Review Article

Vertical root fracture: Biological effects and accuracy of diagnostic imaging methods

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Abstract

This review assessed the most up-to-date literature on the accuracy of detecting vertical root fractures (VRFs] using the currently available diagnostic imaging methods. In addition, an overview of the biological and clinical aspects of VRFs will also be discussed. A systematic review of the literature was initiated in December of 2015 and then updated in May of 2016. The electronic databases searched included PubMed, Emabse, Ovid, and Google Scholar. An assessment of the methodological quality was performed using a modified version of the quality assessment of diagnostic accuracy studies tool. Twenty-two studies were included in this systematic review after applying specific inclusion and exclusion criteria. Of those, 12 favored using cone beam computed tomography (CBCT) for detecting VRF as compared to periapical radiographs, whereas 5 reported no differences between the two methods. The remaining 5 studies confirmed the advantages associated with using CBCT when diagnosing VRF and described the parameters and limitations associated with this method, but they were not comparative studies. In conclusion, overwhelming evidence suggests that the use of CBCT is a preferred method for detecting VRFs. Nevertheless, additional well controlled and high quality studies are needed to produce solid evidence and guidelines to support the routine use of CBCT in the diagnosis of VRFs as a standard of care.

Key words: *Accuracy, cone beam computed tomography, periapical radiographs, vertical root facture*

INTRODUCTION

Vertical root fractures (VRFs) present extremely challenging diagnostic tasks in dental practice. They are defined as fractures that extend longitudinally from the root apex to the crown.[1] The prevalence of VRFs after root canal treatment varies between 3.7% and 30.8%.[1,2] Moreover, VRFs can also be caused by physical and occlusal trauma, pathological resorption, and repetitive parafunctional habits in addition to iatrogenic complications during and after endodontic treatment.[1]

The detection of these fractures is usually challenging for clinicians, especially when the results from the typical clinical diagnostic tests are inconclusive. In most clinical settings, clinicians rely on findings from both clinical and radiographic tests to make the diagnosis. Unfortunately, some patients must still undergo exploratory surgery to determine if a VRF

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has actually occurred. Thus, there is a pressing need to find less invasive and more reliable methods to diagnose VRFs. Diagnostic imaging plays a pivotal role in the diagnosis of VRFs. Periapical radiographs (PRs) at different horizontal and vertical positions have been used for many years to aid in the diagnosis of VRFs because of their high spatial resolution, however, these two-dimensional (2D) images are inherently plagued with overlapping structures, which makes the diagnostic task especially challenging. Moreover, fractures are generally difficult to detect radiographically unless the X-ray beam is parallel to the line of fractures.[3] Therefore, clinicians often have to rely on indirect radiographic signs, such as perilateral radiolucencies and angular resorption of the crestal bone, for the indication of VRFs.[3] Cone beam computed tomography (CBCT) is currently being utilized with increasing frequency to detect VRFs because it provides submillimeter spatial resolution and three-dimensional (3D) visualization.

This review assessed all of the up-to-date literature regarding the accuracy of the currently available diagnostic imaging methods used to detect VRFs. In addition, an overview of the biological and clinical aspects of VRFs is also presented.

MATERIALS AND METHODS

The methodology used in this systematic review will be described in the following sections: (1) studies considered for this systematic review, (2) a literature search strategy, (3) the selection criteria, and (4) the target condition.

Types of studies

Case reports, case-series, clinical studies, *in vitro* and *in vivo* studies, and comparative studies were considered for this review.

Literature search strategy

For this review, the following electronic databases were searched: PubMed, Embase, Ovid, and Google Scholar. The following key words and subject heading terms were used in combination with the listed Boolean operators: “Cone Beam Computed Tomography,” OR “CBCT,” AND “Vertical root fracture,” OR “VRF,” AND “Diagnosis.” After the studies that matched these search terms were identified, duplications and unrelated studies were removed. The following inclusion and exclusion criteria were applied to narrow the focus on the appropriate research studies.

Selection criteria

Inclusion criteria

- Studies that mention CBCT as a diagnostic tool for the detection of VRFs
- *In vitro* or *in vivo* studies performed on human permanent teeth
- Clinical studies that have verified VRFs by clinical and surgical exploration
- Studies that have mentioned all exposure parameters for both radiographs and CBCT (e.g., kVp, mA, field of view, voxel size, and resolution) for image acquisition
- Studies comparing CBCT and different digital and conventional radiographic techniques
- Studies in which accuracy parameters, such as sensitivity, specificity, or receiver operating characteristic curves, were used (i.e., at least 1 of them).

