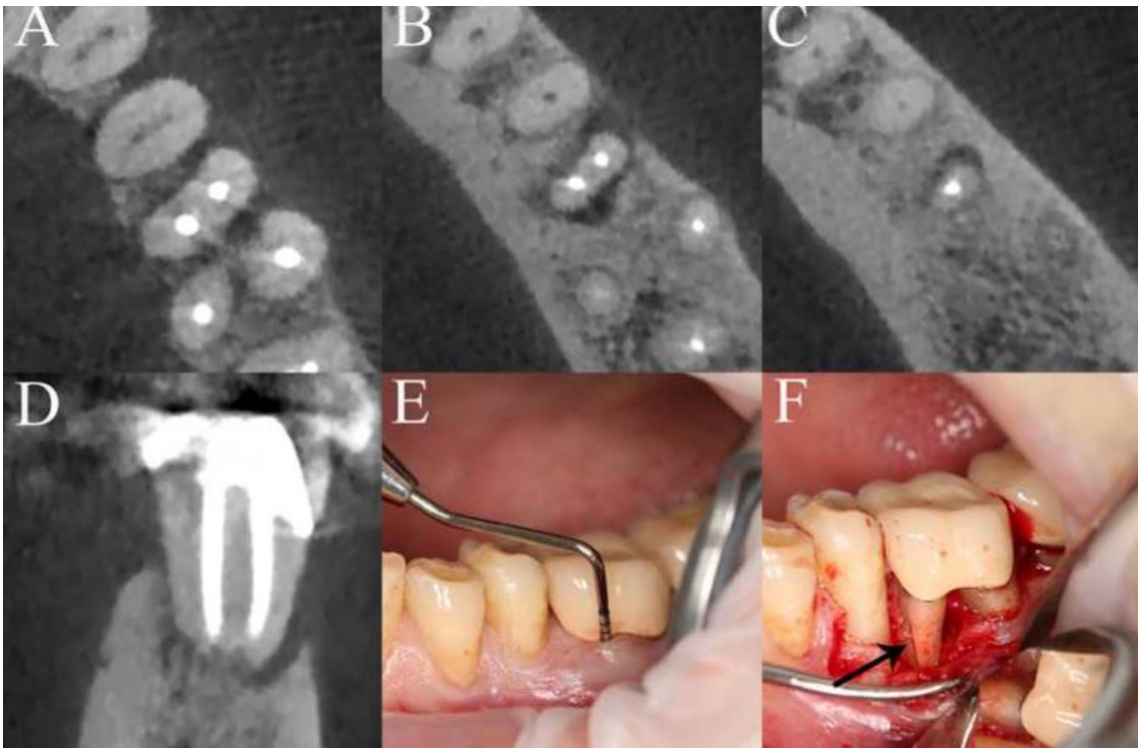


Figure 19. Hidden VRFs on CBCT. Several cuts are seen in the transverse (A-C) and frontal (D) planes but no fractures lines can be seen. In the clinical examination, a deep punctual probing is seen in buccal (E), and after a flap exposition the root fracture is clear on the mesial root of the lower molar (F)(6).

5. Types of healing in horizontal root fractures

Numerous different tissues in the tooth and supporting structures are affected by root fractures. As a result, there will be complicated patterns of healing involving the bone, the cementum, the pulp, the periodontal ligament and the dentin. Dentin and cementum, two hard dental components, break when a root fracture takes place and will not heal as a broken bone. The dental pulp can experience several types of injuries, it depends if the coronal segment has been displaced or not(2,5).

Root fractures appropriately treated heal in about 80% of cases. In 70–80% of intra-alveolar root fractures, pulp vitality is preserved leading to spontaneous repair. After a fracture, the pulpal and periodontal ligament begin to heal and this results in two distinct kinds of wound healing reactions that can coexist or compete with one another. In order for horizontal root fractures to mend, the fracture segments must be joined by either calcified tissue, connective tissue, calcified tissue mixed with connective tissue or granulation tissue (**Figure 20**). Healing by calcified tissue being the rarest type and connective tissue the most frequent(1).

