Diagnostic Accuracy of Digital Phosphor Plates Using Pseudo-Color Enhancement for Detection of Horizontal Root Fractures in Single-Rooted Teeth

Sandra Mehralizadeh[1], Sahar Mohammadi[2], ✉ Ahmadreza Talaeepour[3], Peaiman Mehrvarzfar[4], Maryam Mirzaee[5].

[1]Assistant Professor, Department of Oral & Maxillofacial Radiology, School of Dentistry, Islamic Azad University. Tehran, Iran
[2]Department of Oral & Maxillofacial Radiologist, School of Dentistry, shaheed beheshty University of Medical Sciences, Tehran, Iran
[3]Professor, Department of Oral & Maxillofacial Radiology, School of Dentistry, Islamic Azad University. Tehran, Iran
[4]Associate Professor, Department of Endodontics, School of Dentistry, Islamic Azad University. Tehran, Iran.
[5]Oral & Maxillofacial Radiologist

✉ Corresponding author:
Sahar Mohammadi, Department of Oral & Maxillofacial Radiologist, School of Dentistry, shaheed beheshty University of Medical Sciences, Tehran, Iran
drsaharmohamma-di88@gmail.com

Abstract

Background and Aim: If root fractures remain undetected, pulp necrosis will occur in 25% of cases leading to eventual tooth loss. The purpose of this study was to evaluate the diagnostic accuracy of digital phosphor plates using pseudo-color enhancement for detection of horizontal root fractures in single-rooted teeth.

Materials and Methods: Eighty-two human single-rooted teeth were evaluated (41 with no horizontal fracture and 41 with horizontal fractures). Digital intraoral imaging plate system.

(Digora® Optime PSP System, Soredex) was used to obtain 16-bit gray scale images. Five 16-bit images were obtained from each specimen and saved (one original and four with pseudo-color enhancement). Four observers evaluated the images twice with a 2-week interval. Accuracy, positive predictive value (PPV), negative predictive value (NPV), specificity and sensitivity for each observer and each image group were calculated.

Results: The diagnostic sensitivities were not significantly different among the five images (p absolute=0.125, p complete=0.170). But, statistically significant differences were found in the diagnostic specificity (p absolute=0.019, p complete=0.016) among the five views. Cool and Summer views had higher diagnostic specificity than Bone, Copper and Original views (p=0.025). Kappa and Weighted Kappa values showed statistically significant differences for intra- and inter-observer reliability in the five views (p=0.032).

Conclusion: Both Cool and Summer views were suitable for detection of horizontal root fractures and had statistically significant differences with the original view.

Key Words: Dental digital radiography, Image enhancement, Tooth fracture detection

Introduction

Root fractures occur horizontally or vertically depending on the direction of trauma. Among these, horizontal root fractures in the middle third of the root are the most common [1, 2]. If root fractures remain undetected, tooth may become non –vital and pulp necrosis will occur in 25% of cases leading to eventual tooth loss [3-8]. On the other hand, if a root fracture is detected as traumatic injuries are being evaluated, the prognosis of the fractured root may be promising with appropriate treatment [1, 2].

Radiographic detection of root fracture is difficult requiring much attention to details [9, 10]. In the recent years, digital imaging systems have mainly replaced film radiography [11] and according to

the literature, the diagnostic accuracy of digital imaging systems is comparable to that of film radiography [12]. One of the main advantages of photostimulable storage phosphor (PSP) digital system is the possibility of image enhancement with the aid of dedicated software programs [13], which improve the quality of observation of details [14] and the diagnostic accuracy [14, 15]. Furthermore, PSP digital system has a wide dynamic range, which allows the correction of under- and over-exposed images without the need to retake the image [16, 17].

A study performed by Alpoz E et al. showed that using the enhancement features of the digital imaging software like pseudo color, negative contrast, histogram equalization and contrast/ brightness improved the detection of image details in comparison with the original digital images [18]. Pseudo color is an algorithm that makes the conversion of gray scale images to color images possible and its main indication in industrial and medical imaging is to improve the visibility and interpretation accuracy of details in gray scale images [19].