Exclusion criteria

- Unrelated studies (e.g., studies on jaw fractures, systemic disease, or regenerative endodontics)
- Studies on horizontal root fractures
- Studies focused on the management of tooth fractures
- Studies that mention CBCT to evaluate manifestations other than VRFs
- Studies associated with cracked teeth and craze lines.

Target condition

The target condition was VRFs in any permanent, endodontically, or non-endodontically treated tooth. After applying the above strategy, only 22 studies met our criteria and were thus included in this systematic review [Figure 1].

Biological effect

VRFs can be either complete or incomplete fractures of the tooth and usually occur in patients over 40 with endodontically treated teeth.[4] A complete VRF is a catastrophic event for a patient, and frequently can only be treated by extraction of the affected tooth. A VRF is more likely to occur in a tooth that has been previously extensively treated, such as a tooth with a compound restoration, a tooth that had too much dentine removed during a root canal treatment, or a compaction of a canal filling material during an endodontic treatment.[5] Preventive measures have been suggested by endodontists to reduce the possibility of developing a VRF during

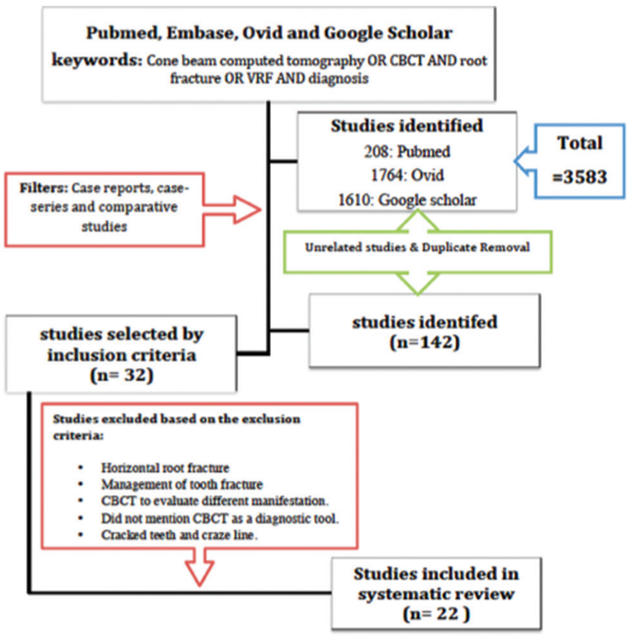

Figure 1: Flow chart of the search strategy used in this review

and after treatment. This includes using careful and conservative endodontic therapy approaches, such as performing conservative access cavities and avoiding extensive and over-tapered root canal preparations.[6,7] In addition, patients involved in sports or suffering from bruxism are recommended to use mouth guards when playing the sport of choice or sleeping, respectively. Furthermore, instructing the patient to avoid chewing, particularly hard items, such as ice or other hard foods, is important until these teeth receive the proper coverage after root canal treatment.[8]

Khasnis *et al.* investigated the difficulties in detecting VRFs in both endodontically treated and healthy teeth. Yet, clinical detection of VRFs is likely to be done by an endodontist rather than a general dentist since VRFs usually involve endodontically treated teeth.[4] Khasnis *et al*. discussed and recommended the use of CBCT due to its accuracy in detecting VRFs.

Llena-Puy *et al*. conducted a study investigating the theory that endodontically treated teeth were more susceptible to VRFs than healthy teeth.[9] They examined endodontically treated teeth with VRFs and found that the mean time for teeth to develop a VRF was 54 months despite the presence or absence of previous endodontic work.

Mullally and Ahmed studied the difficulties associated with diagnosing VRFs as well as the resulting challenges associated with tooth loss. They stated that VRFs should be considered whenever a periodontal crisis is found in an unusual site.[8] As such, early detection and extraction of the affected teeth will maintain proper alveolar bone levels for future implants.[4] On the other hand, other researchers are still trying to produce innovative ideas as alternative treatments for VRFs. For example, Haddrosek and Dammaschke reported the case of a 78-year-old woman who presented with a VRF. Her existing root canal filling was replaced by a calcium-based cement, and the tooth was stabilized with a composite and titanium splint after replantation. At a 24-month follow-up, the tooth was stable, and the gums had reattached to the tooth.[10] In addition, Nizam *et al.* reported that adhesive cementation of VRFs followed by intentional replantation can be a successfully alternative treatment plan for extraction in maxillary single-rooted teeth.[11]

Psychological effect of losing teeth

Unfortunately, the most common treatment option for VRFs seems to be extraction.[2,12] Thus, losing teeth can be a tragic life event; indeed, the long-term emotional effect may be underestimated. It not only affects the financial status of the patient it also involves pain and sometimes depression.

