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Quality assurance phantom for digital dental imaging

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Objective. The purpose of this research was to develop a simple quality assurance phantom that could be used for the initial calibration and follow-up testing of commercially available intraoral digital imaging systems.
Study design. A radiographic phantom was constructed that contains a calibrated step wedge for measuring dose response, an etched pattern of slits in a metallic background for measuring the spatial resolution in line pairs per millimeter, and 2 rows of wells of varying diameter and depth in an acrylic background for contrast-detail analysis. Quality assurance protocols were developed and validated.
Results. The quality assurance phantom provides a method of assessing a digital intraoral imaging system by measuring the sensitivity and dynamic range, the contrast/detail detectability and the spatial resolution.
Conclusions. This quality assurance phantom can serve as an effective means to calibrate and monitor the performance characteristics of a digital dental intraoral imaging system. **(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:632-639)**

Although radiation exposure to individuals undergoing dental examinations is considered to be low relative to other diagnostic radiology examinations,[1] it is worth noting that the most frequent x-ray examination in the United Kingdom is the dental radiograph.[2] A similar situation exists in other European countries[3] and similarly in the United States, with approximately 100 million examinations per year.[4]

Most states and regulatory bodies have guidelines stating that regular quality assurance of all radiographic equipment is to be performed. Similar guidelines have been advocated by the American Academy of Oral and Maxillofacial Radiology[5,6] and the American Dental Association.[7] This means regular testing to detect equipment malfunctions, and planned monitoring and scheduled maintenance to produce consistent diagnostic radiographic images. All dental facilities using x-ray equipment, from a simple intraoral dental unit to an advanced 3-dimensional imaging system, such as cone beam computed tomography, will benefit from adopting a quality assurance program.

There are 3 components involved with any intraoral digital imaging system: the intraoral x-ray generator, the digital image acquisition component (solid-state sensor or photostimulable phosphor [PSP] plate and scanner), and the image display component (computer/monitor). Each of these components needs to be regularly monitored for performance and function as part of the quality assurance program.

The intraoral x-ray generator should be tested for x-ray filtration, half-value layer, x-ray beam collimation and alignment, and tube head stability as part of the initial equipment acceptance testing.[8] The x-ray generator may be evaluated periodically by measuring the x-ray output, operating potential, and exposure time. Probably the simplest quality assurance assessment would be measuring the tube output at periodic inter-

All three authors are joint developers and inventors of the intra-oral imaging phantom with a patent pending on the above-described device by Dental Imaging Consultants LLC, San Antonio, TX.

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vals under the same geometry. This quantity can be compared from time to time to help establish consistency in equipment performance.[9]

Another aspect of the digital imaging chain that requires verification of performance standards is the computer display monitor. The image display component can be evaluated by displaying a standard digital image, such as the Society for Motion Picture and Television Engineers (SMPTE) Medical Diagnostic Imaging Test Pattern.[10] The contrast and brightness should be adjusted to optimize contrast at the lowest and highest luminance of the image. Optimal viewing conditions include a quiet, darkened room with proper digital background masking of the screen so that most of the light from the display is from the digital image. The overall SMPTE image appearance should be inspected to ensure the absence of gross artifacts, such as blurring or bleeding of bright display areas into dark areas or aliasing of spatial resolution patterns. As a dynamic range test, both the 5% and 95% areas should be seen as distinct from the respective adjacent 0% and 100% areas.

The digital image acquisition component can be evaluated either qualitatively or quantitatively using a radiographic phantom designed to produce a digital image containing information related to fundamental imaging characteristics. These include spatial resolution, contrast resolution or dynamic range, contrast/detail resolution, field uniformity, saturation, and signal-to-noise response. Several such quality assurance phantoms have been described in the literature.

One phantom designed primarily for conventional x-ray film is the Center for Devices and Radiological Health (CDRH) Dental Image Quality Test Tool.[11] The phantom was developed as a joint collaboration with the Food and Drug Administration (FDA), CDRH, and Conference of Radiation Control Program Directors. The phantom is designed specifically for testing the functionality of dental x-ray units and provides a means of evaluating x-ray output, half-value layer, and overall image quality. The test tool also contains a human tooth to simulate a clinical image.