A study by Rayan et al, in 2006 proved the efficacy of pseudo color enhancement in detection of cephalometric soft tissue landmarks [20]. Despite numerous articles about different enhancement features in digital system software programs like zoom and reverse color, pseudo color and its effect on detecting root fracture has been paid less attention.

The purpose of this study was to determine the diagnostic accuracy of pseudo color enhancement in the software program of PSP digital radiographic system for detection of horizontal root fractures in single-rooted teeth.

Materials and Methods

In this diagnostic study, 82 single-rooted human teeth with closed apices were used. Extracted teeth were collected from four clinics in Tehran city. Age and sex of patients and the reason for tooth extraction were not important in the course of this study. There were no root fractures among the specimens. The teeth were divided into two groups of case and control (n=41 in each group).

The teeth in the case group were placed on a soft base and fractured by applying mechanical force with a hard object (hammer). To prevent displacement, the two fracture fragments were precisely glued together.

Twenty teeth were examined to determine the amount of force required for fracturing the teeth without shattering them. For the exact determination of fracture site as the gold standard, this site was marked with a red pencil.

Imaging of teeth

In this study, digital intraoral imaging plate system (Digora® Optime PSP System, Soredex, Orion Crop., Helsinki, Finland) was used to scan 16-bit gray scale images. System configurations were as follows:

1-Digora Optime unit for imaging plate readout: Pixel size: 64μm (high), bit depth: 10-bit gray scale, resolution: 14.3 lp/mm, readout time 4.3 - 7.5s.

2-Digora Imaging plates: size 1, dimensions: 24×40 mm, image size (pixels): 64μm 685 ×1143 pixels, image size: 64μm (1053MB).

Each specimen was separately placed in a human skull. PSP plate was placed in a fixed position for all teeth using a film holder and the x-ray beam was directed orthogonally in a faciolingual direction. The exposure settings were 20 cm SOD, 1 cm ROD, 8 mA, 70 kVp, 0.3 s.

Evaluation and inspection of specimens were performed using a software program (Digora® 0ptime for windows 2.7 Scanora 4.3 .1.1) .Original 16-bit gray scale images were saved and observed after applying pseudo color enhancement. First, a pilot study was carried out with 20 intact teeth and 20 teeth with fractured roots and 4 pseudo color enhancement features were selected from the available 12 by an experienced oral and maxillofacial radiologist. The four features assumed to have the highest diagnostic value were: Summer enhancement (green hue), Copper enhancement (copper hue), Cool enhancement (combination of purple hue and reversed contrast) and Bone enhancement (blue hue). Five 16-bit images were obtained from each specimen and saved (one original and 4 pseudo color enhanced images).

Observation and evaluation of images

Four observers participated in this study (two oral and maxillofacial radiologists, one endodontist and one oral and maxillofacial radiology post-graduate student), who were experienced in detection of root fractures. Images were observed on a 17" LCD

monitor in a semi dark room. The observer-monitor distance was 20-30 cm. There was no time limitation for observers to view the images.

Observers were calibrated for detection of fracture lines prior to inspection of images. Fracture line was defined as a radiolucent line on the root surface. Images of intact teeth and teeth with fractured roots were shown randomly to each observer.

Afterwards, observers separately inspected root fractures and recorded their response using a 5-point probability scale as follows:

1-Fracture definitely present, 2-Fracture probably present, 3-Unsure, 4-Fracture probably not present, 5-Fracture definitely not present.

In order to eliminate memory bias and to evaluate the intra-observer reliability, the images were inspected again by the observers two weeks after the initial observation. Results were entered in SPSS version 18 and diagnostic parameters including specificity, sensitivity, NPV, PPV and accuracy were calculated. Furthermore, inter- and intra-observer reliability values were calculated using Weighted Kappa and Kappa tests. Parameters were calculated as both complete and absolute values.

Describing values as absolute indicates definite presence of fracture or intactness of teeth and equals to two-point scale (yes/no) in other reports, but describing values as complete contains probability also and equals to five-point scale.

Results

The In the current study, 82 teeth (41 intact and 41 fractured) were evaluated. The mean values of the five diagnostic parameters (accuracy, sensitivity, specificity, PPV and NPV) were calculated based on the observers' opinions and are shown in Tables 1 and 2.