Davis *et al*. reported that most of the patients who had lost their teeth had suffered from emotional difficulties in terms of accepting their tooth loss. These patients were also more likely to have low confidence, feel inhibited in daily activities, and be less able or willing to accept the change in their facial shape due to the extraction.[13]

Similarly, Roohafza *et al.* reported an association between psychological factors such as depression, anxiety, and stress with tooth loss.[14] In addition, Okoje *et al.* also reported that only 40.9% of the patients were prepared for the emotional effect associated with the loss of their teeth. The emotional effects following tooth loss were reported as sadness, depression, feelings of aging, and the feeling that something was lost from their body; only a few respondents reported feeling unconcerned about their tooth loss.[15]

When considering the relevance of tooth loss from a psychological perspective combined with the biological effect of losing a tooth due to a VRF, we realize that the clinician and patient need to approach the problem holistically and not just from a purely clinical standpoint. For example, certain available treatment options may help the patient better transition to accept their tooth loss.

Symptoms and diagnosis

A VRF can cause a patient severe, deep, traumatic pain, which may be described as shooting or throbbing; moreover, this pain is usually surprising and frustrating. As previously indicated, there is a higher prevalence of VRFs amongst root canal treatment patients, though it is not the only procedure that can leave teeth vulnerable. Trauma, pathological resorption, and repetitive parafunctional habits are other predisposing factors.[16] In addition, the number of canals per root, and the type of the final irrigation and obturation materials can all be factors that influence the prevalence of VRFs in endodontically treated teeth.[17,18] Pain alone or a single event cannot explain the presence of VRFs as other potential causes can cause similar symptoms. Thus, ruling out these other potential issues may help in the diagnostic procedure to ensure that the patient receives the appropriate treatment more quickly.

Seo *et al.* analyzed the characteristics and the associated factors of fractured teeth to better understand and aid in correctly diagnosing these fractures. Their results revealed that fractured teeth displayed sensitivity to a standard bite test (82%). Most VRFs occurred in heavily restored teeth (72%) as compared to healthy ones (28%). The use of non-bonded restorations (i.e., gold or amalgam) increased the risk of VRF. The overall conclusion of their study was that the bite test was the best method for reproducing symptoms.[19]

Interestingly, there are demographic factors associated with VRFs. Teeth with VRFs have fractures that can extend through enamel, dentin, pulp, and down the long axis of the tooth. Cohen *et al*. investigated several factors and looked for statistical correlations for the presence of VRFs. Their findings indicated that VRFs are statistically more prevalent in mandibular molars and maxillary premolars. They can mostly be associated with pain to percussion, extensive restorative work, periradicular bone loss, and seem to occur more often in females and older patients.[5] Therefore, clinicians should remain aware of these factors when attempting to assess undiagnosed cases of VRFs.

In addition, to correctly diagnose VRFs, the clinician needs to understand the pathogenesis of the condition.[12] Clinical presentation and 2D radiographs were both deemed to be inadequate for confirmation of the diagnosis, especially when the correlation between the signs and symptoms and the severity of the symptoms are not sufficient for a definite diagnosis.[1,20] Hence, new approaches and methods are needed to better improve our diagnostic approach for VRFs. Moreover, treatment of root fractures depends on a number of factors, such as the position of the fracture line, mobility of the tooth, and pulpal status. Thus, treating such cases requires a multidisciplinary approach in order to achieve complete rehabilitation of the affected tooth.

Cone beam computed tomography as a novel approach to detect vertical root fractures

Diagnostic imaging is continually evolving and provides consistently accurate images and information. CBCT is one such example of a relatively new imaging technique that has overcome some of the inherent limitations of conventional radiographs, such as overlapping structures and limited spatial and contrast resolution.[16] Consequently, clinicians have gravitated toward this imaging method to assist them in challenging diagnostic tasks such as detecting VRFs.[1]

There is growing evidence that CBCT has superior accuracy in detecting VRFs as compared to conventional radiographs.[1,16] However, this accuracy is still limited for detecting small hairline fractures as compared to thick and displaced VRFs.[9] In addition, the specificity and sensitivity of the ability to detect VRFs varies depending upon several factors, including the make and model of the CBCT unit used.[21] Moreover, root canal filling materials usually create image artifacts that deteriorate the quality of the images, thereby reducing their accuracy. In 2015, Valizadeh *et al.* investigated this issue and tested teeth with posts that were scanned in five different positions. They concluded that the center-scanned position was found to be the only position that had reliable sensitivity for detecting VRFs.[22] Moreover, note that advances in radiology must also be accompanied by advanced user-level expertise with the specific diagnostic task.

