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Digital intraoral radiographic quality assurance and control in private practice

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At present, the American Dental Association and the American Academy of Oral Maxillofacial Radiology have guidelines for the dental environment that include quality assurance and control of film-based radiography. Approximately 19%-30% of US dental offices use some form of digital intraoral radiography, and growth is expected to continue. It is anticipated that new tools and guidelines will be needed to aid in the development of quality assurance (QA) and control of digital intraoral radiographic images. Working with a representative sample of private practice dental offices, this study examined and evaluated the entire digital intraoral radiographic system used in each operatory. The X-ray machine was tested for equipment performance and accuracy, and the computer monitor calibration was evaluated and adjusted as needed.

The results confirm the continued need for updated QA procedures in the dental office that include digital X-ray imaging. By implementing these changes and practices, dentists should be able to improve the diagnostic quality of radiographs while reducing the radiation exposure of the patient.

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In their textbook, *Oral Radiology: Principles and Interpretation,* White & Pharoah state:

A quality assurance (QA) program in radiology is a series of procedures designed to ensure optimal and consistent operation of each component in the imaging chain. When all components are functioning properly, the result is consistently high quality radiographs made with low exposure to patients and office personnel.[1]

Beginning in the 1960s, several national studies were initiated that pointed out the need for quality assurance in medical and dental radiology. The Division of Radiologic Health, within the United States Public Health Service, conducted a program called *SurPak,* the goal of which was to identify X-ray generators that were lacking sufficient filtration and collimation.[2] In the 1970s, the Nashville Dental Project, conducted by the Bureau of Radiological Health (formerly the Division of Radiologic Health), was directed toward the elimination of unnecessary exposure to the dental patient. Also in the 1970s, the Bureau of Radiological Health conducted the *Nationwide Evaluation of X-Ray Trends* (NEXT), which focused on patients' exposure to ionizing radiation during standard examinations. Dental radiology was included in this evaluation.[2] Another project was the *Dental Exposure Normalization Technique* (DENT), which found that 40% of the X-ray units evaluated were operating in excess of the recommended ranges.[2,3]

In December 1979, the Bureau of Radiological Health published a set of QA guidelines based on the recommendations of their Medical Radiation Advisory Committee.[4] These guidelines were general in nature, and covered all diagnostic radiology facilities, including dental offices. In 1981, Valachovic et al outlined a program for QA tests and frequency of performance, tailored specifically for the private dental office.[5] In 1983, the Quality Assurance Committee of the *American Academy of Dental Radiology* (now *American Academy of Oral and Maxillofacial Radiology*) published a set of QA guidelines based on the Bureau of Radiological Health guidelines, but designed specifically for dental use.[6] The authors of the National Council on Radiation Protection and Measurements' (NCRP) Report No. 145, *Radiation Protection in Dentistry,* referred to the protocol proposed by Valachovic et al when making their own QA recommendations.[5,7] In September 2006, the *American Dental Association's* (ADA) Council on Scientific Affairs updated its recommendations (based on NCRP Report No. 145) for the use of dental radiographs.[8] The Council recommended developing and implementing QA protocols in each dental healthcare setting for the X-ray machine, imaging receptor, film processing, dark room, leaded aprons, and thyroid collar.[8] For example, the X-ray machine should be inspected at regular intervals by a qualified expert, per state regulations. The film processor should be evaluated daily using 1 of 3 methods: sensitometry and dosimetry, stepwedge, and reference film. Image receptor devices (such as film and intensifying screens) along with the cassettes should be inspected every 1-6 months. Darkroom integrity should be checked monthly, along with a leaded apron and collar inspection.[8] This protocol was also recommended by White & Pharoah.[1]

Many states require by law that dentists have a written QA protocol for dental radiography. For instance, Texas law §289.232(i)(7) states:

For all dental radiation machines, the registrant shall perform, or cause to be performed, tests necessary to ensure proper functioning of equipment with the indicated standard for each item specified in paragraph (6) (H)-(M) of this subsection. After installation, the test listed shall be performed every four years.[9]

Historically, published QA and quality control (QC) protocols were intended for film-based radiography. In fact, NCRP Report No. 145 refers to digital radiography by acknowledging that "the required standards, apparatus and software for dental systems do not currently exist."[7] With the advent of digital intraoral radiography, the details are different but the need for QA remains. In addition to the

X-ray equipment, any guidelines for QA must consider the digital sensor's dynamic range, contrast detail resolution, contrast depth resolution, and spatial resolution, as well as the settings of the computer monitors used to view the radiographs and all of the working software programs.[10] The computer display monitor should conform to a standardized digital image, such as the Society of Motion Picture and Television Engineers (SMPTE) test pattern for medical viewing monitors.[11,12] The computer used for diagnosis and treatment planning should be located in an area of the office that is suitable for optimum viewing, with subdued lighting and a quiet environment.[8]