Sensitivity and specificity

There was no statistically significant difference among the five selected views regarding the diagnostic sensitivity (p absolute=0.125 and p complete=0.170). But, the difference in diagnostic specificity was significant (p absolute=0.019 and p complete=0.016).

According to Tables 1 and 2, diagnostic specificity of Cool and Summer views was equal; and the diagnostic specificity of Bone, Copper and original views was also of equal value. Moreover, diagnostic specificity of Cool and Summer views was

higher than that of Bone, Copper and original views (p=0.025).

Inter-observer reliability

The inter-observer agreement co-efficient was calculated with Kappa and Weighted Kappa tests (Table 3).

Cochrane –Q test showed statistically significant difference in Kappa value among the 5 views (p=0.039). Pairwise comparisons revealed no significant difference in Kappa value among Copper, Cool and Summer views. In the original view, reproducibility with Kappa was significantly less than that in the three other views (p=0.045); but it was significantly higher than that of Bone view (p=0.04).

Cochrane-Q test showed statistically significant difference in Weighted Kappa value among the five views (p=0.029) and pairwise comparisons showed that Bone view had significantly lower Weighted Kappa value in comparison with the other 4 views (p=0.01). However, the difference among the four other views was not significant.

Intra-observer agreement coefficient was also calculated using Kappa and Weighted Kappa statistics (Table 4). Cochrane-Q test showed statistically significant difference in Kappa value among the 5 views (p=0.026). There was no statistically significant difference in Kappa value between original and Bone views. Also, difference in Kappa value for Copper, Cool and Summer views was not statistically significant (P=0.059).

Cochrane-Q test showed statistically significant difference in Weighted Kappa value among the 5 views (P=0.029). Pairwise comparison revealed no significant difference in Weighted Kappa value among Bone, original and Copper views. These three views showed less Weighted Kappa value than the other two (p=0.045); also, there was no significant difference between Cool and Summer views.

Discussion

Digital system enhancements include changes in contrast/brightness, pseudo color, zoom, noise reduction and subtraction, which are task specific and their use depends on the observer's personal taste [18, 20, 21].

Pseudo color is one of the enhancement features of the digital system, and only a few studies have

Table 1. The mean values of absolute and complete sensitivity and specificity of the observers for detection of horizontal root fractures in the 5 views

Color view	Complete		Absolute	
	Sensitivity	Specificity	Sensitivity	Specificity
Original	62/2±5/8	58/55±21/9	76/25±3/05	81/7±8/6
Copper	65/22±5/4	68/97±34/7	71/95±8/3	81/1±21/4
Bone	70/12±8/3	65/85±43/3	77/45±9/4	71/9±28/3
Summer	64/65±8/3	84/77±20/8	68/3±9/9	88/42±15/06
Cool	57/3±1/3	85/35±22/8	64/27±6/3	91/45±10/8

Table 2. The mean values of absolute and complete accuracy, PPV and NPV of the observers for detection of horizontal root fractures in the 5 views

View	Absolute			Complete		
	NPV	PPV	Accuracy	NPV	PPV	Accuracy
Original	48/17±10/6	51/82±10/6	60/37±12/04	52/72±5/3	47/27±5/3	68/97±3/6
Copper	51/8718/6	48/12±18/6	67/1±16/4	54/57±14/1	45/42±14/1	76/52±8/1
Bone	47/86±18/5	52/13±18/5	67/98±16/6	47/22±17/7	52/77±17/7	47/67±11/5
Summer	60/06±14/2	39/93±14/2	74/71±6/9	60/06±12/4	39/93±12/4	78/36±2/7
Cool	64/02±11/7	35/97±11/07	71/32±11/1	63/36±8/5	63/36±8/5	78/08±2/3

Table 3. Calculation of Kappa and Weighted Kappa coefficients of inter-observer reliability

Inter observer reliability	Kappa	Weighted Kappa
Original	0/67	0/84
Bone	0/44	0/49
Copper	0/78	0/89
Summer	0/81	0/89
Cool	0/87	0/92

Table 4. Calculation of Kappa and Weighted Kappa coefficients of intra-observer reliability