The accuracy of cone beam computed tomography for detecting vertical root fractures

Before the introduction of volumetric CBCT imaging into the field of dentistry, 2D conventional PRs were routinely used for the task of detecting VRFs despite their limitations. Other 3D imaging techniques that were explored for this diagnostic task included conventional computed tomography (CT) and tuned-aperture CT (TACT). However, the cost and radiation risk associated with these 3D imaging modalities limited their use and application.[1] In 2010, Varshosaz *et al.* reported that 3D images from CBCT were significantly superior at detecting VRFs as compared to conventional PRs.[1] Then, in 2012, Khedmat *et al.* also concluded that CBCT is more accurate and sensitive than digital radiography (DR) in the detection of VRFs ($P < 0.05$).[23] More recently, Komatsu *et al.* investigated the 3D images from CBCT of 32 maxillary pre-molars, of which 16 had a fractured root and 16 did not. They found that the CBCT images offer a high degree of accuracy in detecting teeth with VRFs.[24] Takeshita *et al.* also reported higher sensitivity and specificity for CBCT images as compared to PRs based on the results of their study, which demonstrated a significant increase in the accuracy of CBCT with and without a metal post (MP) (0.953 vs 0.753) and (0.778 vs 0.956), respectively.[16]

The issue of an accurate diagnosis of VRF is highlighted repeatedly in the literature due to the critical and urgent nature of obtaining an early diagnosis to prevent treatment complications and improve clinical outcomes. Imaging plays a pivotal role in this diagnostic task, however, the risk of radiation exposure remains a concern to both clinicians and patients alike. With regards to the radiation risk associated with this technique, CBCT imaging used especially for endodontic purposes can be modified to deliver a reduced radiation dose that carries a significantly lower risk when compared to other volumetric imaging options.[16] However, there is always a tradeoff between radiation exposure and image quality. Thus, the goal of much of the current research is to reduce the radiation dose of the CBCT imaging while maintaining imaging quality. One technique was to decrease the level of resolution to some degree while still balancing the need for clarity.[1] However, there is still ongoing debate whether CBCT can be used as the standard of care for detecting VRFs.[25]

RESULTS

Twenty-two studies were included in the systematic review after applying the inclusion and exclusion criteria. Of those, 12 favored using CBCT for the detections of VRFs as compared to periapical radiographs, whereas 5 reported no differences between the two techniques. The remaining 5 studies confirmed the advantages of using CBCT in diagnosing VRFs and looked into parameters and limitations associated with this diagnostic procedure, but they were not comparative studies. A description and summary of all included studies are presented in Tables 1 and 2.

DISCUSSION

This systematic review described the best way to image and detect VRFs based on the best current literature.

Table 1: Summary of included studies type

Type of study	Number of studies	Reference No.
Case report	1	[30]
Case series	5	[31, 32, 44, 45, 48]
Clinical study	2	[20, 33]
In vitro study	12	[1, 16, 23, 34-39, 41-43]
In vivo study	2	[21, 40]
Total	22	

Twenty-two studies were considered in this review after applying the inclusion and exclusion criteria, however, these studies have a high level of heterogeneity. This heterogeneity may come from several factors, including the size of examined samples; the different CBCT types used; the different digital or conventional PRs used; the different testing parameters; whether the study was conducted *in vitro*, *ex vivo*, or in clinical settings; the population included in each study; and the expertise of the study evaluator.

Several systematic reviews and meta-analyses had been conducted, and many have reached controversial conclusions regarding the use of CBCT for detecting VRFs [Table 3]. The recently published review by Chang *et al.* concluded that there is still deficiency in the current evidence to support the use of CBCT as a reliable method to diagnose VRFs.[25] In addition, the systematic reviews of Corbella *et al.* and Rose *et al.* also concluded that CBCT has no superiority compared to conventional radiographs for detecting VRFs, thereby indicating that there is still not sufficient evidence to advocate the use of CBCT as a reliable tool to diagnose VRFs.[26,27] In contrast, Talwar *et al.* reported that CBCT has better sensitivity and specificity compared to PRs in detecting VRFs.[28] Furthermore, Long *et al.* also reported that CBCT has a high diagnostic accuracy for VRFs.[29] This clearly shows discrepancies in the conclusions reached by systematic/meta-analysis reviews to date. This may be mainly due to the differences in applied inclusion and exclusion criteria in addition to the authors' opinions on the statistical tests used. When examining our included studies individually, 12 studies favored the use of CBCT as compared to PRs in detecting VRFs,[1,16,21,23,30-37] whereas 5 studies concluded that there were no significant differences between CBCT and PRs in detecting VRFs and stated that both imaging modalities has their own set of limitations.[38-42] In addition, the remaining 5 studies were not comparative studies; however, they investigated the usefulness of CBCT for the detection of VRFs while using different parameters and conditions. They all agreed

