An Ability of CBCT in Vertical Root Fracture Detection in Non-filled and Filled Root Canal Treated Teeth: *an Ex vivo study*

Kittipong KETPAN [1], Atchara INGPRAPANKORN [2], Onanong SILKOSESSAK [3] and Somsinee PIMKHAOKHAM [4,*]

[1] Master student in Endodontology program, Department of Operative Dentistry, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand

[2] Bangplee Hospital, Samutprakarn, Thailand

[3] Department of Radiology, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand

[4] Department of Operative Dentistry, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand

*Corresponding author: Somsinee PIMKHAOKHAM (somsinee.p@chula.ac.th)

ABSTRACT

Background: Vertical root fractures (VRFs) is one of the most cause of tooth loss. VRFs can be found more often in endodontically treated. Various signs and symptoms make VRFs difficult to diagnosis. A conventional radiograph (CR) is an adjunct tool in VRFs detection but CR has a limitation due to a superimposition of fracture line to an anatomical structure. Cone beam computed tomography (CBCT) was widely used in aid of VRFs detection due to providing 3-dimensional images. Many studies show CBCT is more accurate than CR in diagnosed VRFs. However, the sensitivity and specificity of CBCT in VRFs detection can be reduced due to image artifacts caused by gutta-percha and sealers.

Objective: This study aimed to verify the ability of CBCT in the detection of VRFs in a root canal with and without gutta-percha by using micro-computed tomographic (µCT) as the reference standard.

Methods: Sixty extracted premolar with one straight root canal was collected. Access and root canal preparation was performed, VRFs were created in 40 specimens by universal testing machine and the rest were intact (20 teeth). VRFs verification was done by µCT. All teeth were scanned by 3D Aquitomo 170 before and after gutta-percha obturation by matched cone techniques. Sensitivity, Specificity, and Ability of CBCT in VRFs detection were determined. Comparison of the ability of CBCT in VRFs detection between filled and non-filled root canals was achieved by using Wilcoxon signed rank test at a significant level of $p<0.05$.

Results: There was no significant difference of CBCT in VRFs detection between non-filled and gutta-percha filled root canal. The overall area under the curve (AUC) value of CBCT in VRFs detection for non-filled was 0.81 and filled root canal was 0.63 (P=0.068). The overall sensitivity of non-filled (77.5%) was higher than filled root canal (55.88%) (P=0.144) and specificity of non-filled (88.75%) also higher than filled root canal (70.00%) (P=0.197)

Conclusion: CBCT has a high ability in VRFs detection in non-filled root canal teeth. Once the root canal filled with gutta-percha, the ability of CBCT in VRFs detection is reduced.

Keywords: Cone beam computed tomography, Microcomputed tomography, Vertical root fracture, Endodontically treated teeth, Gutta-percha

---

INTRODUCTION

One of the most common reason lead natural teeth to extraction is vertical root fractures (VRFs).[1] VRFs is defined as longitudinal fractures of the root originated from the apex and propagate to the coronal part.[2] Communication of root canal system and periodontal tissue caused by VRFs invites various irritating agents like bacteria and their metabolites to cause a periapical breakdown. The most susceptible roots to fracture are premolars, the mesial root of mandibular molar and mandibular incisor where the shape of the root is oval and narrower mesiodistally.[3,4] VRFs can be found more often in endodontically treated teeth than in vital teeth. This may due to the decrease of the remaining dentin thickness from root canal preparation and the increase of dentin stiffness from dehydration of root canal treated teeth.[1] VRFs has various clinical signs and symptoms. Most of the time, conventional radiograph (CR) is an adjunct tool to detect VRFs. But with limitations of CR that show superimposed anatomical structures on fracture line, detection of VRFs is extremely difficult. The lack of a definitive diagnosis often leads to unnecessary invasive surgery and/or extraction of the tooth.[5]

Nowadays, cone beam computed tomography (CBCT) was used widely as an aid to diagnose VRFs as it has been recommended by the American Association of Endodontists (AAE.).[6] CBCT providing 3-dimensional images allow the precise visualization of VRFs especially in the axial plane view.[7] It has been shown in many studies to be more accurate in VRF detection as compared to conventional radiographs.[8-10]

However, in case of a root-filled tooth, the sensitivity and specificity of CBCT in the detection of VRFs can be reduced due to image artifacts, such as streak or beam hardening, that caused by gutta-percha and sealers.[11-13] This study aimed to verify the ability of CBCT in the detection of VRFs in the root canal with and without gutta-percha, ex vivo, by using micro-computed tomographic (µCT) as the reference standard.