Another phantom is the QUART DigiTest/DigiDent Dental phantom (Zorneding, Germany),[12] which is designed to monitor high-contrast and low-contrast spatial resolution. In addition, an Unfors Mult-O-Meter (Billal, Sweden) external detector can be inserted into the phantom to measure kVp, dose, and exposure time.

A third phantom is the CD Dent phantom (Elimpex-Medizintechnik, Austria),[13] which is designed to monitor high-contrast and low-contrast spatial resolution. It is a 3-mm-thick piece of aluminum with 100 cylindrical holes of varying depths and diameters. The CD Dent phantom is promoted as an aid for improving image quality.

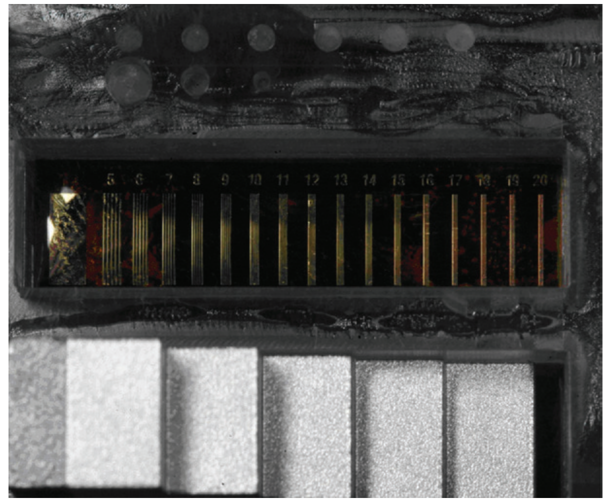

Fig. 1. Internal components of intraoral digital dental quality assurance phantom. Image is available in color at www.ooooe.net.

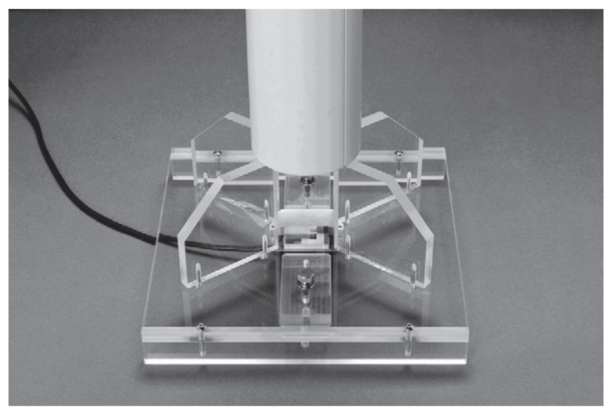

Fig. 2. Beam indicating device positioned on dental digital quality assurance phantom.

Another test device, the Diquad Analyzer (Steger, IL, USA), has been recently introduced for evaluating the performance of film-based and digital intraoral imaging systems in the United States. This device consists of a Luxel+ dosimeter from Landauer, Inc. and 2 Kodak dental films (Rochester, NY, USA), D and E-F speed.

The problem is that the described quality assurance devices fail to provide an adequate representation of digital imaging in a clinical situation where the physical properties of dynamic range, contrast perceptibility, and spatial resolution work simultane-

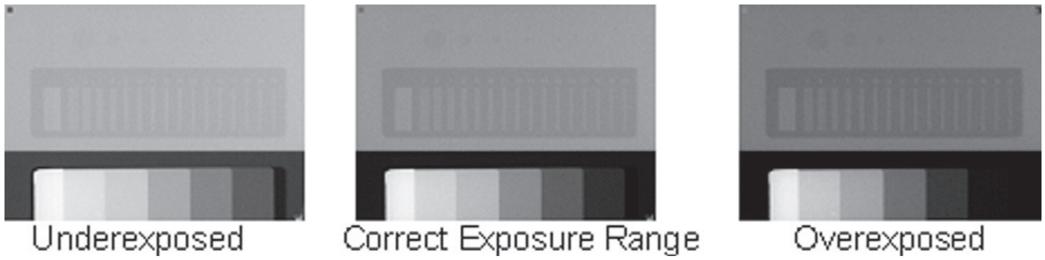

Fig. 3. Radiographs depicting various exposures.