Table 2: Description and summary of all included literature data

#	Authors	Year	Study design	Sample size	Method summary	Conclusion
1.	Ezzodini *et al.*[37]	2015	*In vitro*	80	Eighty extracted single maxillary and mandibular teeth were used after VRF was induced in half of these teeth. The other half was left without fracture as control. All teeth were examined by CBCT and PA radiographs	The sensitivity and accuracy of CBC in detecting VRFs was significantly better than PA radiographs
2.	Chavda *et al.*[40]	2014	*In vivo*	21	Twenty one hopeless teeth were scanned by CBCT and digital radiographs (DR) to compare their accuracy. Teeth were finally extracted and examined visually by a microscope. Thirteen examiners under standard conditions viewed images twice	1-DR and CBCT had poor sensitivity 2-DR and CBCT have high specificity and similar accuracy 3-Fracture width does not affect the detection of VRF
3.	Takeshita *et al.*[16]	2014	*In vitro*	20	Twenty root canal treated teeth received metal posts (MPs). Artificial fractures were created in 10 teeth, and they were all examined with CBCT and periapical radiography (PR). The sample consisted of periapical radiography with post and without post, and CBCT with post and without post; each group with 5 fractured and 5 non-fractured teeth	1-CBCT was more accurate than conventional periapical radiography in detecting VRF 2-MPs did not influence the diagnostic accuracy of fractures for either imaging methods
4.	Jakobson *et al.*[41]	2014	*In vitro*	100	One hundred human, single-rooted endodontically treated premolars were divided into 5 groups with different VRF orientations and with or without post. All groups were scanned by 2 CBCT systems (NewTom® 3G and i-CAT Next Generation®) and digital radiography (DR)	1-The presence of metallic posts did not influence the sensitivity of any detecting method 2-The fracture line orientation may influence VRF detection 3-Both CBCT and DR have similar sensitivity for detecting VRFs in teeth with MPs
5.	Junqueira *et al.*[38]	2013	*In vitro*	18	Eighteen single-rooted human teeth were endodontically treated, prepared for MPs. Teeth were artificially fractured. The samples were subjected twice (with and without posts) to digital periapical radiography at 3 different angles and to CBCT examinations, The images were evaluated by 3 oral radiologists	No significant differences were observed between CBCT and periapical radiography in the detection of VRFs
6.	Zhang *et al.*[30]	2013	Case report	1	Comparing CBCT with PRs in detecting VRFs in one case	CBCT was more accurate in diagnosing root fracture than conventional PRs
7.	Bechara *et al.*[43]	2013	*In vitro*	66	All were treated endodontically. One-half of the roots were fractured, resulting in 2 root fragments, which were then glued together. Teeth were scanned with 180° and 360° motions and the number of basis images were doubled	1-Only the specificity improved by the increased rotation and doubling of images 2-doubling the images reduced the false positive rates
8.	Da Silveira *et al.*[42]	2013	*In vitro*	60	Sixty rooted teeth and 20 teeth were endodontically prepared and obturated with gutta-percha, 20 had a MP after the filling, and 20 had no preparation. Then further divided into two groups: experimental and control. The teeth from the experimental group were fractured Teeth were then radiographed with PRs in 3 different horizontal angles and scanned with CBCT in 3 different voxels	1-Due to the insignificant difference between CBCT and conventional radiographs, PRs are encouraged as the first approach 2-Different CBCT voxels should be used according to the root canal status; voxels of 0.3 for unfilled canals and 0.2 for filled ones

Contd...

Table 2: Contd...