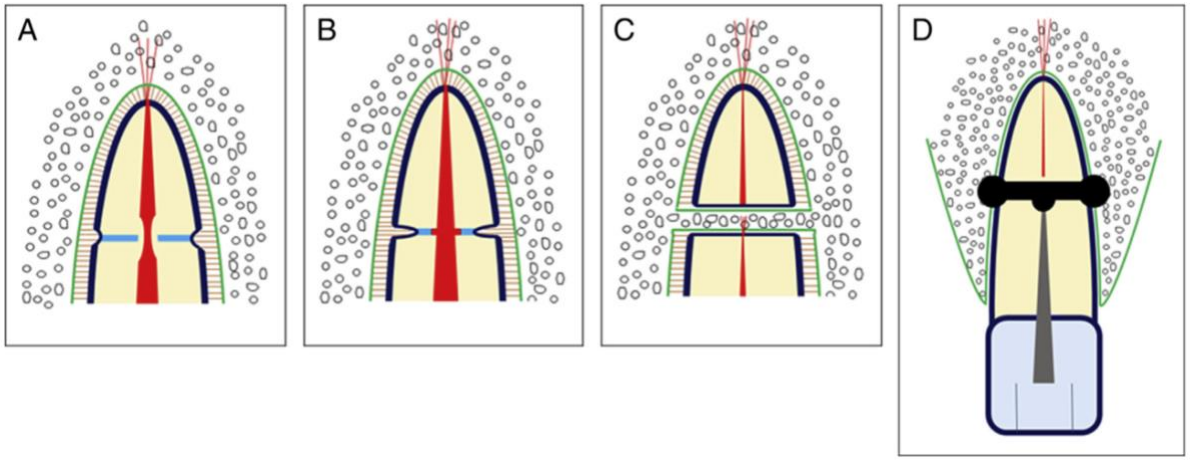


Figure 20. (A) Healing by calcified tissue, (B) healing by interposition of connective tissue, (C) healing by calcified tissue and connective tissue and (D) interposition of granulation tissue(1).

5.1. Healing with calcified tissue

In a major study, repair by hard tissue took place in 30% of the 400 teeth with fractured roots studied. This type of healing is the best one and can be identified after 6 weeks. It occurs when there has been little to no displacement of the coronal piece and good repositioning (**Figure 21**). As a result, the pulp's odontoblasts are in a good position to form reparative dentin that will join both fragments. As the blood supply at the apical foramen has not been impacted, the pulp remains normal. In both segments, calcification of the pulp canal, commonly known as obliteration, develops over time. Artvinli et al. published a case of a horizontal root fracture below the alveolar crest that healed by interposition of hard tissue and survived even though it was not treated. The main reason for that being the poor severity of the trauma and displacement of the coronal fragment(2,17,18).

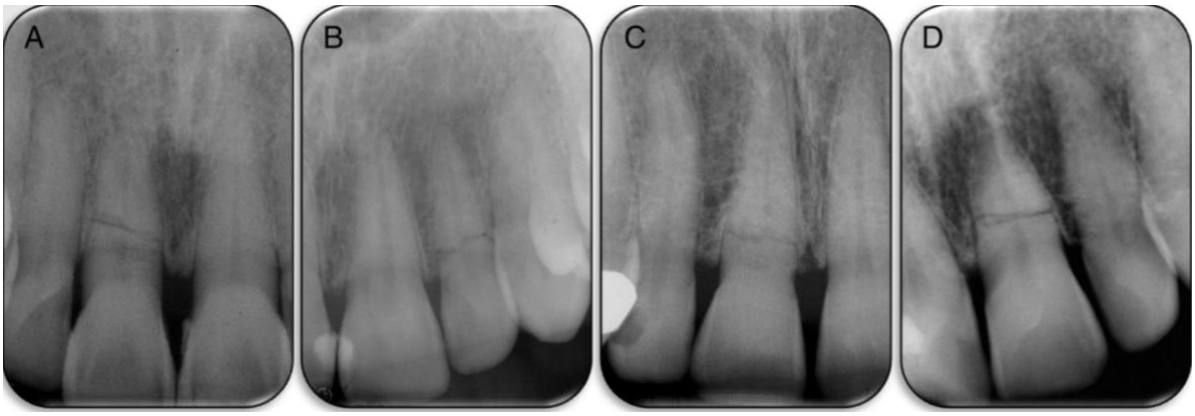


Figure 21. Cases of healing by calcified tissue: (A and C) Tooth 11, 18 months and 25 years after injury. (B) Tooth 22, 5 years after injury. (D) Tooth 21, 50 years after injury(2).

