A comparison of 18 different x-ray detectors currently used in dentistry

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Purpose. There has been a proliferation of available dental x-ray detectors over the recent past. The purpose of this short technical report is to provide a basic comparison of spatial resolution, contrast perceptibility, and relative exposure latitudes of 18 current dental x-ray detectors, including solid-state systems (CCD and CMOS), photostimulable phosphors, and analog film.

Methods. Spatial resolution was measured using a 0.025 mm Pb phantom test grid with a measurement range from 1.5 to 20 lp/mm. For contrast perceptibility, a 7-mm thick aluminum perceptibility test device with wells of 0.1-0.9 mm depth at 0.1 mm intervals and 1 defect of 1.5 mm was used. The relative exposure latitude was determined by expert consensus using clear discrimination of the enamel-dentin junction as the lower limit and pixel blooming or unacceptable levels of cervical burnout as the upper limit.

Results. The highest spatial resolution was found with Kodak InSight film, RVG-ui (CCD), and RVG 6000 (CMOS) detectors, each of which achieved 20 lp/mm, followed by the Planmeca Dixi2 v3 at ≥16 lp/mm. Contrast resolution was at least to 0.2 mm through 7 mm aluminum for all 18 detectors, with the best results being found for the Visualix HDI, RVG-ui, RVG 5000, and RVG 6000 detectors and the Schick CDR wired and wireless systems. The greatest exposure ranges were found with photostimulable phosphors and the Kodak RVG 6000 and RVG 5000 detectors.

Conclusions. Most current x-ray detectors generally perform well in terms of spatial and contrast resolutions, and in terms of exposure latitude. These findings were independent of the modality applied.

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Essential properties for any digital imaging system should include the following: (1) the image produced is of diagnostic quality; (2) the radiation dose is equal or reduced compared to film; (3) that digital radiology techniques are compatible with conventional x-ray generators; (4) that lossless archiving is allowed in an image file format that promotes interoperability within the DICOM standard; and (5) the time required for the total procedure should be equal to or less than with film.[1] The detector need not be identical to film in all image properties; however, it should provide sufficient information for necessary diagnoses. The information needed might be task dependent: eg, high spatial resolution could well be needed to accurately measure the lengths of fine endodontic instruments, but would not necessarily be required in the detection of proximal surface dental caries. At this time there is a surprising dearth of information on the resolution and contrast requirements for detection of different dental structures and disease processes both for analog film radiographs and for their digital counterparts. It should be remembered that the ideal detector should be able to multitask and therefore both sufficient spatial resolution and good contrast discrimination are needed.

The production of a radiographic image can be considered to follow an imaging chain. This chain starts with the production of x-rays by a generator and their selective attenuation by the tissues to be studied. A detector with high sensitivity to x-radiation requires the use of a generator with a high accuracy at low dosages, particularly given a narrow exposure latitude. On the other hand, excessive latitude could results in unnecessarily high radiation dosages being applied to the patient if care is not taken to avoid this eventuality.

At the level of the detector the imaging chain differs depending on the technology involved. For film radiography, the intraoral package needs to be unpacked in a dark/safelight environment and processed chemically. The quality of film images is greatly dependent upon appropriate time and temperature and strength of the chemistry applied. Optimal film radiograph results are only attained given appropriate processing conditions.

For photostimulable phosphors, the latent images are highly light sensitive.[2] The exposed plates need to be kept out of direct normal light prior to processing or they can lose much of the x-ray signal. This is not always apparent to the dentist as images can be optimized by virtue of the acquisition and display software; however, the results of poor handling are likely to be measurable

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physically. The processing of a photostimulable phosphor plate requires scanning by a laser and the photomultiplication and analog to digital conversion of the resulting signal. This process takes from seconds to minutes. The time is greater when high spatial resolution is desired as this requires a smaller scanning pitch be applied. The quality of the image from a photostimulable phosphor is dependent not only on the quality of the phosphor plate itself, but also on the scanning mechanism, the electronics, and the acquisition and display software.

Solid-state detectors vary in construction; presently, however, they all consist of a charge-coupled device (CCD) or complementary metal oxide semiconductor (CMOS) chip that is sensitive to light and a scintillator layer that converts x-rays to light. There may be an intervening fiberoptic or the scintillator can be applied directly to the chip. The quality of an image produced by a solid-state detector is dependent upon not only the chip pixel dimensions, but also upon the type and configuration of the scintillator layer, the electronics including analog to digital conversion, and the acquisition and display software.