#	Authors	Year	Study design	Sample size	Method summary	Conclusion
9.	Kajan *et al.*[31]	2012	Case series	10	Conventional PR and CBCT images of 10 cases, each with a suspected diagnosis of root fractures was included. A radiologist who was unaware of the clinical symptoms of the patients evaluated images. Then, the radiologist and an endodontist, aware of patient symptomatology, performed a second evaluation by comparing these images with clinical findings. Final patient results were based on direct visualization of each extracted tooth and its colorization	1-CBCT shows good accuracy in detecting VRFs verses PRs 2-A combination of clinical symptoms and images can lead to an accurate diagnosis
10.	Metska *et al.*[20]	2012	*In vivo*	39	Thirty-nine endodontically treated teeth suspected of VRFs from 39 patients were included. No fracture line was visible in periapical radiographs. Detecting of VRFs were done using 2 CBCT systems (NewTom 3G and 3D Accuitomo 170).Three observers evaluated the CBCT images independently and twice	3D Accuitomo 170 has superior results compared to NewTom 3G in detecting VRFs. And therefore, reproducibility and accuracy in VRF detection depend on the CBCT system used
11.	Khedmat *et al.* (23)	2012	*In vitro*	100	100 extracted teeth were prepared and divided into 2 experimental (fractured teeth) and 2 controls and were viewed with digital radiography (DRs), CBCT, and Multidetector Computed Tomography (MDCT). Specificity and accuracy of each imaging technique in the presence and absence of gutta-percha were calculated and compared	1-CBCT was the most sensitive method in detecting VRFs 2- Unlike MDCT, the accuracy, specificity, and sensitivity of CBCT and DRs were reduced by the presence of Gutta-Percha 3-MDCT can be used as an alternative to CBCT in endodontically treated teeth
12.	Fayad *et al.*[44]	2012	Case series	7	Seven cases are presented to demonstrate the use of CBCT in detection of VRFs in endodontically treated teeth	CBCT can provide valuable additional diagnostic information in the detection of VRFs and may help prevent unnecessary treatment
13.	Kambungton *et al.*[39]	2012	*In vitro*	60	Sixty extracted, single-rooted human teeth were divided equally into two groups: a control group of 30 teeth and an induced fracture group of 30 teeth. All teeth were randomly placed into sockets in six dry mandibles. Each tooth was imaged by three modalities: CBCT, intraoral digital radiography and intraoral F-speed film	There was no significant difference between intraoral film, a high-resolution complementary metal oxide semiconductor digital imaging system and CBCT in detecting vertical root fractures in mandibular single-rooted teeth
14.	Wang *et al.*[33]	2011	Clinical study	135	One hundred and thirty five teeth with clinically suspected VRFs underwent conventional PR, CBCT and eventually surgical exploration, to confirm the presence or absence of VRF. Among the 135 teeth, 86 were non-endodontically treated teeth and 49 were endodontically treated teeth. Two oral radiologists independently analyzed the dental radiographs and CBCT images	1-CBCT is more accurate than conventional PR in the detection of root fractures 2- Both the sensitivity and specificity of PR were not influenced by the presence of root canal fillings. Yet, the sensitivity of CBCT was reduced in the presence of root canal fillings but its specificity remained unaffected
15.	Edlund *et al.*[20]	2011	Clinical study	32	Thirty-two teeth in 29 patients with clinical signs and symptoms suggestive of VRF were included in the study. They underwent a limited area CBCT evaluation. Two oral radiologists assessed the presence or absence of VRF through sequential evaluation of the three-dimensional volume	This study revealed the superior diagnostic accuracy of CBCT for detection of VRF

Contd...

Table 2: Contd...

