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Comparison between intraoral indirect and conventional film-based imaging for the detection of dental root fractures: an *ex vivo* study

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Abstract – Digital intraoral radiographic systems have been rapidly replacing conventional dental X-ray films for diagnosis of dental diseases. Current scientific literature supports the use of these digital systems for the detection of dental caries, periodontal bone loss, and periapical pathologies. However, relatively few studies have been published addressing the detection of dental root fractures. The purpose of this study was to compare the intraoral F-speed film (Insight) with two photostimulable phosphor (PSP) indirect digital systems (ScanX and Digora Optime) for the detection of simulated dental root fractures. Ten raters evaluated images acquired from 10 dry human cadaver mandibles under optimal viewing conditions. These data were analyzed by a 5-point receiver operating characteristic curve analysis for statistical differences. Sensitivity and specificity of these systems were also assessed. Since statistically significant difference between the systems was not observed, the results of this study agreeably support indirect digital PSP plates as an alternative to the evaluated conventional film for the detection of dental root fractures.

Dental fractures are a relatively common etiology of tooth loss. Epidemiologic data reveal that splits or fractures are the third most common cause of tooth loss in industrialized countries (1). A survey done in the United States reports that general dentists see an average of more than 12 cases per month involving dental fractures (2). The problem resides in the fact that if left unresolved a dental fracture finally leads to dental loss by extraction, which will cause a considerable reduction in the individual quality of life (3).

Some fractures are relatively easy to diagnose when the fracture is clinically apparent. The majority of dental fractures, however, are difficult to diagnose because often patients are not able to correctly identify the offending tooth or quadrant (4). Frequently, they report unrelated and long-time standing orofacial symptoms that may not completely be assessed by clinical examination alone (5, 6). This makes the diagnosis of dental fractures one of the most difficult tasks for dentists (7). Radiographic examination can be a useful adjunct to the clinical examination in the diagnosis of dental fractures.

In the late half of the 1980s, advances in digital receptor technology and increased availability of personal computers provided the impetus to replace X-ray films with digital radiography making it viable and attractive to the dental community (8, 9). According to a survey among active diplomates of the American Board of Endodontics published in 2009, 72.5% of the respondents were already using digital radiology in their practice (10). This market has expanded and numerous digital systems are available from a variety of dental manufacturers.

With the introduction of new imaging technologies, it is imperative that they be evaluated to verify whether they perform as well as currently used and accepted methods. Detection of any diagnostic information is task dependent, that is to say one system may be superior in the task of detecting proximal surface dental caries; however, it may be inferior for the identification of a dental fracture. Unfortunately, there is lack of evidence in the current scientific literature comparing conventional and digital systems for the identification of dental fractures. These studies are essential to support, validate, and promote digital technology among dentists. Consequently, the primary intent of this study is to compare the existing film-based radiography with currently available photostimulable phosphor (PSP) digital systems for the detection of induced dental fractures.

Materials and methods

Ten (10) human mandibles were obtained from the collection of skull specimens at the Bexar County Forensic Science Center Building (San Antonio, TX, USA). The mandibles were imbibed in a 10% formalin solution and no soft tissue was present. Each mandible was marked and identified using a code number.

Forty-five posterior teeth without large metal restorations were selected for this study, and in order to confirm their integrity, each tooth was removed from its alveolus and visually evaluated for pre-existing fractures. Twenty-seven teeth were kept intact and 16 were artificially fractured using a bench vise with swivel base. To produce vertical fractures, a metal pin was introduced in the apex of the tooth and then rocked in the bucco-lingual orientation until a vertical fracture could be seen. To produce horizontal fractures, a hammer was used to horizontally impact the occlusal surface of the tooth until a crack was heard. When separation of the fractured fragments was confirmed, the parts were approximated in close relationship without visible gaps, cemented with cyanoacrylate-based adhesive (Super Glue gel, 3 M; Scotch, St Paul, MN, USA) and repositioned into the original dental alveolus.

The following systems were used in this study:

1. Insight® X-ray Film (Eastman Kodak®, Rochester, NY, USA) – Film.
2. ScanX® (Air Techniques Inc®, Hicksville, NY, USA) – PSP.
3. Optime® (Soredex®, Milwaukee, WI, USA) – PSP.

Table 1 summarizes features and specifications of each imaging system. As guide of image sharpness, spatial resolution was provided in line pairs per millimeter (lp/mm).