Inter observer reliability	Kappa	Weighted Kappa
Original	0/69	0/85
Bone	0/72	0/86
Copper	0/84	0/88
Summer	0/90	0/96
Cool	0/88	0/97

evaluated its efficacy. In the current study, the diagnostic accuracy of pseudo color filter in PSP digital radiographic system for detection of horizontal root fractures was evaluated. In the current study, the clinical setting was simulated for each specimen. Horizontal root fractures were induced by mechanical trauma applied using a hard object, which is similar to severe traumatic condition in the clinical setting. Then, two fragments were precisely glued together. Four pseudo color filters were evaluated including Copper view (copper hue), Bone view (blue hue), Summer view (green hue) and Cool view (combination of purple hue

and reverse contrast). Each of these views has specific characteristics and reasons for selecting each of these filters are: first, their higher diagnostic accuracy for detection of horizontal root fractures in the pilot study and second, differences in their hues in order to evaluate different colors. These are the advantages of the present study over the previous ones.

In the current study a 5-point scale [1-5] was used to detect horizontal root fractures, which is one of the advantages of this study because with 5-point scale accurate evaluation of observers' detection ability and definite calculation of diagnostic para-

meters in each view can be achieved. Additionally, parameters were calculated as absolute and complete values.

Describing the parameters in absolute value indicates definite presence or absence of root fracture, which is equivalent to the two-point scale (yes/no) in other studies. But describing the parameters in complete value includes probability, which is equivalent to the 5-point scale.

In a study by Ji-Un-Lee et al, inverted views showed higher diagnostic specificity in comparison with original views with no significant difference. However, it was concluded that diagnosis of horizontal root fractures was enhanced with inverted views [22]. This result is in agreement with the results of the current study considering the Cool view (combination of purple hue and reverse contrast) and it can be added that purple hue improves the diagnostic specificity of invert filter.

PPV, NPV and accuracy parameters were also calculated. The highest NPV (absolute, complete) belonged to Cool and Summer views and the highest absolute PPV belonged to Bone view with the highest complete PPV value for Cool view.

The intra- and inter-examiner agreements were also calculated in the current study using Kappa and Weighted Kappa statistics. Kappa value was equal for absolute parameters and Weighted Kappa value was similar for complete parameters.

Considering the Kappa and Weighted Kappa values, the least amount of reproducibility belonged to the original view with blue hue. This is an interesting finding considering the fact that one of the main reasons for addition of blue hue to conventional radiographic film base is to improve the diagnostic accuracy and efficiency of radiologists [23], which seems to be in contrast to the results of the present study with digital images.

In a study by JI-Un-Lee, Kappa value was 0.42 for inter-observer agreement and 0.57 for intra-observer agreement [22]. In the study by Rayan, Kappa value was reported to be high for the intra-observer agreement [20].

In a study by Kositbowornchai, Kappa value for 1:1 images was reported to be high. For pairwise relations among three magnifications, the highest amount of inter-observer agreement was reported to be 0.80[24].

Studies on the use of enhancement filters in digital radiographic systems show controversial results.

In a study by Wenzel et al, a higher diagnostic sensitivity was reported for the CCD system in detection of horizontal root fractures (15-20 lp mm) in comparison with PSP Digora® (approx. 8 lp mm) system (P<0.05); but the difference for diagnostic specificity was not significant (P>0.05)[25], which is due to differences in spatial resolution of these two systems.

In a study by Igor Tsesis et al, a higher diagnostic specificity was reported for CCD (20 lp mm) system in detection of vertical root fractures in comparison with conventional radiography with no significant difference in diagnostic sensitivity [21]. This result was due to greater difficulty in detection of vertical root fractures compared to the horizontal type.

In another study by Wenzel et al, a more advanced model of Digora® Optime system and cone beam computed tomography (CBCT) (icat, imaging science) were used for detection of horizontal root fractures and a higher level of diagnostic sensitivity (74%) was reported in comparison with the results of another study by the same author; but diagnostic specificity values were equal in the two systems [9]. In the current study, spatial resolution of Digora® PSP system was 14.3 lp mm and the highest sensitivity (77%) and specificity (91%) values were reported for the Cool view.

Yoshiura et al. showed satisfactory results after using enhancement filters for evaluation of small mass changes in a phantom [26].