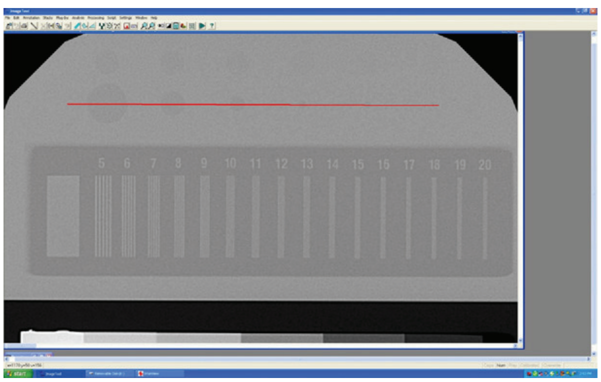

Fig. 4. Computer screen indicating a line profile for contrast detail analysis. Image is available in color at www.ooooe.net.

ously to create the observed radiographic image. All these features need to be evaluated in a single image at a source-to-detector distance that is representative of that used in the clinical environment. Although the previously described quality assurance devices will measure some of the features, they do not perform this evaluation at a distance that which is representative of clinical practice.

The purpose of this research was to develop and test a simple quality assurance phantom designed specifically for digital intraoral radiography.

MATERIAL AND METHODS

Radiographic phantom

A new quality assurance phantom for intraoral digital dental imaging has been developed at the University of Texas Health Science Center at San Antonio (UTHSCSA) (Fig. 1). The phantom contains 4 components: (1) an aluminum alloy 1100 step wedge of sufficient thickness to simulate the range of subject contrast encountered in dental intraoral radiography; (2) a piece of polymethyl methacrylate plastic of uniform thickness with 2 series of 6 cylindrical wells, one of constant diameter and varying depths (0.125-0.75 mm) and another series of cylindrical wells of gradually diminishing diameter (0.20-2.5 mm) and uniform depth to provide low-contrast detectability patterns; (3) a high-contrast pattern of line pairs with gradually increasing spatial frequency encompassing the range of frequencies encountered in dental intraoral radiography; and (4) a 7-mm-thick piece of aluminum alloy 1100 material overlying areas (2) and (3) to attenuate the x-ray photons to the middle portion of the range determined by the step wedge, as shown in Fig. 1.

The imaging area of the intraoral phantom is approximately 31 × 41 mm (suitable for any #2 size imaging device). To stabilize the intraoral phantom, the device has been incorporated into a large acrylic base with supporting beams to allow for clearance of the sensor and on the top aspect there are 4 stops for the beam-indicating device of the x-ray source to rest on. These 4 plastic rest tabs allow the beam-indicating device to rest securely and ensure a parallel alignment of the x-ray source and sensor for both round and rectangular beam-indicating devices. These rest tabs also establish a source-to-receptor distance equivalent to that used for clinical imaging with the use of Dentsply Rinn (Elgin, IL, USA) or similar positioning devices.

Initial baseline assessment

The detector to be evaluated is placed directly under the central portion of the phantom device and secured in position by adjusting the 2 spring-loaded clamps to center the detector (Fig. 2). With size 0 or 1 sensors, the operator may need to adjust the position of the sensor to image all the contrast detail wells. This may cut off part of the step-wedge portion of the phantom owing to the small active areas on the size #0 or #1 detectors. The x-ray beam–indicating device is placed directly on top of the 4 rest tabs on the top of the phantom to maintain reproducible x-ray projection geometry.

The kVp and mA are adjusted to the settings that will be used for clinical exposures. Starting at the lowest possible exposure time, a series of digital images is acquired and saved while incrementally increasing the exposure time. The next step is to determine the highest and lowest exposure where all of the features of the

