A Comparison of intra-oral digital imaging modalities: Charged Couple Device versus Storage Phosphor Plate

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Abstract

Background

This in vitro study was conducted to compare the accuracy of two digital image receptors in identifying the location of tip of a fine endodontic file and radiographic apex in mandibular posterior teeth.

Methods

Fourteen human cadaver mandibles with retained molars were selected. These molars were prepared for access to the canals and an endodontic file #10 was introduced into the canal at one of the three random distances from the apex of the tooth. At each distance from the apex and at the apex of the tooth, images were made with two different image receptors; DenOptix storage phosphor plates and Gendex CCD sensor. Six raters viewed all the images for identification of the radiographic apex of the tooth and the tip of the endodontic file. Images were displayed randomly under standardized conditions. To assess intra-rater reliability, all the examiners viewed a subset of randomly selected images again after a time period of one week, inter rater reliability was also assessed. At the end of the study, teeth were extracted and the length of the canals measured to obtain a gold standard.

Results

T-test revealed a significant main effect for the type of image, indicating that raters' error in identifying structures of interest was significantly higher for Denoptix storage phosphor plates.

Conclusion

The results of the study clearly reveal that Gnedex CCD produce most reliable images for Root Canal working length estimation when compared with Denoptix SPP.

Introduction:

Radiographs are arguably the single most useful diagnostic tool at dentist's disposal; however, they should be used only after the history is recorded and clinical examination is accomplished. Although radiography is a very useful tool in dentistry, it has some limitations. First, a radiograph is a two dimensional presentation of a three dimensional object. As a result, important clinical structures are superimposed and subject to limited visualization. A second limitation of radiography is that interpretation is subjective and may result in different interpretations of the same radiograph. In a study Goldman et al studied the reliability of radiographic interpretation and found significant differences of opinion among endodontists' varying experience[1]. Their findings also suggest different interpretations of same radiograph by same endodontists after some time interval. Therefore radiography should always be used as an adjunct to clinical findings, and not as the only diagnostic investigation. To overcome these limitations Clark in 1909 introduced radiographs taken at two different positions[2]. This technique was later reported in literature by Richards in 1952 as buccal object rule (SLOB)[3].

Establishing an accurate working length is one of the most critical steps of endodontic therapy. Cleaning, shaping and obturation of the root canal system cannot be accomplished accurately unless the working length is determined precisely[4, 5]. This precise determination of working length using Ingle's method[6] requires radiographic images with high spatial resolution. After the discovery of x-rays by Wilhelm C. Roentgen in 1895, film has been used as the only medium of capturing radiographic images, until the introduction of digital radiography. Although image resolution of conventional film is superior to digital images, conventional films are relatively poor detectors of radiation[7,8]. Therefore, they require more radiation to produce an image of diagnostic quality. Dental digital radiography was introduced by Dr. Frances Mouyen in 1984 and was manufactured by Trophy Radiologie Vincennes, France[9]. It has been more than two decades since then, and digital radiography is becoming increasingly popular in the dental community. Compared with film based imaging several advantages have been reported with digital imaging in dental radiography. These include reduction of patient dose from 50-95% for same diagnostic procedure, immediate image generation which helps in reducing overall treatment time, image manipulation which includes brightness and contrast adjustment according to clinicians' requirement. Digital radiography also eliminates the use of processing chemicals and maintenance of a dark room. Also digital radiography enhances one's ability to educate patient [10, 11, 12, 13, 14].

Direct digital receptors include the charged-couple-device (CCD) and the complementary metal oxide semiconductor active pixel sensor (CMOS-APS). Storage phosphor plates (SPP) are indirect digital image receptors. The CCD direct digital image receptor was the first digital image receptor used in intraoral radiography. The CCD uses silicon wafers whose crystals are formed in a picture element (pixel) matrix. The size of each pixel varies from 20 microns to 70 microns. When x-rays interact with these pixels, the covalent bonds in the silicon crystals are broken and electron-hole pairs are produced. This production of electron-hole pairs is proportional to the amount of radiation received by the sensor. After these electrons are produced, they travel to the most positive potential in the pixel and form charge packets. Each pixel is represented by one charge packet and the pattern formed by these charge packets forms the latent image. Once the latent image is formed, it is read out by transferring each row pixel by pixel in a "bucket brigade" fashion. These charges are transmitted to the ADC as a voltage which is either within or connected to a computer. In the ADC, each charge packet is assigned a number representing a shade of gray. Images in digital format are sent to a computer monitor for viewing[15, 16].