5.2. Healing with connective tissue

Healing with connective tissue is the most common response for a root fracture with a displaced coronal piece. Depending on the degree of dislocation, the pulp may be severely stretched or entirely cut. In the case of avulsion, the pulp will be totally cut. If there is no contamination in the gap or inside the fragment, the pulp may undergo repair by revascularization after relocation and splinting. The periodontal ligament is the primary contribution to the healing process, causing the connective tissue produced from its cells to develop into the area of fracture. In some cases, pulpar tissue can develop into the fracture space. The shattered pieces in these situations do not unite, yet the coronal fragment may still be stable. Cementum production may occasionally occur and to some extent join the two fragments (**Figure 22**)(2).

Although at first the pulp in the apical part remains normal, pulp calcification typically develops with time in both fragments. In the same study including 400 teeth with fractured roots, 43% of the teeth healed with connective tissue(2,17).

Figure 22. Two cases of middle third root fractures healed with connective tissue. (A) Tooth 11, 6 years after injury. (B) Tooth 21, 42 years after injury(2).

5.3. Healing with bone and connective tissue

If root fractures happen before the alveolar bone had finished growing, healing with bone and connective tissue usually happens. In general, the apical fragment stays stays at the same place while the coronal fragment erupts regularly during the normal alveolar growth. Both fragments must not join and there should not be any bacteria in the pulp for this to happen. Radiographically, a periodontal ligament gap is frequently apparent around the two pieces (**Figure 23**). The corners of the fragments frequently round off and eventually develop pulp canal calcification. In order to create a new blood supply, blood vessels of the pulp in the coronal fragment usually fuse with the ones of the tissue between the fragments. The blood supply at the apex has not been impacted, so the pulp in the apical segment of the root remains healthy. In the study of 400 teeth with fractured roots, 5% of the teeth recovered with the help of bone and connective tissue(2).

Figure 23. Superior left central incisor that healed with bone and connective tissue, 15 years after injury(2).

5.4. Healing by granulation tissue

If the proximal pulp becomes necrotic and infected, granulation tissue will develop and the fracture does not heal. In most cases, the granulation tissue also penetrates into the bone, providing the impression that the radiolucency is expanding laterally (**Figure 24**). The periapical tissues have a similar inflammatory response as if the root canals were infected. The fracture line can be considered as a new "apical foramen" of the coronal fragment. At the edge of the fracture line, external resorption and remodeling of the cementum may also take place to produce rounded corners(2).

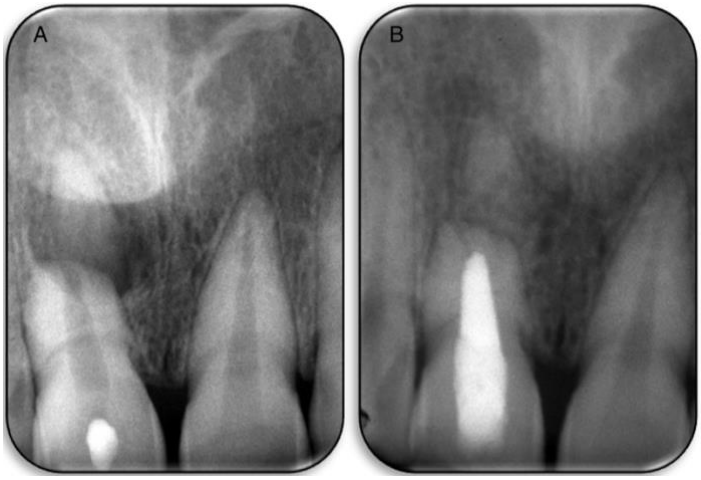


Figure 24. (A) Tooth 11 with interposition of granulation tissue. (B) The tooth is treated with CaOH medication, after a year a hard tissue barrier is formed at the new apex of the coronal segment(2).

II. OBJECTIVES AND HYPOTHESES

1. Objectives

In order to restore endodontically treated teeth, it is common to use intra-radicular posts to support the restoration after significant tissue loss. Two main types of posts are known; metal and fiber posts.

Our main objective is to compare the incidence of root fractures after endodontic treatment with metal and fiber posts.