A matter of great concern has always been the entrance skin exposure (ESE) of ionizing radiation used to obtain a diagnostic radiograph.[13] Currently, the *Diagnostic Reference Level* (DRL) and *Achievable Dose* are being promoted widely as standards of practice.[10,14] The ICRP Report No. 73 recommended using DRLs for patients to maintain or improve image quality "appropriate to the clinical requirements of the procedure through the process of optimization."[15] The report defines optimization as the process of assuring clinically effective images while achieving the appropriate radiation dose to the patient.[15] In 2001, the state of New Jersey implemented changes in their radiation control program, with ESE and image quality among the criteria to be measured.[13]

A 2008 study by Gallagher et al suggested the need for a commercially available test phantom to evaluate image quality.[16] Several phantoms are available for dental use. The US Food and Drug Administration Center for Devices and Radiological Health created a dental image quality test tool for film-based dental radiographs.[3] Other devices have been designed that are intended to be used with digital-based imaging systems. For the present study, the authors selected the Digital Dental QA (DDQA) phantom (Dental Imaging Consultants, LLC) because it was designed specifically for clinical application.[17]

This pilot study sought to determine if implementing QC tests designed specifically for digital dental radiography would prove beneficial in a private office environment.[17] The settings and calibrations of the X-ray equipment and sensors, the technique factors used, the associated radiation doses, and the viewing environments of a sample of private offices were evaluated. Appropriate recommendations for optimizing a system were made if needed.

Materials and methods

Twelve representative dental offices that used digital radiography were visited. Six offices used Schick sensors (Sirona Dental Systems, Inc.) and 6 offices used Dexis sensors (Henry Schein Dental). The essential components of the intraoral digital radiographic system used in each operatory were evaluated using the Unfors Solo Rad Meter (RaySafe), the DDQA radiographic phantom, and the SMPTE medical video monitor calibration pattern.[11] These tools tested the accuracy and consistency of the X-ray machine parameters, the ESE, the quality of the digital image, and the calibration setting of the monitor. All combinations of sensors and X-ray machines used in the offices were evaluated.

X-ray measurements

The X-ray tube was positioned directly over—and in contact with—the Unfors Solo Rad sensor. The accuracy of the peak kilovoltage (kVp), the reproducibility of repeated exposures, and the half-value layer of each X-ray generator were measured. Using the adult molar bitewing exposure setting for each individual machine used routinely in daily practice, the ESE was measured and recorded. All data were tabulated within an Excel spreadsheet (Microsoft).

Image quality measurements

The DDQA phantom was used to assess image quality. This phantom consists of 4 primary components: a 5-step aluminum (Al) step wedge (with a sixth step of lead and a seventh step of air for dynamic range), 6 low-contrast resolution wells of varying depth, 6 low-contrast detail wells of varying diameters, and a high-contrast resolution line pair gauge measuring 5 to 20 line pairs/mm. The line pair gauge and 2 rows of contrast wells were covered by an Al alloy block (7 mm thick) to ensure that the background density was midway on the gray scale. Four vertical acrylic spacers (measuring 2.75 inches from the base of the DDQA phantom) were used to approximate a clinical distance from the X-ray source to the sensor and to ensure accurate, repeatable placement of the X-ray tubehead.[17]

A series of radiographic images with the DDQA phantom was acquired with the digital intraoral sensor/X-ray machine combination used in each operatory. The series began with very low exposures; eventually, the exposure time was increased up to and beyond the routine setting used for an adult molar bitewing. The radiographic images acquired were exported from the acquisition software and saved in .tif format for subsequent analysis. All images were assessed visually on a calibrated monitor and analyzed by a third-year oral maxillofacial radiology resident in a room with subdued lighting. At the time of analysis, 4 parameters were evaluated, and the ImageJ software system—created by the National Institutes of Health—was used when applicable.[18,19]

The first parameter was the number of visible steps in the step wedge. The total number of distinct steps (including the air step) should equal 7. The grayscale density of each step in the wedge was measured and recorded.

The second parameter—high contrast resolution as defined by the number of visible line pairs/mm—was measured utilizing the ImageJ software.[19] A graph was produced with the line profile analysis tool; each visible group of line pairs will produce 5 distinct peaks and 4 valleys in the graph. The maximum line pair resolution is defined as the final group of peaks and valleys that can be resolved clearly. This analysis was accomplished by averaging the pixels on either side of the line drawn through the image of the line pair gauge. To produce a smooth graph, a total of 25 pixels on either side of the line was chosen.

The third parameter was visual identification of the total number of varying diameter wells that could be seen in the image. This number was evaluated and recorded. A similar evaluation was performed for the varying depth wells.

Monitor calibration and viewing conditions

The SMPTE medical viewing monitor test pattern was used to calibrate contrast and brightness of the computer monitors that were used to view radiographic images in the clinical setting. Brightness and contrast were considered acceptable

if 5% of the squares on either end of the grayscale were visible within the larger grayscale squares, with 0% representing black and 100% representing white. A linear test pattern (a known standard for comparison) also was incorporated to evaluate the monitors' spatial resolution and distortion.[12] In addition to evaluating monitor calibration, the environment in which the monitor was viewed was assessed for diagnostic purposes.