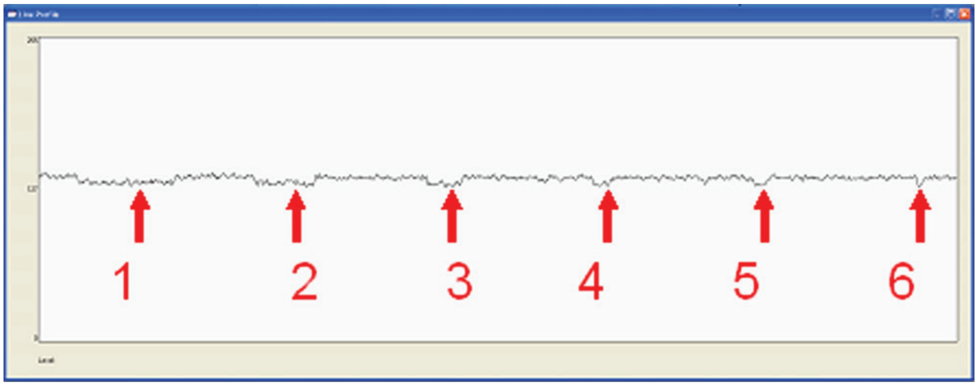

Fig. 5. Plot of intensity values for contrast detail analysis. Image is available in color at www.ooooe.net.

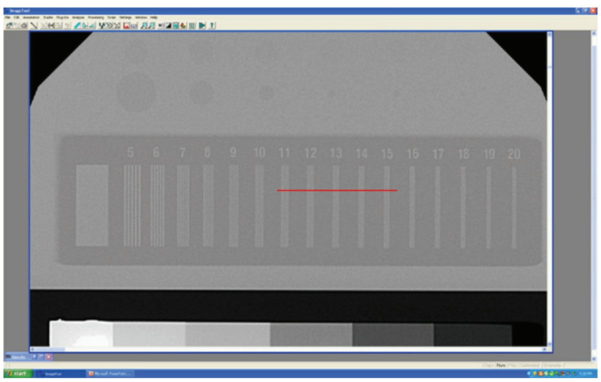

Fig. 6. Computer screen image indicating line profile for spatial resolution analysis. Image is available in color at www.ooooe.net.

phantom, including all the steps (7 density levels) of the wedge, can be clearly delineated. Examples of images of the radiographic phantom at low, middle, and high exposures are shown in Fig. 3.

The number of discernible line pairs (maximum 20) and the number of wells (maximum 6) in both rows of the low-contrast perceptibility are determined for each image. The lowest exposure in which the maximum line-pairs and maximum number of wells in each row can be visualized is selected as the baseline quality assurance exposure.

Longitudinal quality assessment

At each monitoring interval, a new digital image of the phantom is acquired using the baseline quality assurance exposure. This image is compared with the baseline quality assessment image for any change in dynamic range, high-contrast spatial resolution, or contrast/detail resolution.

Subjective versus objective analysis

A subjective analysis can be performed with the naked eye but such an analysis is subject to many variations, such as eyesight and perceptual ability among users, eye fatigue, stress, lighting conditions, and a host of other variables. An objective analysis, therefore, would be more consistent and suitable for a quality assurance program to detect even small variations from the baseline image.

One alternative to subjective analysis is an objective computer-based analysis of the various portions of the digital dental quality assurance phantom using the UTHSCSA ImageTool or equivalent computer software. ImageTool is a Microsoft Windows–based image processing and analysis program that is freely available via the World Wide Web at http://ddsdx.uthscsa.edu/dig/download.html. The software supports a wide range of file formats, including .tif, .jpg, or .bmp. The digital quality assessment image can be opened in a window.

To analyze the low-contrast perceptibility in the low-contrast wells, a line profile can be drawn across the entire set of 6 contrast wells, as shown in Fig. 4. The results on the image are then displayed on the computer screen as an image with deflections in the line where a contrast well is detected, as shown in Fig. 5.

To analyze the high-contrast spatial resolution, a line is drawn across the line-pair section of the image using the line profile tool in the UTHSCSA ImageTool, as shown in Fig. 6, and the associated line profile is displayed in Fig. 7. The highest line-pair segment with 5 distinct peaks and 4 distinct troughs is considered the spatial resolution of the system.

Even the steps in the step wedge can be analyzed using the UTHSCSA ImageTool software, by drawing a line profile across the steps on the dynamic range portion of the Dental Digital Quality Assurance (DDQA) phantom, as shown in Fig. 8. The image displayed on the screen