The second objective is to put in evidence the differences between CaOH and MTA in the formation of a dentin barrier.

2. Hypotheses

H0: The incidence of root fracture is higher with metal post than with fiber post.

III. MATERIAL AND METHODS

1. Eligibility criteria and source of information

The databases used for this systematic review were PubMed (MEDLINE) and Google Scholar. The references used were researches and articles done in English. The date on which the last research was conducted was on December 19th, 2022. Inclusion and exclusion criteria are described in **Table 3** and the research strategy is shown in **Table 4**.

The database searched yielded 2 793 records in PubMed and 108 300 for Google scholar in total. After selecting the different filters according to the inclusion and exclusion criteria, and assessment of the titles and abstracts, 40 articles (PubMed) and 88 articles (Google Scholar) remained. A total of 10 records was included in the literature review after full-text assessment of the articles (**Figure 25**).

Table 3. Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Systematic reviews, RCTs Case reports	Meta-analysis, books
English	Animal studies
Clinical human studies	Articles dated before 2012
Root fractures only	Crown fractures only
Crown and root fractures	

2. Search strategy

Table 4. Description of the research strategy done in the different databases

DATABASE	SEARCH STRATEGY	RESULTS OBTAINED	RESEARCH DATE
PubMed	(Non vital tooth) OR (Devitalized tooth) OR (Pulpless tooth) OR (Endodontically treated tooth) AND (Fiber post) OR (Metallic post)) OR (Cast dowel)) OR (Dowel)) OR (Metal post)) OR (Carbon-fiber post)) OR (Glass-fiber post) OR (Quartz-fiber post) OR (Fiber-reinforced post) OR (Post core system) OR (Post and core technique) AND (Controlled clinical trials) OR (Cohort) OR (Cohort studies) OR (Epidemiologic methods) OR (Clinical trial) AND (Root fracture) (2012-2022)	926	17/12/2022
	(Tooth fracture) AND (Healing)) AND (Prognosis) (2012-2022)	69	18/12/2022
	(Root fractures) AND (Different treatments)) AND (Clinical management)) NOT (Bone)) NOT (Alveolar)) NOT (Mandible)) NOT (Instruments) (2012-2022)	290	19/12/2022
Google Scholar	Incidence of root fracture in endodontically treated teeth post OR placement OR fiber glass post OR metal post OR resistance (2012-2022)	4 590	19/12/2022
	Influence AND prognosis AND survival AND healing AND tooth AND root fracture "root fracture" -bone » (exclusion: bone, must include root fracture (2012-2022)	17 800	19/12/2022
	Possible treatments and management after root fractures treatment "clinical management" -diagnosis (2018-2022)	17 400	19/12/2022

IV. RESULTS

The search flowchart done for this study is shown in **Figure 25**.

Out of the 10 records included in the review, 4 articles were destined to answer the first objective and 6 articles correspond to the second objective. The results of the articles are shown in **Tables 5 and 6.**