All images were acquired using a Planmeca Intra high frequency X-ray generator (Planmeca Oy, Helsinki, Finland) with a focal spot size of 0.7×0.7 mm and filtration of 1.5 mm of aluminum (Al) equivalent. An optical bench was used to ensure standardized and reproducible projection geometry between the X-ray source, specimen, and image receptor (Fig. 1). A source to receptor distance of 25 cm was used for all exposures. All exposures were taken bucco-lingually in orthogonal position. The specimens were mounted using dental impression material (Reprosil Easy Mix Putty, Dentisply, Elgin, IL, USA) to provide reproducible positioning in the optical bench apparatus. To simulate soft tissue scatter, a 1.7-cm-thick acrylic block was placed between the X-ray source and the specimen.

All films were processed on the same day of exposure under controlled dark room condition using an automatic film processor (AT2000, Air Techniques Inc., Melville, NY, USA) following manufacturer ideal condition (fresh developer and fixer in 80°F after thorough machine cleaning). All digital images were acquired with a laptop computer (Latitude D620; Dell Inc, Austin, TX, USA) using the respective acquisition software provided by each manufacturer. No image processing was performed on the digital images. All digital images were exported in uncompressed 8 bit tagged image file format.

For all radiographic exposures, only the exposure time varied, kVp was maintained at 63 and mA at 8. Before the definitive image acquisition, a preliminary study was performed to determine the ideal exposure time for each specimen in which all dental structures were properly differentiated with a consistent density and comparable contrast. The ideal exposure was determined by consensus among oral and maxillofacial radiologists using clear discrimination of the dentin–enamel junction as the criterion for the minimum acceptable exposure and cervical burnout, or the maximum exposure attainable with the X-ray generator as reference to dictate the upper limit. The exposure time for each modality is presented in Table 1, and a sample of the obtained radiographic images is shown in Fig. 2. Of interest is the fact that in our study the chosen exposure time for the conventional film was lower than for the PSP systems.

Ten dentists (raters) with experience in evaluating conventional and digital images were asked to identify the presence or absence of dental fractures in a specific tooth using a 5-point confidence score:

1. Definitely absent.
2. Probably absent.
3. Unsure.
4. Probably present.
5. Definitely present.

The raters consisted of four oral and maxillofacial radiologists, two specialists in orofacial pain, two dental general practitioners, one endodontics resident, and one periodontics resident. The raters had no prior knowledge of the distribution of the fractured teeth in the study. The images were evaluated by each rater in three separated sessions, with a minimum of 1 week interval between successive evaluations to prevent any correlation between the reading sessions. In each session, each rater evaluated all images taken by one specific imaging modality. The sequence of these sessions was randomly assigned.

Table 1. Dental conventional and digital radiographic systems and exposure time used in this study

System	Technology	Manufacturer	Active area (mm)	Pixel size (μm)	Spatial resolution (lp/mm)	Image size (pixels)	File size (Kb)	Exposure time (s)
Insight®	Silver halide	Kodak®	30 × 40	n/a	≥ 20	n/a	n/a	0.20
ScanX®	PSP	Air Techniques®	30 × 40	12.5	12–14	1490 × 1950	2800	0.32
DigoraOptime®	PSP	Soredex®	30 × 40	64	8	477 × 630	287	0.32

PSP, photostimulable phosphor; n/a, not applicable.

Fig. 1. Optical bench used for image acquisition.

The intraoral radiographic films were placed in dark mounts and assessed using a 5 × 24 cm fluorescent light viewing box partially covered by a dark cardboard. A twofold magnifying glass was provided.

All digital images were displayed on a 24 inch LCD flat panel display (UltraSharp 2408WFP; Dell Inc.) with a screen resolution of 1920 × 1200 pixels. The display was calibrated for optimal settings of brightness and contrast by the principal investigator. Raters were not allowed to adjust the display system or the digital images in any way. The digital images were presented using dedicated viewing software (Irfanview, version 4.25; Irfan Skiljan, Wierner Neustadt, Austria) with a black background. All assessments were carried out in the same viewing room with dimmed background lighting under optimal viewing conditions. No time limit was set for the viewing procedure and distance between the rater and the display was approximately 80–100 cm. To preclude any memorization bias, images for each digital system were mixed, inverted, and presented in randomized order. Web-based software was used to generate this randomization (http://www.random.org/sequences/), and the author maintained proper random sequence order by means of a coding system.

Data analysis

A total of 1350 responses were obtained and diagnostic accuracy of each rater was evaluated using receiver operating characteristic (ROC) curve analysis for each observation session. The responses of each rater for each tooth and system along with the actual status of the tooth root (fractured or not fractured) were entered into the 'ROC Analysis Web-based Calculator', http://www.rad.jhmi.edu/jeng/javarad/roc/JROCFITi.html (11). ROC curves and the area under the curve (A_z) were obtained, which serve as a numerical estimate and summary measure of the diagnostic accuracy.