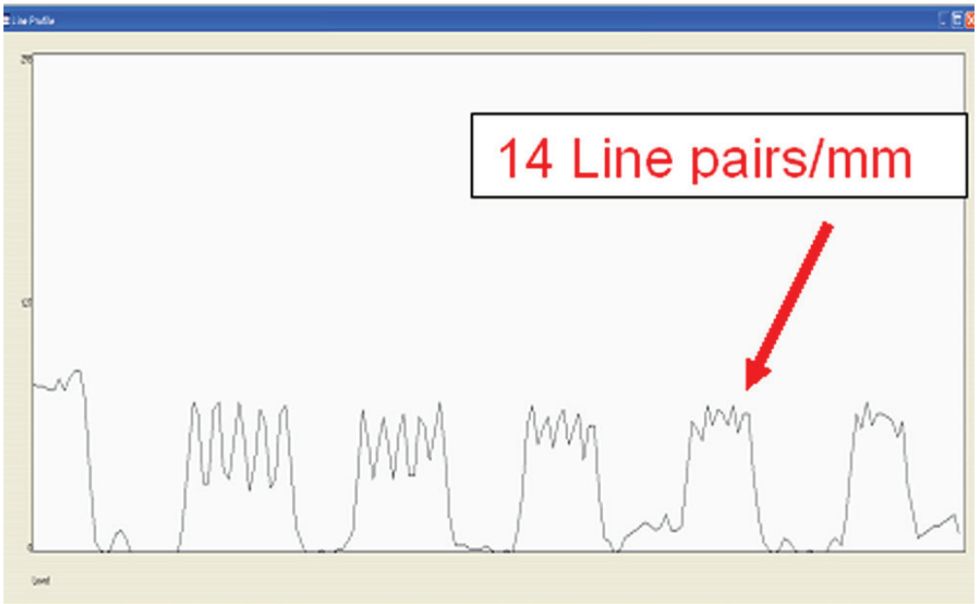

Fig. 7. Plot of intensity values for spatial resolution analysis. Image is available in color at www.ooooe.net.

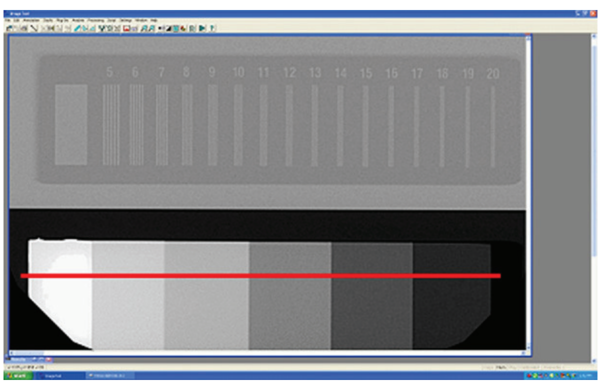

Fig. 8. Computer screen image indicating line profile for dynamic range analysis. Image is available in color at www.ooooe.net.

would appear similar to the one in Fig. 9 where each step is visualized.

Validation

The new phantom has been deployed as part of a comprehensive digital radiology quality assurance program for digital imaging at the University of Texas Dental School at San Antonio Outpatient Clinic. The quality assurance program is intended to ensure that the complete imaging system of the x-ray source, sensor or imaging medium, and monitor display is operating effectively. A change in any of the optimal performance properties would result in a change in the overall performance of the intraoral imaging system.

Table I shows the results of a series of exposures used to determine the baseline exposure level for a representative PSP plate system in the outpatient clinic. As the exposure time is increased, the number of visible line pairs and contrast wells increases until it reaches a peak performance at an exposure time of 0.200 seconds. This was selected as the baseline exposure. For times beyond 0.400 seconds, the thinnest steps are no longer visible.

Table II shows baseline reference exposures for 3 different types of digital intraoral image receptors within the clinic. It will be noted that the baseline exposures differ widely among systems, even within systems of the same type.

Table III shows a longitudinal assessment of the same imaging system with PSP plates and the same x-ray generator. At monthly intervals, an exposure was made at the baseline exposure settings of 63 kVp, 8 mA, and 0.200 seconds and the data were recorded. It will be noted that the 3 measured parameters of dynamic range, spatial resolution, and contrast perceptibility remained the same as the baseline exposure, indicating there was no degradation of the imaging system performance over a 3-month period.