Indirect digital imaging is based on photostimulable phosphor plate (PSP) or storage phosphor plate (SPP) technology. With SPP, the image is captured in analog format and then converted into digital format. SPP has a polyester base coated with a crystalline halide emulsion that converts x-radiation into stored energy. The crystalline emulsion is a europium-activated barium flouro-halide compound. When the emulsion is exposed to x-rays, the x-ray energy is stored temporarily. This energy is released as blue fluorescent light when the plates are scanned using a helium-neon laser. This emitted light is captured and intensified by a photomultiplier and converted into a digital format[17]. With consistent advancement in the field of radiology, digital radiology has reached a point where diagnostic efficacy is either equal to or superior to conventional radiography[18, 19, 20, 21, 22]. Therefore, digital radiography, with the advantages of lower radiation dose and instant image processing, should be used in clinical practice[23].

To date, the literature suggests that digital image receptors produce images comparable to conventional images by using less radiation[24]. These digital image receptors although being advantageous in many aspects have disadvantages of high initial cost and image receptors being rigid and thick are less acceptable to patients. Purpose of this study is to compare the ability of two digital image receptors CCD and SPP in identifying tip of fine endodontic file and radiographic apex of mandibular posterior teeth.

Materials & Method:

Twenty human cadaver mandibles with well preserved posterior teeth were obtained. Soft tissues attached to the cadaver mandibles were removed. The mandibles were examined radiographically for any bony changes or pathology which might interfere with the visualization of the roots. Similarly, teeth with calcification, resorption, previous endodontic treatment or fracture were excluded. Only posterior mandibular teeth, i.e. molars and premolars, with completely preserved anatomy and which met the inclusion criteria as previously stated were included in the study. 14 mandibles met the inclusion criteria.

Coronal surfaces of selected teeth were ground flat to the level of the crestal bone to help standardize measurements. To identify endodontic canals in the selected specimens, teeth were approached occlusally using a high speed handpiece (DENTSPLY International. Des Plaines, IL) and a #2 round diamond tip (KERR Corporation, Romulos, MI). All the canals in each tooth were isolated. An endodontic file #10 was introduced into the canal to the point of maximum resistance. At this point a conventional radiograph was taken to verify the position of the file in the canal. File position was adjusted until the file tip was flush with the radiographic apex of the tooth. This procedure established the radiographic working length. After establishing radiographic working length, the file was placed at different locations within canal short of the radiographic apex of the tooth. Radiographs were taken at these file positions using standardized procedure. Each file position was imaged using both image receptors. The length of the file for each canal was checked using an endodontic ruler before introducing the file into the canal and after the radiograph was taken, to verify the measured file length. A rubber stop at each file length was stabilized with sticky wax (Dentsply, York, PA) to prevent changes in file length between exposures.

An optical bench was designed to assure reproducibility of the projection geometry for the exposures of the three image receptors. Both image receptors, i.e. DenOptix® SPP (Dentsply International, Des Plaines, IL) and Gendex® CCD (Gendex Dental Supply Milan, Italy) were tested to determine exposure factors which produced images of optimum quality. This was achieved by taking radiographs with a Gendex 770 x-ray machine (Gendex, Milwaukee, WI) using different exposure factors to produce images of varying density and contrast. A panel of two board certified oral and maxillofacial radiologists selected the images with optimum contrast and density for each image receptor by consensus. The exposure factors selected were 15 mA, 8 impulses and 72 kVp Gendex® CCD and for Denoptix SPP 10 mA, 15 impulses and 72 kVp, same exposure factors were used throughout the study to produce images of comparable density and contrast.

The images were exposed with a Gendex 770 (Gendex, Milwaukee, WI) dental x-ray unit using #2 size image receptors. All images were processed using the manufacturer's proprietary software. Images were then stored in JPEG format, and transferred to Adobe Photoshop (Adobe systems Inc. San Jose, CA).