A study by Furkart et al. showed that using magnification in digital radiographic systems may improve the diagnosis of periodontal bony lesions [27]. In a study by Moystad et al. It was concluded that higher levels of magnification in digital radiographic systems lower the diagnostic ability of examiners [28]. Reddy suggested that using pseudo color and subtraction enhancements significantly helps the diagnosis of periodontal lesions [29]. Additionally, in a study by Rayan et al, the efficacy of applying embossed and pseudo color enhancements in PSP digital system was evaluated for detection of cephalometric landmarks and it was concluded that both enhancements were effective for detection of the landmarks and raised the overall interpretation ability [20]. However, in a

study by Scarfe et al, it was shown that pseudo color enhancement was of little significance in size estimation of periradicular lesions [30].

In the current study, four different pseudo color filters were evaluated but in similar studies only one popular type of pseudo color enhancement was used [20, 29, 30].

Considering the results of the mentioned studies, it is obvious that controversy exists regarding the use of enhancement filters in digital systems and further studies are required to resolve these controversies.

Conclusion

Cool and Summer views are suitable for detection of horizontal root fractures and are superior to the original view for this purpose.

Acknowledgment

References

1. Marco Aurelio Versiani, Cassio Jose Alves de Souza, Antonio Miranda Cruz- Filho, Danyel Elias de Cruz Parez, Manoel Damlao Souza–Neto. Clinical management and subsequent healing of teeth with horizontal root fractures. Dent Traumatol. 2008 Feb; 24(1):136-9.

2. Molina JR, Vann WF Jr, McIntyre JD, Trope M, Lee JY. Root fractures in children and adolescent: Diagnostic consideration. Dent Traumatol. 2008 Oct;24(5):503-9.

3. Kamburoğlu K, Ilker Cebeci AR, Gröndahl HG. Effectiveness of horizontal root fracture. Dent Traumatol. 2009 Jun ;25(3):256-261.

4. Takeuchi N, Yamamoto T, Tomofuji T, Murakami C. A retrospective study on the prognosis of teeth with root fracture in patients during the maintenance phase of periodontal therapy. Dent Traumatol. 2009 Jun; 25(3):332-7.

5. Bornstein MM, Wölner-Hanssen AB, Sendi P, von Arx T. Comparison of intraoral radiography and limited cone beam computed tomography for the assessment of root fractured permanent teeth. Dent Traumatol. 2009 Dec; 25(6):571-7.

6. Nair MK, Nair UP, Grondahl H-G, Webber RL, Wallace JA. Detection of artificially induced vertical radicular fractures using tuned Aperture computed tomography. Eur J Oral Sci. 2001 Dec; 109(6):375-79.

7. Iikubo M, Kobayashi K, Mishima A, Shimoda S, Daimaruya T, Igarashi C, etal. Accuracy intraoral radiography, multidetector helical Ct, and limited cone–beam CT for the detection of horizontal booth root fracture. Oral Surg Oral Med Oral Phathol Oral Radiol Endod. 2009 Nov; 108 (5):70-4.

88. Nair MK, Nair VP, Grondahi HG, Webber RL. Accuracy of tuned aperture computed tomography in the diagnosis of radicular fractures in nonrestored maxillary anterior teeth: An in vitro study. Dentomaxillofac Radiol. 2002 Sept; 31(5):299-304.

9. Wenzel A, Haiter-Neto F, Frydenberg M, Kirkevang L-L. 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 Dec; 108(6): 939-45.

10.Costa FF, Gaia BF, Umetsubo OS, Cavalcanti MG. Detection of horizontal root fracture with small-volume cone-beam computed tomography in the presence and absence of intracanal metallic post. Basic Res Technol. 2011 Oct; 37(10): 1456-9.

11.Kositbowornchai S, Nuansakul R, Sikram S, Sinahawattana S, Saengmontri S. Root fracture detection: A comparison of direct digital radiography with conventional radiography. Dento - maxillofac Radiol. 2001 Mar;30(2):106-9.

12. Syriopoulos K, Sanderink GC, Velders XL, van der Stelt. radiographic detection of aproximal caries: A comparison of dental film and digital imaging system. Dentomaxillofac Radiol. 2000 Sept; 29(5):312-8.