In clinical practice, images may appear normal despite the presence of underlying problems with the imaging system. An example is shown in Fig 10. When an image is acquired using the same sensor with the DDQA phantom, a Swiss-cheese pattern is noted across

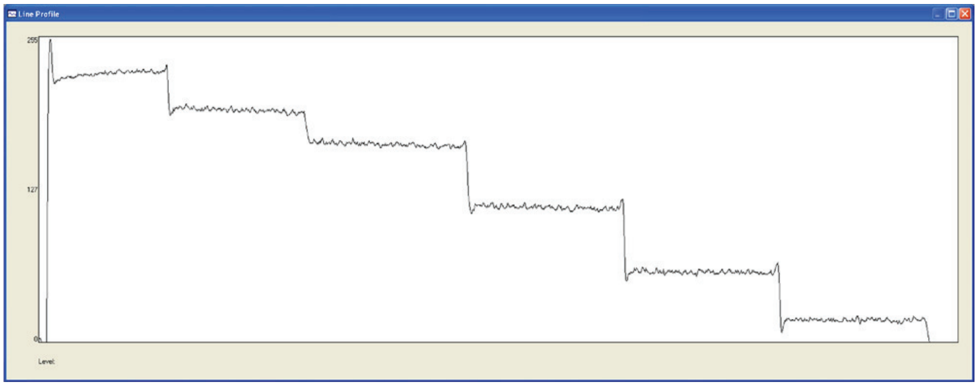

Fig. 9. Plot of intensity values for contrast detail analysis. Image is available in color at www.ooooe.net.

Table I. Initial baseline worksheet
Digital dental quality assurance

Exposure time, s	*Steps*	*Line-pairs*	*Top row of contrast wells*	*Second row of contrast wells*
0.010	7	6	0	1
0.012	7	6	0	1
0.016	7	6	0	2
0.020	7	6	1	4
0.025	7	6	1	4
0.032	7	6	1	4
0.040	7	6	2	4
0.050	7	7	2	5
0.064	7	7	2	5
0.080	7	7	2	5
0.100	7	7	3	5
0.125	7	7	3	5
0.160	7	7	3	5
0.200	7	7	4	6
0.250	7	7	4	6
0.320	7	7	4	6
0.400	7	7	4	6
0.500	6	7	4	6

Date: August 1, 2010.
Sensor: Air techniques PSP.
X-ray machine: Planmeca Intra.
kVp: 63.
mA: 8.
Technician: Pat Smith.
Baseline Quality Assurance Exposure: 0.200 seconds.

the entire sensor surface with a resulting loss in image quality as measured in contrast perceptibility and spatial resolution (Figs. 10 and 11). Even if one were to perceive the circular patterns on Fig. 10, they may be misinterpreted as calcifications or pulp stones in the pulp space or the circular patterns as calcifications in the gingival tissue and possibly an osteitis, osteoma, or even periapical cemento-osseous dysplasia in the bony regions.

DISCUSSION

There are many motivations for dentists and the dental industry to introduce digital radiography systems into dental practice, including reduction in patient radiation, decrease in treatment time, decrease in dental office space, elimination of harmful processing chemicals, improved information management, improved diagnostic value of radiographic images, and ultimately better patient care.[1-9,11,14-18]

Radiographic image quality is critical to the value of radiographic images and may affect the diagnosis and associated treatment decisions.[7,18] Nevertheless, from the time they are first installed by the service technician or manufacturer's representative, most dental practices do not conduct quality control assessments of the performance of digital intraoral sensors. Most dentists and dental auxiliaries do not have the time or knowledge on how to test the function of the digital intraoral sensors. Moreover, the dentist, hygienist, and dental auxiliary have no standard on which to base the quality of digital images. Digital images may be easily subject to an underexposure or overexposure, which has been ignored by both clinicians and manufacturers of digital imaging equipment alike in favor of an image that is esthetically pleasing to the eye of the clinician.

The test phantom described in this article was designed to aid the dentist or dental auxiliary in determining the qualities of the sensor at hand and to monitor its function over time. The phantom has been demonstrated to be easy to use and requires approximately 15 to 20 minutes to perform the initial baseline assessment and only a couple of minutes for the longitudinal assessment. Using this phantom, quality assurance is a simple process that can be performed at any time in a dental office setting without additional training and other specialized equipment.