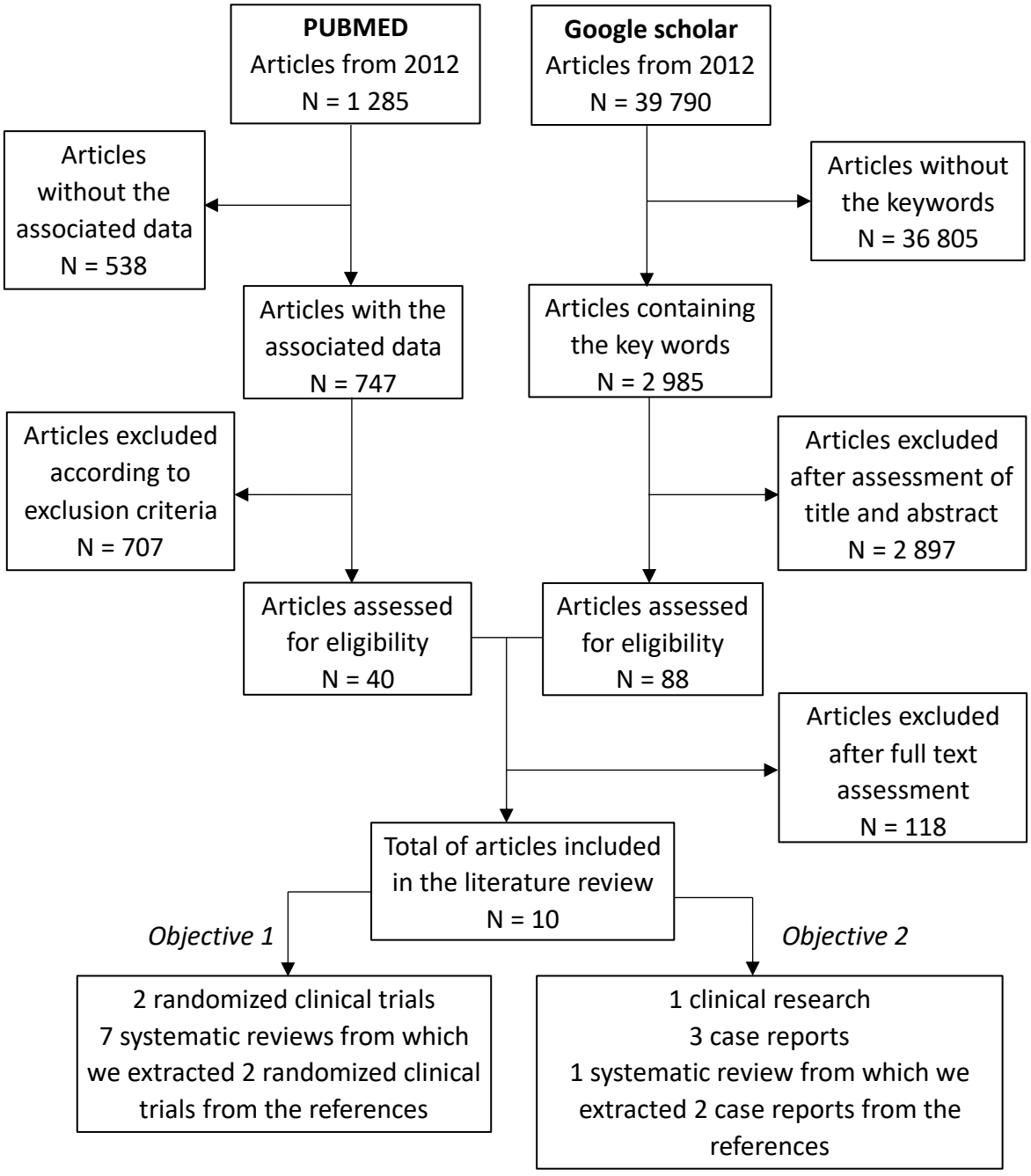


Figure 25. Search flowchart.

Table 5. Results for objective 1.

					FIBER POST			METAL POST		
Study, Year	Follow-up	Def. Rest.	Cement	Coronal wall	N	Failure	Success/ AFR	N	Failure	Success AFR
Gbadebo et al, 2014(19)	1 and 6 months	PFM	Dual-curing resin cement	Minimum 2 mm of ferrule effect	20	0%	Success 100% AFR 0%	20	2.5%	Success 97.5% AFR: 5%
Sarkis Onofre et al 2020(20)	6 months then yearly for 9 years	PFM	Glass FP: self-adhesive resin cement Cast metal posts: self-adhesive cement	No coronal walls or 1 wall in enamel without dentine support (ferrule height 0-0.5 mm)	111	17 failures: 5 crown de-bonding, 7 root fractures 2 post debonding, 1 secondary caries 1 crown and post debonding 1 endo failure	AFR 1.7%	72	6 failures: 1 crown debonding 3 root fractures 1 post debonding 1 crown and post debonding	AFR 1.2%

Cloet et al 2017(21)	1, 3 and 5 years	FCC	Dual curing resin cement	Enough tissue left: Minimum 2 dentin walls (>2mm) and wide pulp chamber Insufficient tissue left: < 2 walls (<2mm) and small pulp chamber	65 PFP 26 CFP = 91	PFP: 6 AF 7 RF CFP: 2 AF 3 RF	Success CFP 87.8% PFP 81.6% Survival CFP 92.1% PFP 91.4%	104	14 AF 10 RF	Success 86.9% Survival 91.2%
Sterzenbach et al 2012(22)	3, 6, and 12 months then yearly for 7 years	PFM	Self- adhesive resin cement	< 2 walls of the crown	41	1 cervical root fracture 1 middle root fracture 1 enhanced mobility 1 core fracture	Survival 90.2%	46	3 endo failures	Survival 93.5%

Def. Rest.: definitive restoration, AFR: annual failure rate, PFM: porcelain fused to metal, FP: fiber post, FCC: full ceramic crown, PFP: prefabricated fiber post, CFP: cast fiber post, AF: absolute failure, RF: relative failure.