Contrast resolution is an important characteristic of the diagnostic image. Some available systems can produce grayscale images in 16-bit depth making it possible to have up to 65,536 gray levels recorded. However, standard computer monitors at this time can display only a depth of 8-bit or 256 gray levels, but the remaining information need not be wasted as it is possible to select different viewing windows. Care needs to be made to differentiate between the detector bit-depth capability and the actual information that is stored and can be retrieved. Often digital detectors are capable of acquiring images of a greater bit-depth than is stored, and specific bits are discarded to "reduce noise."

The last steps in the imaging chain are display, viewing conditions, and observation. All diagnostic radiographs should be viewed under subdued ambient lighting, whether analog or digital. For digital imaging it is very important to have a high-quality display and to set the display to the recommended settings. Sixteen-bit color or less is not sufficient to display digital grayscale images at a contrast resolution of 256 gray levels (8-bit grayscale) irrespective of the system being used. Further, using the wrong resolution settings can impair apparent image spatial resolution if a 1:1 image size is not possible. Getting the most out of any imaging system requires training and experience of the observer.

There has been a proliferation of available dental x-ray detectors over the past decade; however, there has been no recent study that independently compares these devices. This short technical paper briefly compares the spatial resolution, contrast perceptibility, and diagnostically acceptable exposure ranges of 18 currently marketed detectors including solid-state (CCD and CMOS), photostimulable phosphors, and analog film modalities. The newly released high-fill CMOS RVG 6000 and RVG 5000 detectors produced by Trophy Radiology are reported for the first time.

METHODS

The detectors studied were the following: CMOS devices including CDR wired and wireless systems (Schick Technologies, Inc, Long Island City, NY), RVG 6000 and RVG 5000 (Eastman Kodak, Rochester, NY); CCD-devices including CygnusRay MPS (Cygnus Technologies, Scottsdale, Ariz), Dexis (Provision Dental Supplies, Atlanta, Ga), Dixi@ v3 (Planmeca Oy, Helsinki, Finland), DSX 730 USB and DSX 730 Évolution (Owandy/Julie RadioVision, Gragny, France), Sigma (GE/Instrumentarium Imaging, Tuusula, Finland), Sidexis (Sirona, Bensheim, Germany), RSV (Visiodent, St Denis, France); RVG-ui (Formerly Trophy Radiology, now Kodak), ViperRay (Integra Medical, American Fork, Utah), and Visualix (Gendex, Des Plaines, Ill; photostimulable phosphor systems including DenOptix (Gendex), and ScanX (Air Techniques Inc, Hicksville, NY); and analog InSight silver halide film (Eastman Kodak, Rochester, NY). (See Fig 1 and Table I.)

The AC x-ray generator used was an Irix with CCX timer (Kodak) operated at 70 kVp, 8 mA, with a nominal focal spot size of 0.7 mm and 2.5 mm Al equivalent filtration. For the CDR Wireless system, the detector to radio frequency receiver distance was kept to 1 m with the battery level and signal strengths maintained in the 75% to 90 % levels.

The analog film used was InSight (Lot No. 2104844, Expiry date 2004-11). All films were processed in a darkroom under safelight conditions (GBX-II, Kodak) using an automatic processor (Air Techniques AT 2000) with freshly primed ReadyMatic processing solutions (Kodak) at 28°C. Exposures for all modalities were measured using an Unfors 512 Mult-O-Meter (Unfors Instument, Billdal, Sweden).

Film radiographs were evaluated in a darkened room using transmitted light from a viewbox, with all extraneous light masked. The digital radiographic images were displayed on a 17-inch CRT screen (Samsung, Korea) in the same a darkened room. The 4 evaluators worked independently. Outcomes were decided by consensus when there were discrepancies in ratings.

Spatial resolution

As a guide to image sharpness, spatial resolution was measured in line pairs per millimeter (lp/mm). The test grid employed was a Pb 0.025 mm (Nr. 81551, Nuclear Associates, Carle Place, NY) phantom providing