Table II. Sample of results from various digital systems

Types of digital image receptor	*Exposure parameters*	*Entrance air dose, mGy*	*Dynamic range (# visible steps)*	*High-contrast spatial resolution (line pairs /mm)*	*Low-contrast perception constant depth*	*Low-contrast perception constant diameter*
PSP 1	63 kVp 8 mA 0.200 s	1.187	7	8	4	6
PSP 2	63 kVp 8 mA 0.200 s	1.187	7	8	3	6
CCD	63 kVp 8 mA 0.064 s	0.377	7	7	3	6
CMOS 1	63 kVp 8 mA 0.200 s	1.187	7	15	4	6
CMOS 2	63 kVp 8 mA 0.125 s	0.739	7	8	1	5
CMOS 3	63 kVp 8 mA 0.064 s	0.377	7	8	2	5

Table III. Longitudinal quality assurance record

Baseline date	*Technician*	*Steps*	*Line-pairs*	*Top row of contrast holes*	*Second row of contrast holes*
August 1, 2010	Pat Smith	7	8	4	6
Date	*Technician*	*Steps*	*Line-pairs*	*Top row of contrast holes*	*Second row of contrast holes*
September 1, 2010	Pat Smith	7	8	4	6
October 1, 2010	Pat Smith	7	8	4	6
November 1, 2010	Pat Smith	7	8	4	6

Sensor: Air techniques PSP.
X-ray machine: Planmeca Intra.
kVp: 63.
mA: 8.
Baseline Quality Assurance Exposure: 0.200 seconds.

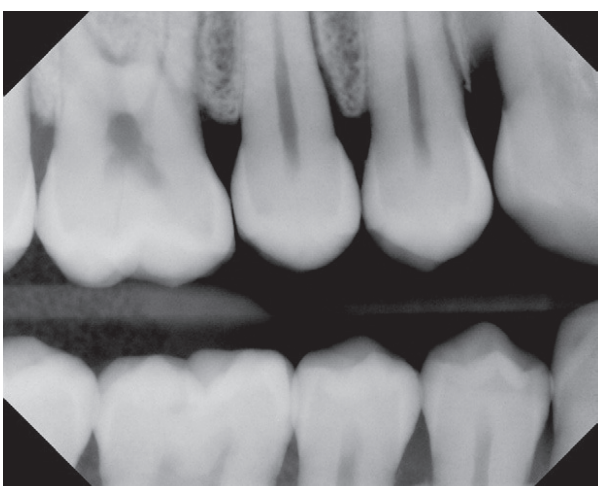

Fig. 10. Radiographic image of teeth on defective sensor.

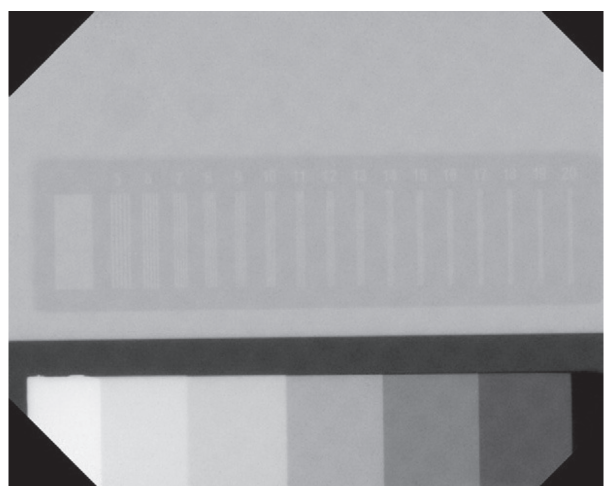

Fig. 11. Radiographic image of dental digital quality assurance phantom on defective sensor.

Although the phantom allows the operator to determine if there is deterioration in image quality of the system, it does not isolate the exact cause of the problem. Other tests and steps may be required to deduce the exact nature of the problem, such as x-ray source output, computer monitor display parameters, and radiographic technique among other possible sources of error.

CONCLUSIONS

The dental x-ray phantom developed in this study is a useful tool for quality assurance. The device will allow a dentist or an auxiliary staff member to perform an assessment of any intraoral imaging system using an objective evaluation of 3 performance parameters:

range of sensitivity, contrast detail resolution, and image resolution as measured in line pairs/mm. A change in these characteristics on a subsequent occasion may indicate to the user that deterioration may have taken place and that corrective action is required. Regular quality control monitoring with this phantom should be combined with periodic monitoring of the x-ray equipment and video display.

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