Prepared images were used as background images and using the Layer Tools in the Photoshop software, masking layers of each image was generated for each rater since multiple raters viewed the same image, these masking layers enabled the raters to identify the required landmarks without changing the background image. Prior to the evaluation, six raters were given written and verbal instructions for evaluation of the images and a demonstration of image evaluation on five sample images. Image evaluation was in a random order per session. Raters selected were experienced in viewing digital endodontic radiographs. Each rater was asked to identify the tip of the file and the radiographic apex. Additional sessions of randomly chosen images were re-evaluated by each rater to assess intra-rater reliability. At the end of the study, the teeth from the cadaver mandibles were extracted. The same endodontic file (#10) was introduced into the canals of the prepared teeth. The length of each canal was measured by positioning the file tip flush with the apical foramen. This measurement was considered the gold standard.

T-test was used to assess the effect of different image receptors in identifying a fine endodontic file. The level of significance was set at $\alpha=0.05$. Inter-observer reliability was determined by Pearson correlation coefficient of concordance (W). Intra-observer reliability was determined calculating proportion agreement within ± 0.5mm range.

Results:

Table 1 shows mean distance (±SD) of error in identifying structures of interest using the two sensor types. Mean distance of error in identifying the structures of interest for Gendex CCD it was 1.53 mm, while the mean distance of error for Denoptix SPP was 2.10 mm.

The main effect of sensor was statistically significant, CCD being significantly more accurate in identifying structures of interest than SPP. Figure 1 shows that all raters were relatively consistent when rating images across all sensors with the exception of rater 5 for the SPP sensor. Consistency in identifying the structures of interest for a given sensor can be seen in Table 1, where range of distance of error for Gendex CCD is from 1.50 mm (minimum) to 1.58 mm and for Denoptix SPP mean distance of error ranges from 1.92 mm to 2.36 mm.

Table 2 shows intra-rater reliability for all six raters. Absolute agreement was considered when raters identified the location of structures in the same images within a range of ±0.5mm from actual point of identification for the structures of interest, which ranges from 62%-69%.

Table 3 shows inter-rater reliability for all six raters. Pearson correlation coefficient analysis shows good inter-rater reliability across raters, only for rater 5 where r values were in .8 range for all the other raters r values were .94 and above (p= 0.01).

Discussion:

Our study compared the accuracy in identifying structures of interest of two different digital image receptors: Gendex® Visualix II and Denoptix® SPP. The accuracy of these digital image receptors was evaluated by calculating distance of error in identifying two clinically significant structures of interest for endodontic working length estimation, tip of a fine endodontic file (size # 10) and radiographic apex. The results showed that the identification error was significantly lower (p = .0001) for Gendex Visualix II, while mean distance of error in identifying structures of interest was greatest for DenOptix SPP. The mean distance of error in identification of structures of interest for Gendex Visualix II is 1.53 (S.D. 1.07mm) and for Denoptix SPP 2.10mm (S.D. 1.37). Therefore, the null hypothesis is rejected.

The difference observed in our study with regard to identification of clinically significant structures of interest was attributed to one main factor: type of digital image receptor. The raters were asked to identify and mark the tip of the endodontic file (inserted into the canal at variable distances from the apex) and radiographic apex on images acquired with different digital image receptors when everything else was controlled. These structures of interest are considered clinically important for establishing working length during endodontic procedures. Error in the identification of either of these structures may result in miscalculation of the endodontic working length which may result in failure to achieve apical seal during obturation in endodontic root canal procedure.

This difference may be attributed to the different image acquisition technologies of digital image receptors, For Gendex Visualix II it is CCD (charged couple device) this uses silicon based image receptor, when exposed to radiation, the covalent bonds between silicon atoms are broken producing electron-hole pairs, these are then transferred to read-out amplifier as charged packets in bucket brigade fashion from it is transferred to analog-to-digital converter and image is displayed. Denoptix storage phosphor plates acquire image similar to conventional films where polyester base is coated with emulsion (europium-activated barium flouro-halide compound) which converts x-ray energy into light signals which are then recorded as digital data.

As any other study, this study have certain limitations one of them being this study was an *in vitro* study, and as a result, we were not able to evaluate the accuracy of the tested imaging modalities in a clinical setting. Although *in vivo* studies are always preferred over *in vitro* study, in radiographic studies this may not be the case. In an *in vivo* study, the ideal patient positioning is not always possible and absolute reproducibility is limited. Also comparison with actual anatomical structures cannot be made; also image quality may vary from one patient to another, while *in vitro* studies same structures can be exposed to x-rays repeatedly and ideal positioning of the anatomical specimen with exact reproducibility is possible.