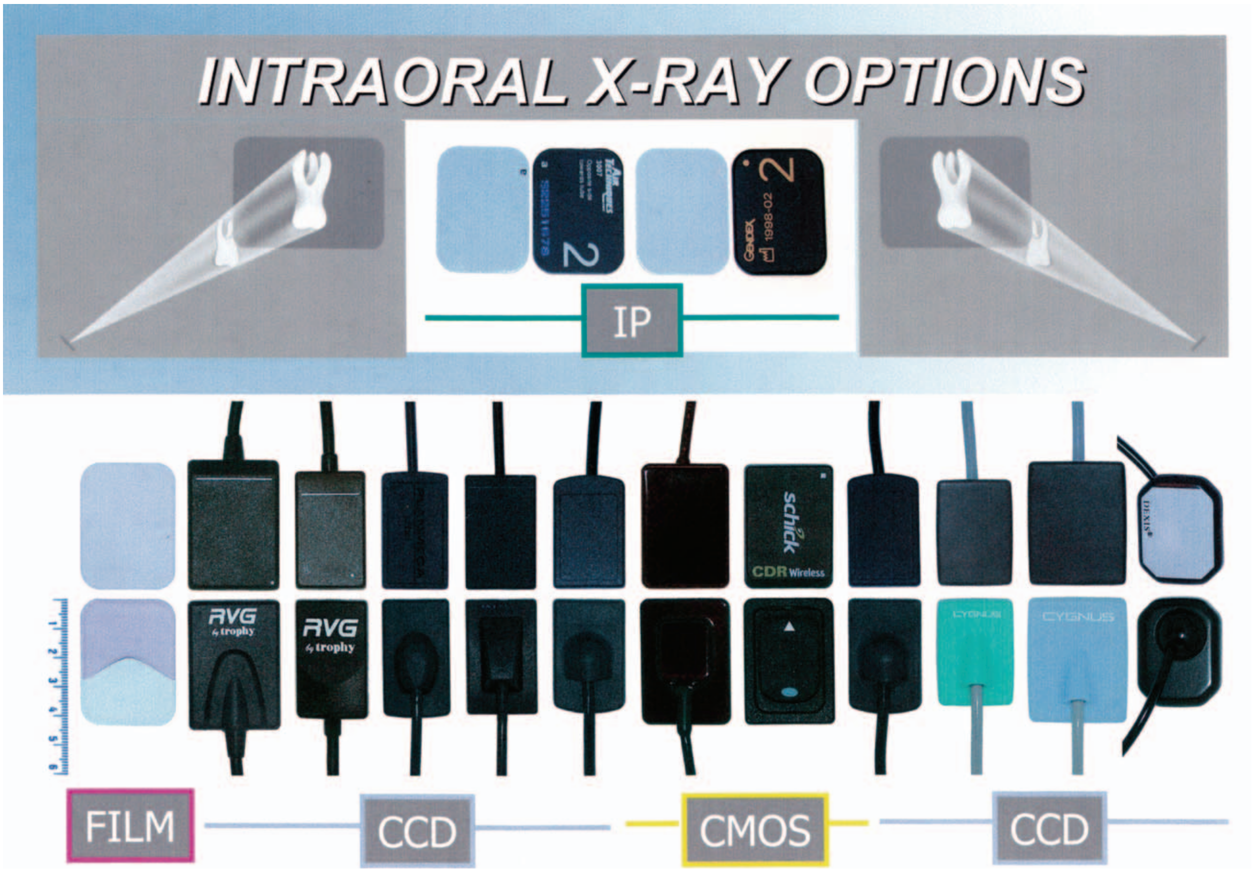

Fig 1. Detectors used in this study.

a measurement range from 1.5 to 20 lp/mm. In accordance with Nuclear Associates' instruction manual, the focus-to-detector distance was set at 1 meter where possible. The one exception was the CDR Wireless TM System (Schick Technologies) where a distance of 75 cm was necessitated to achieve image reception. Given pixel symmetry the results were confirmed at 45 degrees to minimize aliasing. For the ScanX used in high-resolution modes the derived pixels are asymmetrical, necessitating making separate vertical and horizontal assessments. Determination of the limiting resolution by inspecting the finished radiographs for all digital systems was achieved with the assistance of software zoom provided by the manufacturers. For analog film radiographs, limiting resolution was assessed using a ×7 power magnifying glass.

Contrast perceptibility

An aluminum perceptibility test device was manufactured under special order by Rogers Machine Co, Inc (Louisville, Ky). The device measures 25 mm × 14 mm and is 7 mm thick with wells of 0.1-0.9 mm depth at 0.1-mm intervals and one of 1.5 mm. The focus-to-detector distance was set at 25 cm throughout.