MATERIALS AND METHODS

This study was approved by ethical committees in human research of Faculty of Dentistry, Chulalongkorn University. (HERC-DCU-2017-040).

Specimen Preparation

Sixty human mandibular premolars immersed in 0.1% thymol solution were used. Canal curvature was evaluated from 2 periapical radiographs, in buccolingual and mesiodistal direction using Schneider's method.[14] All specimens were confirmed to have 0-5 degree root canal curvature. Crown was cut until the remaining root was 15 mm. long from the most coronal to the root apex. K-type file #15 was inserted into the root canal until the tip of the instrument was visualized at the apical foramen. The length of the K-file was measured and the working length was determined by 1 mm. deduction of this length. Root canal preparation was performed by Protaper Universal Rotary system from SX to F3 (DentsplySirona, Maillefer, Switzerland). Copious irrigation with 2.5% NaOCl during mechanical instrumentation was done with a lot of recapitulations. Specimen's root was covered with a thin layer of putty silicone for periodontium simulation and then was mounted into a resin block at 1 mm. below the most coronal part of the specimen. VRFs was induced in 40 specimens (out of the total 60 specimens) by universal testing machine (Instron 8872, Instron corp., Norwood, MA, USA). The chisel tip (stainless steel sewing needle, 0.7 mm diameter) was pointed inside the prepared root canal and pressed down at speed of 1 mm./min. which will be ceased at a sudden 20% reduction of loading force.[9] (Fig.1). The rests of the specimens (n=20). served as non-fracture specimens. To produce standard references for this study, all specimens were radiographically taken by Micro CT unit (µCT, SkyScan1173, Bruker Corporation, Kontich, Belgium). The µCT images were analyzed. In the case of VRFs specimens, positions of fracture lines were recorded. (Fig.2) In the case of non-fracture specimens, the fracture lines were not seen at all.