#	Authors	Year	Study design	Sample size	Method summary	Conclusion
16.	Tang *et al*.[48]	2011	Case series	2	Two cases, endodontically treated and non endodontically treated were radiographed with PR, and scanned by CBCT (3DX Accuitomo) at 80 kV and 5.0 mA and exposure time was 17.5 s. Final diagnosis was confirmed by direct visualization of the extracted tooth	The two cases reported here demonstrate that the use of (CBCT) successfully diagnoses VRFs even on teeth without representative clinical and periapical radiographic findings
17.	Zou *et al*.[32]	2011	Case series	3	This report presents a set of 3 cases in which 1 endodontically treated and 2 nonendodontically treated mandibular molars were diagnosed with VRFs based on findings from clinical, radiographic, and CBCT examinations	CBCT provided useful information in diagnosing VRFs in both endodontically treated and nonendodontically treated teeth, especially when VRFs could not be confirmed by clinical findings and PRs
18.	Özer *et al*.[45]	2011	Case series	3	The 3 case reports presented here describe the diagnosis and treatment of vertically fractured teeth that had been previously treated endodontically. CBCT was used for diagnostic imaging to detect VRFs. Teeth were carefully extracted and extraorally treated by using a self-etching dual-cure adhesive resin cement, and intentional replantation was done after reconstruction (instead of extracting the tooth)	Extraoral bonding of fractured segments and intentional replantation of teeth after reconstruction provide an alternative treatment to extraction, especially for anterior teeth. Computed tomography-assisted VRF diagnosis is helpful in detecting fractures; however, higher-resolution tomography units providing better image quality would be a better choice for improved visualization of these fractures
19.	Varshosaz *et al*.[1]	2010	*In vitro*	100	Fifty of 100 teeth were subjected to VRF and then placed in dry mandibles. 3D scans were obtained for all teeth, and conventional radiographs were used as control images. All the images were assessed by 6 observers, who determined the presence of root fractures by using a 5-point confidence rating scale	CBCT was shown to be significantly better than conventional periapical radiography for diagnosis of vertical root fractures in vitro. As observing a slice of 0.16 mm in thickness in different axes (sagittal, coronal and axial) is possible with no superimposition
20.	Ozer *et al*.[34]	2010	*In vitro*	80	Teeth divided into 4 groups, 3 experimental and 1 control. The teeth in experimental groups were artificially fractured and fixed together with different thicknesses of 0.2 mm (0.2-mm VRF group), 0.4 mm (0.4-mm VRF group), and smaller than 0.2 mm (crack group). Teeth in control group were kept intact. Three observers evaluated the DR and CBCT images in terms of accuracy for VRF detection	The results of this study showed that CBCT scans are effective for detecting VRFs of smaller thicknesses compared with DR
21.	Kamburoglu *et al*.[35]	2010	*In vitro*	60	The VRFs were created in 30 teeth, and 30 intact teeth served as control samples. Twice, 4 observers evaluated all images. Images were taken by 2 cone-beam CT units [NewTom 3G (small FOV), Iluma (ultra/low resolution)] and an intraoral CCD sensor in the detection of VRF	1-Both ultra-resolution Iluma and NewTom 3G images performed better than low-resolution Iluma and intraoral CCD images in the detection of VRF
22.	Hassan *et al*.[36]	2009	*In vitro*	80	Teeth divided into four groups. The teeth in groups A and B were artificially fractured, and teeth in groups C and D were not. Groups A and C were root filled. Four observers evaluated the CBCT scans and PR images	The accuracy of CBCT is higher than PRs for detecting VRF

Table 3: Description and summary of all current systematic and meta-analysis reviews in the literature

#	Authors	Year	Study design	Sample size	Method summary	Conclusion
1.	Chang *et al.*[25]	2016	Systematic review	4	A systematic review of *in vivo* clinical diagnostic literature (initial search December 2014, updated August 2015)	Due to the inaccuracy of the sensitivity, specificity, positive and negative predictive values plus the bias in some included studies; this systemic review cannot conclude using CBCT as a reliable method to detect VRF
2.	Talwar *et al.*[28]	2016	Systematic review/ Meta-analysis	11	The search included studies conducted from January 1990 to November 2013 in PubMed, Embase, and Cochrane Central Register of Controlled Trials	Sensitivity and specificity of CBCT is better with unfilled teeth when compared to filled roots (root canal treatment)
3.	Rosen *et al.*[27]	2015	Systematic review/ Meta-analysis	6	A systematic search was performed to identify studies evaluating the use of CBCT and its efficacy. The identified studies were subjected to strict inclusion criteria followed by an analysis using a hierarchical model of efficacy (model)	Only 10% of the included studies mentioned the efficacy of CBCT in diagnosing VRF. Therefore, a cautious and rational approach is advised when considering CBCT imaging for endodontic purposes (due to limited evidences)
4..	Long *et al.*[29]	2014	Systematic review/ Meta-analysis	12	Twelve studies were collected from PubMed, Embase, Web of Science, ProQuest Dissertations & Theses, CNKI and SIGLE.The aim of this meta-analysis was to determine the diagnostic accuracy of CBCT in detecting tooth fracture	CBCT has good diagnostic accuracy for VRFs. Although, we should be very cautious especially when using CBCT with root canal treated teeth
5.	Corbella *et al.*[26]	2014	Systematic review/ Meta-analysis	12	Data from studies investigating the sensitivity, specificity and accuracy of both CBCT and conventional periapical radiography (PR) in diagnosing VRFs where included. Data were separated into 4 groups: *in vivo*, *ex vivo*/untreated teeth, *ex vivo*/ treated teeth, and *ex vivo* with post	1-No significant difference was found between CBCT and conventional PR in detecting VRFs 2-Adequate choice of voxel size seems to be important when using CBCT in diagnosing VRFs