Practical exposure range

The practically achievable exposure range to produce an image of diagnostic quality determines the exposure latitude available to the dentist when making radiographs. The wider the latitude the less likelihood of remakes being necessitated by variations in patient bone density and soft tissue bulk. An optical bench was used to assure reproducible projection geometry and to accommodate human tooth specimens and the various x-ray detectors. Seventeen mm of acrylic was placed to simulate soft tissue radiation scatter. The focus to imaging plate was set at 25 cm. No variation in distance or filtration was applied. The acceptable exposure range is subject to variation depending on definition and the specimen employed so the results should be considered to be relative rather than absolute. For this study the exposure latitude was determined by expert consensus using clear discrimination of the enamel-dentin junction as the criterion

Table I. Detector specifications provided by manufacturers

Detector	*Pixel size (μm)*	*Technology*	*Software*
CDR	40 × 40	CMOS	CDR for DICOM Windows 3.0.1
CDR Wireless	40 × 40	CMOS	CDR for DICOM Windows 3.0.1
CygnusRay MPS	22 × 22	CCD	CygnusMedia 3.0
Dexis	40 × 40	CCD	DEXIS Software 3.01
Dixi 2 v3	19 × 19	CCD	Dimaxis Pro 3.1.3
DSX 730 - USB	21 × 21	CCD	Owandy/Julie RV2000
DSX 730 - Évolution	21 × 21	CCD	Owandy/Julie RV2000
Sigma	39 × 39	CCD	CliniView 5.1
Sidexis	39 × 39	CCD	Sirona Sidexis XG
RVG-ui	19.5 × 19.5	CCD	Trophy Windows 5.05
RVG 6000	18.5 × 18.5	CMOS	Kodak Windows 6.0.1
RVG 5000	18.5 × 18.5	CMOS	Kodak Windows 6.0.1
ViperRay [M]	22.5 × 22.5	CCD	Vipersoft 4.0
Visualix HDI	22 × 22	CCD	VixWin 2000
Visiodent RSV	22 × 22	CCD	RSV Imaging XP
DenOptix	Scan Pitch	PIP	VixWin 2000
ScanX	Scan Pitch	PIP	EagleSoft 9.10
InSight	NA	Silver halide	NA

Table II. Measured spatial resolution (lp/mm)

CDR	9
CDR Wireless	9
CygnusRay MPS	8
Dexis	11
Dixi2 v3 High resolution mode	≥16
Dixi2 v3 Normal resolution mode	11
DSX 730	13
DSX 730 Évolution High resolution mode	9
DSX 730 Évolution Low resolution mode	8
Sigma	11
Sidexis	<10
RVG-ui High resolution mode	≥20
RVG-ui High sensitivity mode	12
RVG 6000	≥20
RVG 5000	≥14
ViperRay	7
Visualix HDI	11
Visiodent RSV	6
DenOptix 600 dpi scan	11
DenOptix 300 dpi scan	7
DenOptix 150 dpi scan	5
ScanX Very high resolution scan	9 horiz; 13 vertical
ScanX High resolution scan	8 horiz; 10 vertical
ScanX Standard resolution scan	7
InSight film	≥20

for the minimum acceptable exposure and cervical burnout, pixel blooming, or, depending on which came first, the maximum exposure attainable with the x-ray generator as dictating the upper limit.

Table III. Practical exposure ranges for human tooth specimens with 17-mm acrylic attenuation to simulate soft tissues

Detector	*Mode (if applicable)*	*Acceptable range (μGY)*	*Latitude ratio*
CDR		Min-585*	>4.5:1
CDR Wireless		Min-429*	>3.3:1
CygnusRay MPS		Min-509*	>4:1
Dexis		384-1387	3.6:1
Dixi2 v3	HR	Min-920*	>7:1
	Normal	Min-920*	>7:1
DSX 730 - USB		213-509	2.4:1
DSX 730 - Évolution	High	213-509	2.4:1
	Low	213-509	2.4:1
Visualix HDI		Min-669	>5.2:1
Visiodent RSV		420.7-877.6	2.1:1
Sigma		Min-458*	>3.6:1
Sidexis		Min-458*	>3.6:1
RVG-ui	HR	Min-1308*	>10.2:1
	HS	Min-882*	>6.9:1
RVG 6000		Min-2648*	>20.7:1
RVG 5000		213-4207*	19.8:1
ViperRay		250-1087	4.4:1
DenOptix	300 dpi	442-2336	5.3:1
ScanX	IVS	442-5518	12.5:1
	IS	442->5720†	>12.9:1
InSight		427-644	1.5:1

*Minimum exposure using standard x-ray generator produced diagnostic image. Actual minimal exposure not determinable under experimental conditions.
†Image not saturated at maximum exposure possible from x-ray generator.