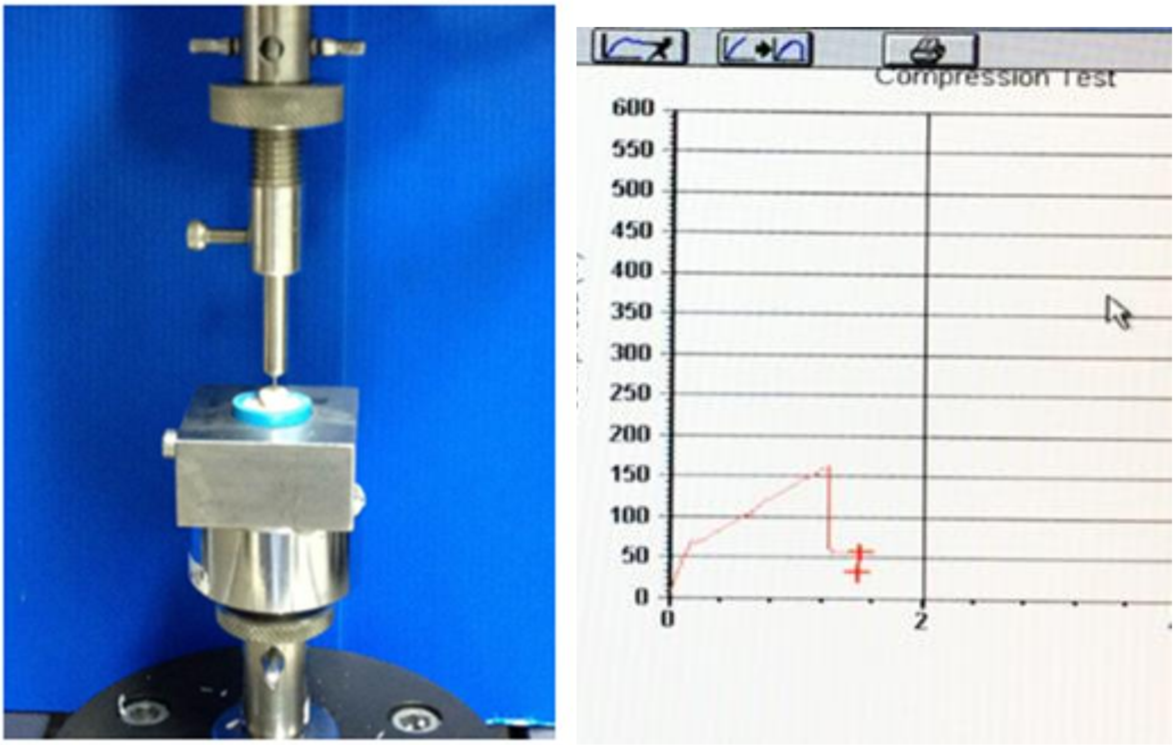

Fig.1 Instron 8872 machine used to simulated incomplete fracture line in specimens (left) and Graph showed twenty percent reduction of loading force during fracture simulation (right)

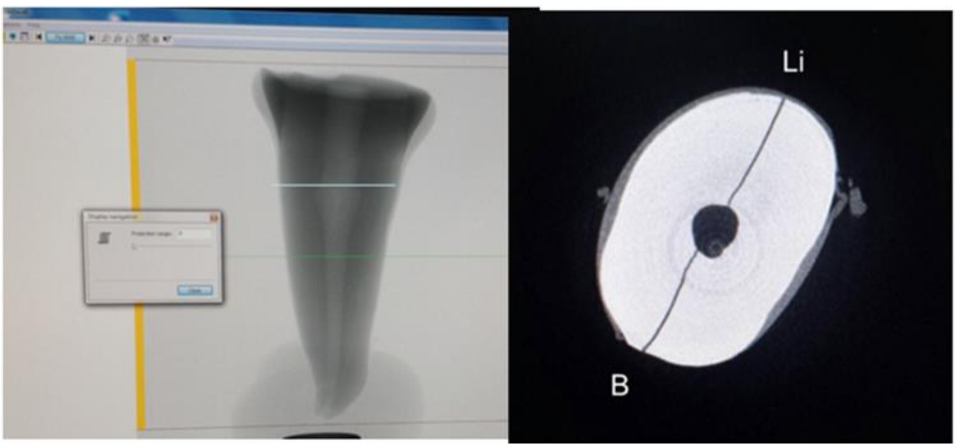

Fig.2 Incomplete fracture line verified with µCT unit

CBCT imaging setting

All specimens were gently removed from the resin blocks and were put inside the dry sockets of Cadaver mandible (Department of Anatomy, Faculty of Dentistry, Chulalongkorn

University) and fixed with utility wax. The cadaver mandible was covered with vinyl polysiloxane impression putty (ExpressTM XT Putty Soft, 3M ESPE, MN, USA) to simulate oral soft tissue. The cadaver mandible was positioned using a jig with an occlusal plane parallel to the floor. This created the same reproducible position for the mandible. The 3D Accuitomo 170 (J Morita, Kyoto, Japan) with same radiation exposure setting (90 kVp and 5.5 mA), FOV of 40x40 mm^2 and image resolution of 0.125 mm. voxel size was utilized for all teeth.

CBCT radiographs of all specimens (60 teeth) with unfilled root canals were taken. Then, matched gutta-percha cone (F3 Protaper cone, DentsplySirona, Maillefer, Switzerland) which was made fit with the prepared root canals as confirmed by periapical radiograph, were put inside the shaped root canals up to apical stop. Then the CBCT radiographs of root-filled specimens were taken and used for analysis.

Imaging Interpretation and Statistical Analysis

Multiplanar CBCT images were analyzed by well-calibrated 4 observers, comprising of 2 endodontists and 2 dental and maxillofacial radiologists using one volume viewer program (J Morita, Kyoto, Japan). VRFs were scored and given for each individual image by 5-point probability scales as followed: 1= fracture definitely absent, 2= fracture probably absent, 3=unsure, 4 = fracture probably present and 5= fracture definitely present. Then the score 1 and 2 were classified as fracture absent while the score 3, 4 and 5 were defined as fracture present.[9,10] Sensitivity, Specificity, Positive and Negative Predictive values were analyzed. Inter- and Intra-examiner agreements were calculated by the Kappa coefficient. The ability of CBCT to detect VRFs was determined by the area under the Receiving Operating Characteristic (ROC) curve. Comparison of the ability of CBCT in VRFs detection between filled and non-filled root canals was achieved by using Wilcoxon signed rank test at a significant level of $p<0.05$.