13. Haiter-Neto F, Casanova MS, Frydenberg M, Wenzel A. Task-specific enhancement filters in storage phosphor images from the vistascan system for detection of proximal caries lesions of known size. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009 Jan;107(1):116-21.

14. Ramanathan GP. Diagnosis of caries: A comparison of three radiograph viewing techniques. J Clin Pediatr Dent. 1999 Spring; 23(3): 235-45.

15. Versteeg CH, Sanderink GC, van der Stelt PF. Efficacy of digital intraoral radiography in clinical dentistry. J Dent. 1997 May-Jul; 25(3-4):215-24.

16. Vander Stelt PF. Filmless imaging. The uses of digital radiography in dental practice. J Am Dent Assoc. 2005 Oct; 136(10):1379-87.

17. Berkhout WE, Beuger DA, Sandeink GC, Van Der Stelt PF. The dynamic range of digital radiographic system: Dose reduction or risk of overexposure. Dentomaxillofac Radiol. 2004 Jan; 33(1):1-5.

18. Alpöz E, Soğur E, Baksi Akdeniz BG. perceptility curve test for digital radiography before processing algorithms. Dentomaxillofac Radiol. 2007 Dec; 36(8):490-4.

19. LU Xiang Ju, DING Ming-Xiao, WANG Yunkuan. A new pseudo color transform for fiber masses inspection of industrial images. Acta Automatica Sinica. 2009 Mar; 35(3):233-38.

20. Ryan B. Wiesemann, James P. Scheetz, Anibal M. Silveira, Taeko T. Farman, and Allan G. Farman. Cephalometric landmark clarity in photostimulable phosphor images using pseudo color and emboss enhancements. Int J CARS. 2006 Aug; 1(2):105-112.

21. Tsesis I, Kamburoglu K, Katz A, Tames A, Kaffe I, Kfire A. Comparison of digital with conventional radiography in detection of vertical root fractures in endodontically treated maxillary premolars: an ex vivo study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2008 Jul; 106 (1):124-8.

22. Lee JU, Kwon KJ, Koh KJ. Diagnostic accuracy of artificially induced vertical root fractures: A comparison of direct digital periapical images with conventional periapical images. Korean Oral Maxillofac Radiol. 2004 Dec;34(4):185-90.

23. Bushong Stewart C. Radiologic science for technologists. 9th ed. Canada: Mosby;2008,180-92.

24. Kositboeornchai S, Sikram S, Nuansakul R, Thinkhamrop B. Root fracture detection on digital images: Effect of zoom function. Dent Traumatol. 2003 Jun; 19(3):154-9.

25. Wenzel A, Kirkevang L-L. High resolution charge coupled device sensor vs medium resolution photostimulable phosphor plate digital receptors for detection of root fractures in vitro. Dent Traumatol. 2005 Feb; 21(1):32-36.

26. Yoshiura K, Kawazu T, Chikui T, Tatsumi M, Tokumori K, Tanaka T, etal. Assessment of image quality in dental radiography, part 2: Optimum exposure condition for detection of small mass changes in 6 intraoral radiography system. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1999 Jan;87(1):123-9.

27. Furkart AJ, Dove SB, McDavid WD, Nummikoski P, Matteson S. Direct digital radiography for the detection of periodontal bone lesions. Oral Surg Oral Med Oral Pathol. 1992 Nov; 74(5);652-60.

28. Møystad A, Svanaes DB, Larheim TA, Gröndahl HG. Effect of image magnification of digitized bitewing radiographs on approximal caries detection: an in vitro study. Dentomaxillofac Radiol. 1995 Nov;24(4):255-9.

29. Reddy MS, Bruch JM, Jeffcoat MK, Williams RC. Contrast as an aid to interpretation in digital subtraction radiography. Oral Surg Oral Med Oral Pathol. 1991 Jan; 71(6):763-769.

30. Scarfe WC, Czerniejewski VJ, Farman AG, Avant SL, Molteni R. In vivo accuracy and reliability of color-coded image enhancements for the assessment of periradicular dimensions. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1999 Nov; 88(5):603-611.