RESULTS

Spatial resolution

Spatial resolution measured in lp/mm is listed for each of the systems in Table II. The highest spatial resolutions (≥ 20 lp/mm) were found for InSight film, the RVG-ui used in high-resolution (HR) mode, and the RVG 6000 detectors. The Planmeca Dixi2 v3 (high-resolution mode) achieved ≥16 lp/mm using a detector and software supplied and installed by the manufacturer (and was substantially superior to a previously tested Dixi2 v2). Resolution of 10 lp/mm or better was also determined for the Dexis, Dixi2 v3 (normal mode), DSX 730-USB (but not Évolution), Sigma, Kodak RVG-ui in high sensitivity mode, Kodak RVG 5000, Visualix HDI, DenOptix (600 dpi scan), and ScanX (very high resolution scan).

Contrast perceptibility

Without added highlight or color filters, only the CDR wired and wireless detectors, the Kodak RVG-ui, RVG 6000 and RVG 5000, and the Visualix HDI proved capable of detecting wells of 0.1 mm depth through 7 mm of aluminum. With added highlight filtration this was also possible using the Dixi2 v3. With added pseudocolor, this was also achieved by the AT ScanX in standard (low-resolution) mode and by the DSX 730 Évolution (low-resolution mode). All other detectors were able to detect wells of 0.2 mm or better within 7 mm of aluminum.

Practical exposure range

Table III lists the practically achievable ranges in acceptable exposures for each system tested using an unmodified commercially available standard dental x-ray generator. The mean minimum entrance exposure achieved under these conditions was 128 μGy. The widest ranges (and highest acceptable dosages permitting a diagnostic image) were found with the photostimulable phosphor systems and the RVG 6000 and RVG 5000 CMOS detectors.

DISCUSSION

Essential properties for a imaging system should include the following: (1) the image produced is of diagnostic quality; (2) the radiation dose is equal or reduced compared to that needed to expose analog film; (3) that digital radiology techniques are compatible with conventional x-ray generators; (4) that lossless archiving is allowed in an image file format that promotes interoperability within the DICOM standard; and (5) the time required for the total procedure should be equal to or less than with film. The present investigation was limited to the first 3 of these ideal property ingredients.

The detector need not be identical to film in all image properties; however, it must provide sufficient information for the diagnostic challenges at hand. The information needed might be task dependent: for example, high spatial resolution could well be needed to accurately measure the lengths of fine endodontic instruments, but might not be critical to the detection of proximal surface dental caries. At this time there is a surprising dearth of information on the resolution and contrast requirements for detection of different dental structures and disease processes both for analog film radiographs and for their digital counterparts. It should be remembered that the ideal detector should be able to multitask and therefore both sufficient spatial resolution and good contrast discrimination are needed. Irrespective of the stored image bit-depth (which varied from 8 to 16), all 18 detectors studied showed excellent contrast resolution in terms of perceptibility of low-contrast details. However, the image display for the digital images was a standard 8-bit computer monitor.

Substantial variations were determined for measured spatial resolution; however, the task-relevance of the measured spatial resolutions remains to be determined by carefully designed scientific trials. Only the Kodak RVG-ui, RVG 6000 CMOS detector, and InSight film proved capable of demonstrating 20 lp/mm or finer spatial resolution, with Planmeca Dixi2 v3 closely following at $\geq$ 16 lp/mm. It should be noted that some manufacturers' advertised claims of theoretical resolution based on pixel dimensions were not achieved in practice. Theoretical spatial resolution estimates based on picture element size do not provide consistently useful information regarding the actual spatial resolution of the system.

The question of whether newer detectors are compatible with existing dental x-ray generators can be answered both in the affirmative and in the negative. Yes, an acceptable diagnostic image could be achieved by all of the detectors with an unmodified dental x-ray generator. However, without increasing filtration or distance the minimum exposure for many solid-state detectors was not determinable. This suggests that additional radiation dosage savings might well be possible using generators capable of achieving lower exposures than commonly in present usage in combination with digital detectors.

CONCLUSIONS

Most current x-ray detectors generally perform well in terms of spatial and contrast resolutions, and in terms of exposure latitude. These findings were independent of the modality applied. Dental x-ray generators should be modified to provide lower exposure options when using digital x-ray detection systems for dentistry.

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