RESULTS

From the µCT analysis, fracture lines were found at apical 1/3 of the root in all VRFs-induced specimens (40 teeth) and were not seen at all in non-fracture specimens (20 teeth). Therefore µCT yielded 100% sensitivity and 100% specificity in VRFs identification.

The overall sensitivity and the specificity of CBCT for the detecting VRFs in the non-filled root canal were 77.5% and 88.75% respectively. While in teeth with filled root canals the sensitivity and the specificity of CBCT were lower as 55.88% (p = 0.144) and 70% (p = 0.197). (Table 1)

PPV and NPV in the non-filled root canal were 93.35% and 65.46%. While PPV and NPV value in root canal filled teeth were 82.33% and 50.76%.

The ROC curve for each observer was shown in fig. 3 and 4. The area under the curve from ROC analysis in teeth with non-filled root canal was 0.81 which was higher than teeth with filled root canal which was 0.63 (p = 0.68).

Table 1 Sensitivity, specificity, positive predictive value (PPV) and negative predictive values (NPV) (%) and Area under the curve (AUC) for individual examiners diagnosing incomplete fractures in non-filled and filled root canal treated teeth using CBCT.

Examiner	Sensitivity (%)		Specificity(%)		PPV(%)		NPV(%)		Area under curve	
	Non-filled RC	Filled RC	Non-filled RC	Filled RC	Non-filled RC	Filled RC	Non-filled RC	Filled RC	Non-filled RC	Filled RC

1	75	62.5	90	90	96.3	92.6	57.6	54.5	0.80	0.76
2	90	95	80	25	90.0	71.7	80.0	71.4	0.85	0.60
3	70	30	90	95	92.3	92.3	60.0	40.4	0.80	0.63
4	75	40	90	70	93.8	72.7	64.3	36.8	0.83	0.55
Mean	77.5	55.88	88.75	70	93.35	82.33	65.46	50.76	0.81	0.63
SD	8.66	28.82	6.29	31.89	2.59	11.70	10.07	15.73	0.24	0.97
Median	75	51.25	90	80	93.55	80.25	62.15	47.75	0.81	0.61
P-value*	0.144		0.197		0.068		0.068		0.068	

*Wilcoxson signed-rank test

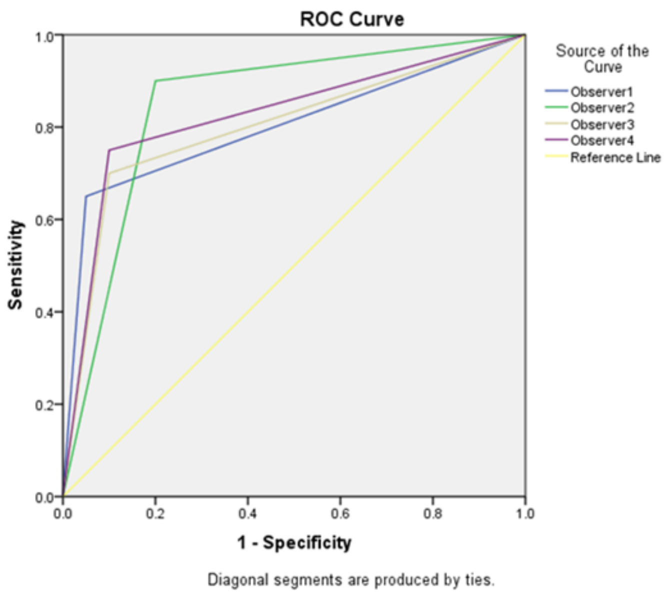

Fig. 3 The Receiving Operating Characteristic (ROC) curve in VRFs detection using CBCT in teeth with non-filled root canal