Table 6. Results for objective 2.

Study, year	Type of study	Tooth, patient	Radiography Diagnostic test	Extent and type of fracture	Endodontic management	Post and adhesion	Fragment adhesion	Splinting	Follow-up
Sivagami et al, 2014(23)	Case report	11 11-year-old female	IOP N/A	Oblique, from mesial to distal	RCT and post	Glass fiber reinforced post Etchant and adhesive: N/A Cement: Flowable composite	37% phosphoric acid 30s with adhesive and composite resin	Splinting with flowable composite for 2 weeks	1 week, 4 months and 9 months
Akhtar et al, 2014 (24) **(Case 1)**	Case report	11 34-year-old male	IOP N/A	Middle third in buccal until cervical third in palatal	RCT and post placement with CaOH	Fiber post Adhesion N/A	Cement: Glass ionomer	None	1 week, 1 month, 6 months then every 6 months

									until 2 years
Raj et al, 2017(25) **(Case 1)**	Case report	11 29-year-old male	IOP Electric, cold and heat tests negative	Horizontal root fracture in the apical third	RCT and post	Fiber reinforced composite post Etchant: 37% phosphoric acid Silane coupling agent Cement: dual cure resin cement	N/A	Rigid splinting with 0.7 mm stainless steel wire and composite resin	3 months 1 year
Kulkarni et al, 2013(26)	Case report	21 10-year-old female	IOP N/A	Fracture line extending apical to the level of crest of the interdental alveolar	RCT and post with CaOH	None	37% phosphoric acid 30s with adhesive and	None	Every 2 months for 1 year

				bone, on the mesial half of the tooth			composite resin		
Choi et al, 2017(27) **(Case 1)**	Case report	11 33-year-old male	IOP Vitality tests normal	Horizontal fracture in middle third	RCT and post with CaOH	None	None	None	2 years
Kim et al, 2016(28)	Clinical research	19 teeth 66,7% male 33,3% female 12-65-year-old	IOP Mobility test, electric and cold test	Horizontal intra-alveolar root fracture	RCT with MTA	None	N/A	Resin wire splint	3 months – 7 years Mean: 3 years 10,5% failure

IOP: intraoral periapical, MTA: mineral trioxide aggregate, N/A: not applicable

V. DISCUSSION

To answer our first objective, we included four randomized clinical trials from Gbadebo et al.(19), Sarkis-Onofre et al.(20), Cloet et al.(21), and Sterzenbach et al.(22), which compared the success and failure rates of diverse kind of posts in ETT. None of them found a significant clinical difference between metal and fiber retainers, which contradicts some studies considered too old to be included in this study. Indeed, King et al.(29), found higher success for metal posts while other studies found the opposite, according to a systematic review by Marchionatti et al.(30) The period of evaluation thought to be one explanation of these discrepancies but only Gbadebo et al(19). had a follow-up period shorter than one year. Cloet et al.(21), Sterzenbach et al.(22), and Sarkis-Onofre et al.(20) are respectively 5, 7 and 9-year follow up studies.

Gbadebo et al.(19) is the only one of our studies to present 100% of success for fiber post compared to 97,5% for metal post. This is explained by its short evaluation period but also by the teeth included that had at least 2 mm of coronal dental tissue, which is a clinical relevance for the prevention of root fracture caused by posts(31). This factor could also explain the poor results obtained for fiber posts by Cloet et al.(21), as they were only cemented on tooth with insufficient tissue left whereas metal posts were fixed on teeth with both sufficient and insufficient tissue left. In fact, when both type of posts were compared using teeth with no coronal walls remaining, like in the study of Sarkis-Onofre et al.(20), both annual rate failures were considered similar, with a slight but non-significant increase of root fractures for fiber posts.