For statistical analysis of the results, 'SPSS' software (version 19, SPSS Inc. Chicago, IL, USA) was used. To compare the performance of each imaging modality, one-way analysis of variance (ANOVA) was applied to test for variability based on rater and imaging modality. The level of statistical significance was set at $P < 0.05$.

In addition, sensitivity and specificity for each imaging modality was also calculated, using the same web-based software (JROC). This software dichotomized the results considering responses '1' and '2' as negative results (fracture not present) and responses '3', '4', '5' as a positive result (fracture present). To evaluate statically significant differences between the systems, one-way ANOVA was used. The level of statistical significance was set at $P < 0.05$.

The protocol of this study was reviewed and approved by the Institutional Review Board of The University of Texas Health Science Center at San Antonio under the number HSC20100223N.

Results

Considering all raters and each imaging system, the mean values of A_z, sensitivity, specificity, and standard deviations (SD) are presented in Table 2. Figure 3 provides graphical comparison between the ROC curves.

Comparing the A_z values of conventional dental X-ray film with the indirect imaging systems, no significant differences were observed ($P = 0.376$). Between the PSP systems, ScanX presented higher mean A_z than Digora Optime, but without statistically significant difference ($P = 0.416$).

Even without statistically significant difference using ANOVA, we decided to apply least significant difference post hoc test to verify P-values between the systems, and we obtained P-values of 0.166 between film and ScanX PSP, and 0.520 between film and Digora Optime PSP. Between the two PSP systems the P-value was 0.448.

Considering sensitivity and specificity, sensitivity ranged from a minimum of 0.53 to a maximum value of 0.94 and specificity ranged from a minimum of 0.43 to a maximum value of 0.96. In our study, no statistically significant differences were observed in either sensitivity ($P = 0.636$) or specificity between any of the imaging modalities ($P = 0.783$).

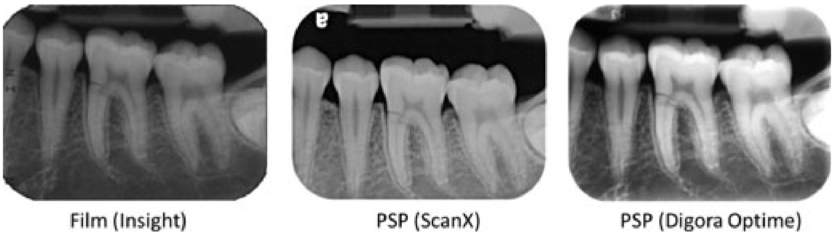

Fig. 2. Sample of images used for comparison between conventional images and indirect digital systems. Note radicular fracture of mesial root of left mandibular first molar.

Table 2. A_z, sensitivity, specificity, and SD of the imaging systems

	A_z			Sensitivity			Specificity		
	Insight®	ScanX®	Digora Optime®	Insight®	ScanX®	Digora Optime®	Insight®	ScanX®	Digora Optime®
Mean	0.77	0.79	0.78	0.65	0.68	0.69	0.71	0.78	0.72
SD	0.04	0.04	0.04	0.09	0.11	0.12	0.12	0.14	0.17

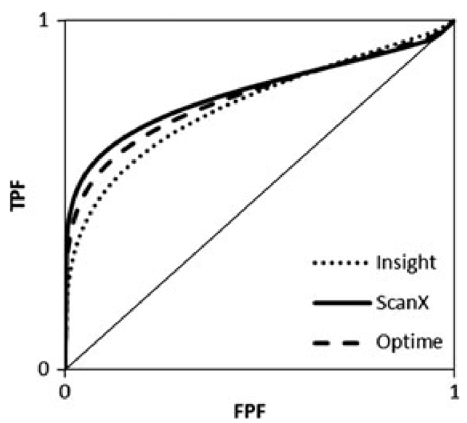

Fig. 3. Mean receiver operating characteristic curves per modality.

Discussion

The diagnosis of dental fractures has been cited as difficult and time-consuming for most of dentists (7) and has traditionally relied on intraoral radiography (12). Since silver-halide dental radiography is a well-established modality, any succeeding technology must provide at least similar or higher diagnostic accuracy than conventional films. Therefore, the purpose of this study was to compare the diagnostic accuracy of conventional intraoral X-ray films and indirect PSP imaging systems for the detection of simulated dental root fractures.