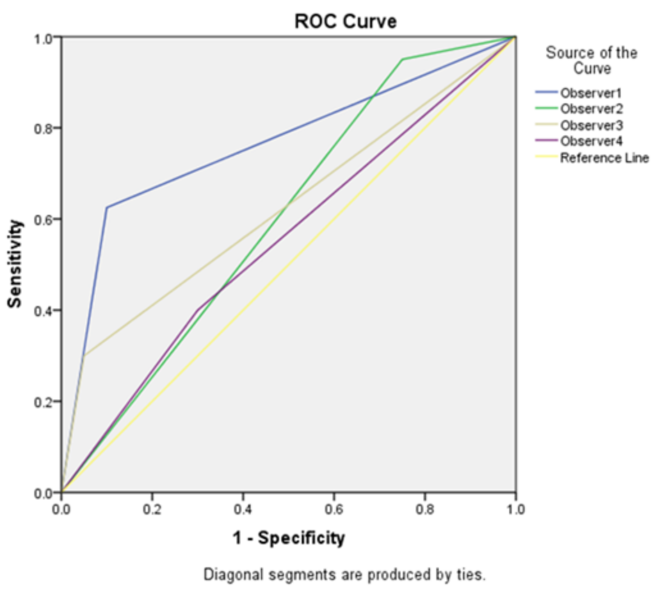

Fig. 4 Receiving Operating Characteristic (ROC) curve in VRFs detection using CBCT in root canal filled teeth

The kappa value for overall inter-examiner agreement for non-filled and root canal filled teeth was 0.485 and 0.146 respectively. The mean intra-examiner agreement was 0.549 and 0.410 for non-filled and root canal filled teeth respectively (Table 2).

Table 2 Kappa values for inter- and intra-examiner agreements in VRFs detection using CBCT in non-filled and root canal filled teeth.

Examiner	Non-filled	Filled RC
1	0.700	0.400
2	0.494	-0.071
3	0.400	0.643
4	0.600	0.524
Mean(SD)	0.549(0.130)	0.410(0.250)
Inter-examiner kappa	0.485	0.146

DISCUSSION

VRFs usually occurred in endodontically treated tooth, it was hypothesized that excessive removal of root canal wall was a preliminary involved factor.[1] It is considered one of the most difficult condition to diagnose especially when the VRFs is an incomplete fracture or nondisplaced type (nVRFs). Various methods have been used to simulate fracture lines such as hammer and chisel[7] and screwing the root canal.[15] Both methods could induce a complete fracture. The method used in this study was modified from that of Patel et al.[9] to induce an incomplete fracture by wedge crosshead attached to the universal testing machine.

The wedging force which was input continuously and increasingly inside the shaped root canal was gradually accumulated apically caused the apical strain which led to VRFs.

CBCT is recommended by AAE to detect VRFs according to higher efficacy than routine periapical radiographs.[8-10, 16] Previous studies compared results of VRFs detection by CBCT with the inspection of root surface under magnification[17] or dying of the root surface.[8] In this study, the µCT was used as a standard reference. Due to a higher resolution than CBCT[18, 19], the true positive numbers of VRFs and the true negative numbers of the non-fractured specimen were more reliable.

The parameters of Accuitomo CBCT used in this study was considered from a pilot study. An unpublished data showed FOV of 40x40 mm^2 and image resolution of 0.125 mm. voxel size created less noise and less radiation for VRFs detection. This was supported by Wenzel et al[20] and Ozer.[21] The multiplaner CBCT images of each specimen including coronal, sagittal and axial plane views were analyzed. It was noted that fracture lines were visible mostly in axial view images which were similar to the previous study.[7]

There were many studies comparing CBCT with periradicular radiograph.[9, 15, 22] It showed higher sensitivity and more accuracy in the detection of VRFs as compared to conventional[23-25] and digital radiography.[25] In case of empty root canal space, CBCT yielded 78 percent accuracy compared to periapical radiograph.[10] The overall sensitivity, specificity, and AUC in this study were also higher than 75% (77.5, 88.75 and 88.86% respectively) in the case of the non-filled root canal.

From this study, CBCT showed higher ability to detect of VRFs in non-filled root canal than in filled root canal, even though there was no statistically significant difference. The overall sensitivity, specificity, and AUC of CBCT in VRFs detection seemed to be reduced when teeth having root canal filled with gutta-percha. This phenomenon can be explained by the opacity of gutta-percha which causes beam hardening effect called streak artifact.[26] Beam hardening occurs when lower energy photons are absorbed by radiopaque mass. Gutta-percha is a radiopaque material that adsorbed lower energy photon. Due to different photons adsorption, the total mean beam energy is increased. This result in distortion and streak artifact production between two different radiopaque objects.[27] The artifact produced by gutta-percha mimic the fracture line (Fig.5) thus led to misinterpreted of examiners and caused more false positive results. This study is consistent of study of Menezes et al[17] who found that root canal presented with gutta-percha and cast post could reduce sensitivity and accuracy of CBCT in VRFs detection