Finally, concerning the type of failure, we see that Cloet et al.(21) made a difference between absolute failures, such as root fractures and other failures that resulted in tooth extraction, and relative failures, which included failures that could be restored. Even though no clinical differences were significantly made with this study, we can observe that there were more absolute failures regarding

metal posts than fiber posts. This concords with the systematic review of Schwartz et al.(31) that states that metal posts tend to cause irreversible failures whereas fiber posts then to provoke failures more likely to be restorable. If we keep the same criteria regarding failures, in the study of Sarkis-Onofre et al.(20), metal and fiber posts caused three and seven absolute failures respectively. Sterzenbach et al.(22), on the other hand, observed two root fractures for fiber posts and none for metal posts. These results contradict Cloet et al.(21) and can be explained once again by the poor ferrule effect of the teeth used for the studies.

Regarding the second objective about the clinical management of a root fracture, only five case reports and one clinical study could be included in this review as there were not any randomized clinical trials conforming to the inclusion criteria.

All of our case reports concerned maxillary central incisors that were treated with RCT and fiber posts, three of them added calcium hydroxide (CaOH) medication between appointments(24,26,27) and they all concluded with a successful management of the fracture with a follow-up period between 1 and 7 years. Two horizontal root fractures were located in the middle part of the root(27,32), one was located apically(25) and three were oblique root fractures that needed exposure by mucoperiosteal surgery(23,24) or orthodontic extrusion(26).

All of the included cases used intraoral periapical radiographs and not any three-dimensional imaging techniques, such as CBCT, which would have enabled a clearer assessment of the fracture without superimposition of structures(3).

All coronal fragments were found still attached to the rest of the tooth. When they were slightly mobile, they were splinted with resin(23) or metal(25) splints except for Kulkarni et al.(26), where splinting was not mentioned. When the mobility was severe, the fragment was detached on purpose and conserved

in saline water like in the study of Sivagami et al.(23), however, Akhtar et al.(24) did not specify which storage medium was used. Some researchers studied the influence of the storage medium on the quality of reattachment of the fragment and concluded that less fractures were observed in teeth rehydrated with saline water, distilled water or milk.(33) For Jalannavar et al.(34), the best results were obtained when the teeth were rehydrated with tooth mousse with Recaldent. In fact, maintaining the fragment's level of moisture guarantees a stronger bond as the dentin collagen fibers will not completely collapse(35).

Kim et al.(28) is the only clinical study of this review, it treated 22 teeth with MTA, and had an averaged follow-up period of 3 years. Failure was considered when presence of sign and/or symptoms by the patient and when granulation tissue without healing was seen on radiographic examination. 2 cases (10,5%) fulfilled these criteria. In this study, only the proximal segment was treated endodontically with MTA. CaOH is a known alternative, but authors observe that it takes time for this compound to create a dentin barrier(36), which seems to appear around 6 months, according to Bakland et al.(37)

Additionally, CaOH requires numerous visits due to the risk of infection, and because of its proteolytic effect, a prolonged exposure may weaken the dentin.(38,39) Moreover, study from Andreasen et al.(38) showed that teeth resisted better to fracture when treated with MTA compared to CaOH. Finally, a systematic review comparing calcium hydroxide with MTA concluded that MTA appears to overcome the shortcomings of CaOH but won’t replace it completely in the everyday practice because of the lack of long-term information regarding the material(37).

VI. CONCLUSION

For our first objective, all of our sources concluded that there are no significant differences in the clinical performance of fiber and metal posts. However, the amount of tissue left and the ferrule effect are important factors for the success of the endodontic treatment. Moreover, studies show that when the teeth restored are similar in terms of restorability, the failure pattern of fiber posts is more advantageous compared to metal posts. Thus, both types of posts can be used in the dental office but fiber posts are promising for the future.

Regarding our second objective, after a trauma, splinting the mobile segment is necessary in order to improve the healing process of the dental piece. When the fragment is detached, a medium similar to saline water or saliva should be preferred. CaOH can be used between appointments to strengthen the tooth cicatrization but it appears that MTA shows potential as a viable alternative to calcium hydroxide for addressing various healing complications related to dental pulp and periodontal tissues after trauma. However, the lack of long-term clinical studies currently prevents definitive conclusions about the safety and effectiveness of this new procedure. It is necessary to conduct randomized clinical trials to compare the outcomes of both materials.

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