The diagnostic accuracy of radiographic images is very technique sensitive and dental fractures may be masked particularly if the projection angle is not perpendicular to the fracture line (13). In our study, we used an optical bench to eliminate any variability in the X-ray projection geometry such as source to object distance, object to receptor distance, and beam alignment between source, object, and receptor. With this method, we were able to produce similar images varying only the type of image receptor, the focus of our study.

As stated by Wenzel and Kirkevang (14), images with high spatial resolution are preferred for the visualization of dental fractures. The ScanX PSP provides the highest spatial resolution of the evaluated systems with a pixel size of 12.5 μm. These findings would tend to support the idea that the smaller the pixel size or higher the spatial resolution the higher the diagnostic accuracy. However, according to our results, no statistically significant difference in diagnostic accuracy was observed between the high-resolution systems (Insight X-ray film and ScanX PSP) and the system with lower resolution (Digora Optime PSP). At least in this study, all evaluated image receptors were able to provide images with acceptable spatial resolution and image quality for the detection of simulated dental fractures.

Comparing the results of this study with others is difficult, in that the majority of the previous studies which evaluated imaging systems for the detection of dental root fractures did not use the ROC method for diagnostic accuracy. The majority of studies only used sensitivity and specificity as indices of diagnostics accuracy. It was for the purpose of comparison with other studies that the results in this study were converted to sensitivity and specificity by collapsing the 5-point confidence scale to a dichotomous decision.

Evaluating the effects of several imaging variables such as exposure time, scanning resolution, and display resolution on the detection of dental fractures using a PSP system, Kunzel et al. (7) reported sensitivity ranging from 0.45 to 0.60 and specificity from 0.82 to 0.98. In a study published by Kamburoglu et al. (12), conventional film and a PSP system were compared for the detection of dental fractures. The sensitivity for conventional film was 0.74 and 0.68 for the PSP system, and the specificity was 0.96 and 0.97, respectively. In our study, sensitivity ranged from 0.65 for the film to 0.69 to the Digora Optime PSP system. Mean specificity values ranged from 0.71 for the film and 0.78 for the ScanX PSP system. In conclusion, in our study no statistically significant differences were observed in sensitivity and specificity between any of the imaging modalities ($P > 0.05$). While the methodologies used in the cited studies differ considerably from those used in our study, it has been demonstrated that their sensitivity and specificity are consistent with the results in this study.

Another important factor affecting diagnostic accuracy in intraoral radiography is the method of image presentation or display. The physical size of the image presented to the clinician was considerably different between the #2 X-ray film (31 × 41 mm) displayed on a light box with 2× magnification glass and the digital images such as the ScanX PSP displayed on a 24 inch high-resolution LCD flat panel. In a study by Kositbowornchai et al. (4), no significant difference was noted for the detection of root fractures when digital images in three magnifications were evaluated. In our study, the film-based system with smaller images scored third. In fact, some raters preferred the ScanX PSP because of the larger displayed image. Therefore, the size of the presented image might have had an influence on the relatively lower performance of conventional X-ray film.

One of the advantages of digital images is the use of available image manipulation tools to enhance radiographic findings. In this study, we have not evaluated these features. In fact, Kositbowornchai et al. (15) could not find any significant difference for the detection of root fractures increasing image sharpness, zooming, and using pseudo color tools, and in a recent study published by Tofangchiha et al. (16) using unprocessed, colorized and images with reversed contrast, the authors verified that the original digital images were able to provide better results for the detection of vertical root fractures. Tsesis et al. (17) and Ludlow and Mol (18) consider the use of these tools subjective, task-specific and dependent on viewer preference.

An uncontrolled variable present in this *ex vivo* study involves the pattern of root fractures, which were mechanically and artificially induced. Unfortunately, their pattern may not reproduce the clinically observable fractures of the human posterior dentition. However, it is used by most of the studies involving root fractures and appears to be well supported by the literature (12, 15, 19, 20).

A disadvantage of any *ex vivo* study is the lack of specific clinical and radiographic findings obviously not available in these types of investigations. Clinically, pain is often associated with a fractured tooth, but symptoms may vary for teeth that have healthy pulps, for teeth with inflamed or necrotic pulps, and for teeth that have been root canal treated (21). Radiographically 'halo' lesion, periradicular radiolucency, and angular resorption of the crestal bone, combined with diffuse or defined but not corticated borders, indicate a high probability of root fractures (22). Consequently, due to modifying factors not available on an *ex vivo* study, the same study performed on actual patients may have different results.

Conclusion

No statistically significant differences in the detection of *ex-vivo* radicular fractures were observed between the evaluated conventional X-ray film and two PSP systems. Therefore, the results of this study support the use of these indirect digital systems as an alternative for silver-halide X-ray films for the detection of dental radicular fractures.

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