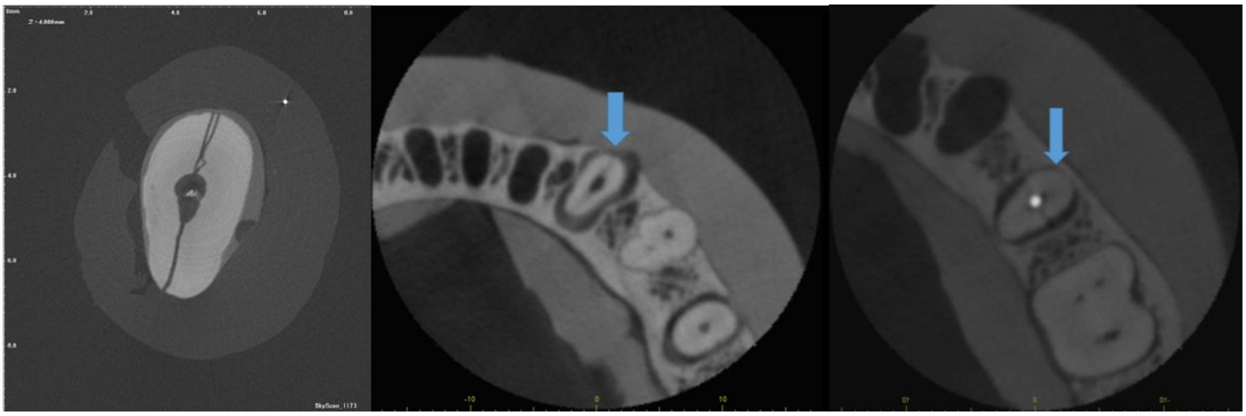

Fig. 5 µCT image of specimens No.59 reveal obvious fracture line (left) and CBCT image of same specimens (arrow) with and without gutta-percha.

The moderate intra-examiner and poor to moderate inter-examiner agreements among each observer in this study are inferred to different experiences in VRFs detection, Endodontists seem to define as fracture present in gutta-percha filled root canal more than radiologists. this result similar to the study of Patel et al[9] but the contrast to the high level of inter and intra-examiner agreements which were reported by Hassan et al[7] and Melo et al[15] in previous studies. The different results may be caused by different methodologies, patterns of size or shape of fracture.

CONCLUSION

Within the limitation of this study, we can conclude that CBCT has high ability in VRFs detection in non-filled root canal teeth. Once the root canal presented which gutta-percha, the ability of CBCT in VRFs detection is reduced.

ACKNOWLEDGEMENTS

We would like to thank Dr. Chayapol Thumrongjaruwat, Dr. Pattamanuch Hirunmekawanich, Dr. Sanphat Benjavongkulchai and Dr. Chutamas Deepho for their contribution in this study.

REFERENCES

1. Sathorn C, Palamara JE, Palamara D, Messer HH. Effect of root canal size and external root surface morphology on fracture susceptibility and pattern: a finite element analysis. J Endod. 2005;31(4):288-92.
2. American Association of Endodontists. "Cracking the cracked tooth code: Detection and treatment of various longitudinal tooth fractures". 2008. Available from: https://www.aae.org/specialty/wp-content/uploads/sites/2/2017/07/ecfesum08.pdf. Accessed April 2019.
3. Yoshino K, Ito K, Kuroda M, Sugihara N. Prevalence of vertical root fracture as the reason for tooth extraction in dental clinics. Clin Oral Investig. 2015;19(6):1405-9.
4. Cohen S, Berman LH, Blanco L, Bakland L, Kim JS. A demographic analysis of vertical root fractures. J Endod. 2006;32(12):1160-3.
5. Rud J, Omnell KA. Root fractures due to corrosion. Diagnostic aspects. Scand J Dent Res. 1970;78(5):397-403.