Conclusion:

Our study showed statistically significant difference between the three image receptors tested for identification of structures of interest (tip of endodontic file and radiographies apex), Gendex CCD performed superior to the DenOptix SPP.

On the basis of our study it can be said that Gendex CCD produce most reliable images for endodontic working length estimation when compared with Denoptix SPP.

Rater	CCD (±SD)	SPP (±SD)
1	1.54 (1.07)	1.99 (1.36)
2	1.54 (1.07)	1.97 (1.32)
3	1.54 (1.05)	2.02 (1.38)
4	1.51 (1.08)	2.01 (1.34)
5	1.50 (ذ1.08)	2.36 (1.53)
6	1.58 (1.12)	1.92 (1.30)
Mean	1.53 (1.07)	2.10 (1.37)

Table 1

Rater	CCD (±SD)	SPP (±SD)
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Mean	1.53 (1.07)	2.10 (1.37)

Table 2

	Rater1	Rater2	Rater3	Rater4	Rater5	Rater6
Rater1	1					
Rater2	0.95	1				
Rater3	0.97	0.95	1			
Rater4	0.97	0.95	0.96	1		
Rater5	0.88	0.89	0.87	0.89	1	
Rater6	0.98	0.94	0.96	0.96	0.88	1

Table 3

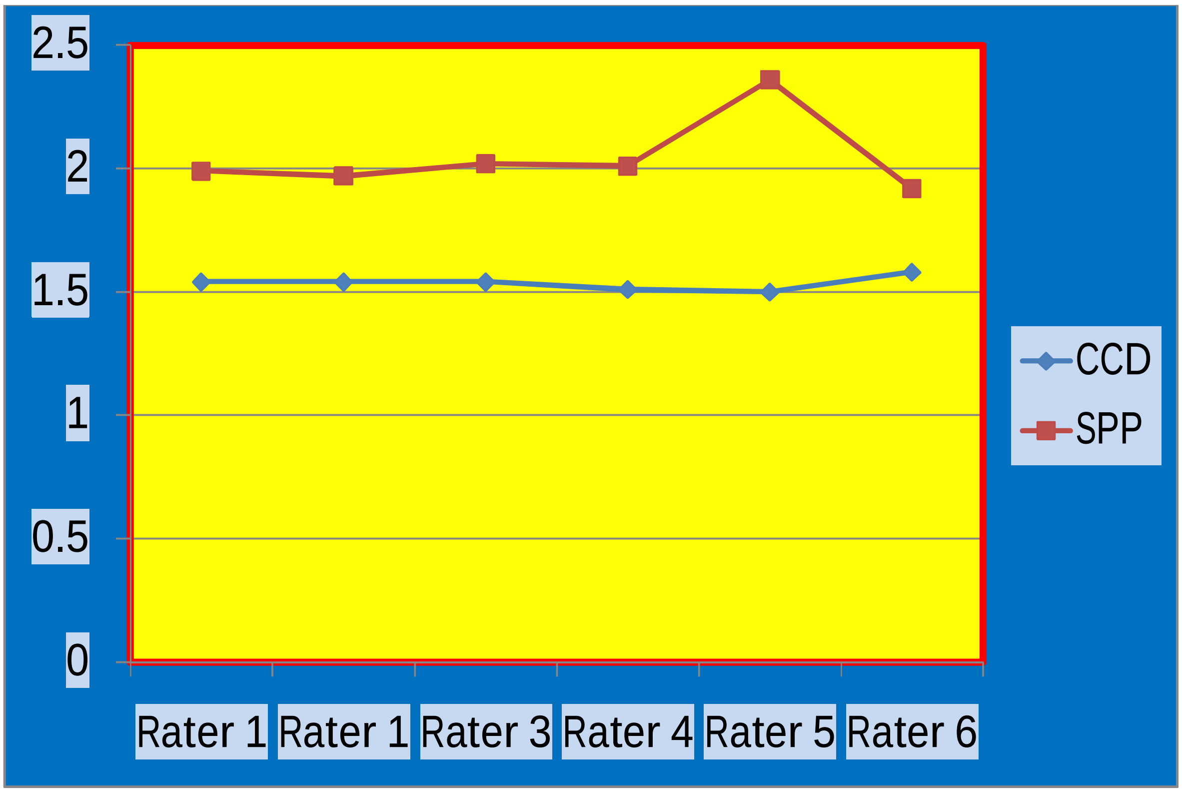

Figure 1 Raters' consistency

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