upon the advantages and accuracy of using CBCT for diagnosing VRFs. However, the type of CBCT used, the voxel size, the tooth condition, the fracture position, the number of rotations and image doubling, and the examiners (i.e. their clinical ability with the CBCT and the interpretation of the images) were all important factors that affected the accuracy of the VRF detection.[21,41,43-45] Our results clearly reveal the controversy in the literature; however, there is, indeed, a strong trend toward supporting the use of CBCT for the detection and diagnoses of VRFs. Hence, more studies are needed to formulate the proper guidelines and parameters of how and when CBCT can be used and considered as an accurate and reliable tool to diagnose VRFs. Horner *et al.* discussed some of these aspects that must be addressed by practicing dentists.[46]

Takeshita *et al.* stated that the accurate diagnosis of a VRF depends on a careful clinical examination, a complete evaluation of the case, and on an imaging examination that assessed the integrity of the bone and the dental structure.[16] In addition, the detection of a VRF is not only influenced by the type of imaging examination (i.e., conventional radiography or CBCT) but also by the presence of the material used in the root canal (e.g., metal posts, filling material, and the remaining restorative material), which can hinder the quality of the CBCT images.[16]

According to Chang *et al.*, from a national health perspective, "the financial burden to the patient and/or the health-care system must also be considered."[25] In Ontario, Canada, a small (i.e., <8-cm diameter) field-of-view CBCT scan can cost at least $125 CAD as compared to just $20 CAD for a conventional periapical radiograph. Thus, any unjustified use of CBCT may cause a financial strain. In addition, according to the updated 2015 joint statement of the American Association of Endodontists (AAE) and the American Academy of Oral and Maxillofacial Radiology (AAOMR), CBCT should not be used routinely for endodontic diagnosis and screening purposes; it should only be used when the patient's history and clinical examination suggest that the benefits to the patient outweigh the potential risk, especially in inconclusive, difficult cases where a VRF cannot be confirmed. Special measures should be taken such as the use of a limited field of view and seeking the opinion of an oral and maxillofacial radiologist for image interpretation.[47]

Furthermore, it is very difficult to discern such microscopic fractures even with high-powered systems. The limitations of the current systems are compounded by the limitations of the humans using them and vary with issues that stem from training to perception. Talwar *et al.* discussed the challenges that face clinicians when diagnosing VRFs. They noted that CBCT has been used with a high accuracy rate and sensitivity level, yet as seen with other studies, they also reported that the superiority of CBCT over PRs is debated in the literature. Interestingly, their research showed that CBCT was more accurate than PRs in detecting VRFs in unfilled teeth, yet low sensitivity and specificity was found for CBCT when detecting VRFs in teeth that had been filled.[28] This research is interesting in that it reveals a potentially new issue in detecting VRFs. That is, the detection of the VRF may not necessarily be better for one type of imaging over another; rather, the detection may depend upon the specific characteristics of the tooth. The clinician may need to choose the type of imaging depending upon whether or not the tooth has been previously treated.

The advice to cautiously use CBCT because of its expense and risk of radiation may seem like a sensible counter to the notion that CBCT should be preferred in all instances. However, this does not address the central problem that 2D analysis has proven to be inadequate. The problem is that 2D radiographs have resulted in radical under-diagnosis, even when a fracture is present. This implicates the need to develop or advance our current methods to fulfill our needs in dentistry while balancing risk, benefit, and the reasonable costs of service.

CONCLUSIONS

While there is overwhelming evidence that suggests that the use of CBCT is a preferred method to detect VRFs, more research is needed before we accept it as the standard of care. We believe that the joint position statement of the AAE and AAOMR is logical and sufficient to guide dentists in general and endodontists specifically for how and when CBCT should be considered.

Therefore, we agree that CBCT can be useful in detecting VRFs; however, it should be used with caution and must be used after a combination of clinical tests and radiographic approaches have failed to finally reach a definitive diagnosis. In addition, if surgical exploration is the only option to confirm a diagnosis, then the use of CBCT is recommended as a diagnostic tool before surgical intervention to prevent performing an unnecessary surgical procedure in the case that a VRF were to be confirmed. More well controlled and high quality studies are needed to formulate the proper guidelines and parameters for how and when CBCT can be considered as a standard of care for the routine diagnosis of VRFs.

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Conflicts of interest

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