6. American Association of Endodontists, American Academy of Oral and Maxillofacial Radiology. AAE and AAOMR joint position statement. Use of cone-beam-computed tomography in endodontics. Pa Dent J (Harrisb). 2011;78(1):37-9.
7. Hassan B, Metska ME, Ozok AR, van der Stelt P, Wesselink PR. Detection of vertical root fractures in endodontically treated teeth by a cone beam computed tomography scan. J Endod. 2009;35(5):719-22.
8. Kambungton J, Janhom A, Prapayasatok S, Pongsiriwet S. Assessment of vertical root fractures using three imaging modalities: cone beam CT, intraoral digital radiography and film. Dentomaxillofac Radiol. 2012;41(2):91-5.
9. Patel S, Brady E, Wilson R, Brown J, Mannocci F. The detection of vertical root fractures in root filled teeth with periapical radiographs and CBCT scans. Int Endod J. 2013;46(12):1140-52.
10. Brady E, Mannocci F, Brown J, Wilson R, Patel S. A comparison of cone beam computed tomography and periapical radiography for the detection of vertical root fractures in nonendodontically treated teeth. Int Endod J. 2014;47(8):735-46.
11. Katsumata A, Hirukawa A, Noujeim M, Okumura S, Naitoh M, Fujishita M, et al. Image artifact in dental cone-beam CT. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2006;101(5):652-7.
12. Lofthag-Hansen S, Huumonen S, Grondahl K, Grondahl HG. Limited cone-beam CT and intraoral radiography for the diagnosis of periapical pathology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;103(1):114-9.
13. Sogur E, Baksi BG, Grondahl HG. Imaging of root canal fillings: a comparison of subjective image quality between limited cone-beam CT, storage phosphor and film radiography. Int Endod J. 2007;40(3):179-85.

14. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol. 1971;32(2):271-5.
15. Melo SL, Bortoluzzi EA, Abreu M, Jr., Correa LR, Correa M. Diagnostic ability of a cone-beam computed tomography scan to assess longitudinal root fractures in prosthetically treated teeth. J Endod. 2010;36(11):1879-82.
16. Talwar S, Utneja S, Nawal RR, Kaushik A, Srivastava D, Oberoy SS. Role of Cone-beam Computed Tomography in Diagnosis of Vertical Root Fractures: A Systematic Review and Meta-analysis. J Endod. 2016;42(1):12-24.
17. Menezes RF, Araujo NC, Santa Rosa JM, Carneiro VS, Santos Neto AP, Costa V, et al. Detection of vertical root fractures in endodontically treated teeth in the absence and in the presence of metal post by cone-beam computed tomography. BMC Oral Health. 2016;16:48.
18. Verma P, Love RM. A Micro CT study of the mesiobuccal root canal morphology of the maxillary first molar tooth. Int Endod J. 2011;44(3):210-7.
19. Ordinola-Zapata R, Bramante CM, Versiani MA, Moldauer BI, Topham G, Gutmann JL, et al. Comparative accuracy of the Clearing Technique, CBCT and Micro-CT methods in studying the mesial root canal configuration of mandibular first molars. Int Endod J. 2017;50(1):90-6.
20. Wenzel A, Haiter-Neto F, Frydenberg M, Kirkevang LL. Variable-resolution cone-beam computerized tomography with enhancement filtration compared with intraoral photostimulable phosphor radiography in detection of transverse root fractures in an in vitro model. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;108(6):939-45.

21. Ozer SY. Detection of vertical root fractures by using cone beam computed tomography with variable voxel sizes in an in vitro model. J Endod. 2011;37(1):75-9.
22. Hassan B, Couto Souza P, Jacobs R, de Azambuja Berti S, van der Stelt P. Influence of scanning and reconstruction parameters on quality of three-dimensional surface models of the dental arches from cone beam computed tomography. Clin Oral Investig. 2010;14(3):303-10.
23. Bernardes RA, de Moraes IG, Hungaro Duarte MA, Azevedo BC, de Azevedo JR, Bramante CM. Use of cone-beam volumetric tomography in the diagnosis of root fractures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;108(2):270-7.
24. Varshosaz M, Tavakoli MA, Mostafavi M, Baghban AA. Comparison of conventional radiography with cone beam computed tomography for detection of vertical root fractures: an in vitro study. J Oral Sci. 2010;52(4):593-7.
25. Valizadeh S, Khosaravi M, Azizi Z. Diagnostic accuracy of conventional, digital and cone beam computed tomography in vertical root fracture detection. Iran Endod J. 2011;6:15-20
26. Schulze R, Heil U, Gross D, Bruellmann DD, Dranischnikow E, Schwanecke U, et al. Artefacts in CBCT: a review. Dentomaxillofac Radiol. 2011;40(5):265-73.
27. Scarfe WC, Farman AG. What is cone-beam CT and how does it work? Dent Clin North Am. 2008;52(4):707-30, v.