Results

Every monitor evaluated was located in the operatories tested and was operating within SMPTE standards. The lighting in the operatories was not subdued, and thus not ideal for diagnostic and treatment planning purposes. Diagnosis and treatment planning were conducted in the doctor's private office for all practices visited. Only 2 of the computer monitors could be accessed; both were operating within SMPTE standards.

Offices using Schick sensors

All 6 offices using Schick sensors used the same practice management software (Eaglesoft, Patterson Dental Supply, Inc.). Schick proprietary software was used for image capture and viewing. The first Schick office had 2 Schick Elite sensors in 5 operatories equipped with Preva X-ray units (Progeny Dental) operating at 60 kVp and 7 milliamperes (mA). For all units, the measured kVp was within 7% of the nominal kVp, and the coefficient of variation (CV) of repeated exposures was <1.2%. The half-value layer of aluminum (Al) for all units was greater than the 1.5 mm required by Texas state regulations. The ESE used for bitewing radiographs in the various operatories ranged from 89.8 to 101.6 milliroentgen (mR), with an average of 95.9 mR. These parameters resulted in images of the phantom with an average of 7 line pairs/mm, 5 varying-diameter wells, and 1 varying-depth well. A series of exposures (with decreasing exposure times) showed no significant deterioration in image quality to exposures at approximately 60 mR. Adjustments to this level resulted in a dose reduction of 35%.

The second Schick office had 1 Schick Elite sensor used in 3 operatories. The first operatory utilized an Image X 70 Plus X-ray machine (ImageWorks) operating at 70 kVp and 7 mA. This unit was operating at 8% over the set kVp, the CV of repeated exposures was 0.4%, and the half-value layer of Al measured 2.6 mm. The second operatory used a Marksman X-ray unit (SS White Burs, Inc.) operating at 70 kVp and 7 mA. The measured kVp was 3% lower than the nominal kVp for this unit. The CV of repeated exposures was less than 2.2% and the half-value layer of Al measured 1.9 mm. The third operatory had a Preva unit operating at 60 kVp and 7 mA, with a measured kVp 2% lower than the nominal kVp. The CV of repeated exposures was 1.5% and the half-value layer of Al was 2 mm.

The ESE used for bitewings in the first operatory was 35.9 mR. Increasing the exposure time by 25% increased the number of visible contrast wells. Exposures used in the second and third operatories were 30%-50% higher than optimum exposure for this sensor, and reduced exposure times were recommended.

The third office had 2 Schick CDR sensors in 4 operatories equipped with Sirona X-ray units (Sirona Dental Systems, Inc.) operating at 60 kVp and 7 mA. All X-ray units operated within 2% of the nominal kVp. The exposures had a CV of <0.8% and half-value Al layers ≥2.2 mm. The ESEs for the bitewing setting ranged from 64.3-84.7 mR; as a result, the step wedge image had only 6 visible steps. Decreasing exposure time by 20% extended the dynamic range to all 7 steps. Using this sensor under optimal conditions, 8-9 line pairs/mm, 4 constant diameter wells, and 2 varying depth wells were visible. In general, the Schick CDR sensor demonstrated better image quality and 30% lower ESE than the newer Schick Elite sensor.

The fourth Schick office had 2 Schick CDR sensors in 3 operatories. Two operatories had Heliodent DS X-ray units (Sirona Dental Systems, Inc.) operating at 60 kVp and 7 mA; the third had a Heliodent MD unit (Sirona Dental Systems, Inc.) operating at 70 kVp and 7 mA. The Heliodent DS units operated within 2% of the nominal kVp, a CV for repeated exposures of <1.5%, and half-value Al layers ≥2.4 mm. The kVp of the Heliodent MD unit was 5% lower than the nominal kVp; in addition, the unit's CV of repeated exposures was <0.1%. The bitewing settings resulted in phantom images with only 6 visible steps. An exposure reduction of approximately 20% resulted in a phantom with 7 visible steps, 7 line pairs/mm, 4 changing diameter wells, and 1 varying depth well. The fifth dental office had 2 Schick CDR sensors used in 4 operatories. These operatories were equipped with Gendex 770 X-ray units (Gendex Dental Systems) operating at 70 kVp and 7 mA. The measured kVp of all 4 units was within 8% of the nominal value and a CV of repeated exposures was <1.1% for all units. The recorded half-value layer of Al for all units was ≥2 mm. The ESE for the bitewing setting ranged from 68.2 to 79.9 mR, resulting in phantom images with 5-6 visible steps, 7-8 line pairs/mm, 5 changing diameter wells, and 2 changing depth wells. Only 1 of the Gendex 770 units could produce a phantom image with 7 visible steps due to the limited available exposure times. ESE was reduced by 30%-33% when the phantom image was optimized within the capability of the X-ray machines.

The sixth office used 1 Schick CDR sensor in 3 dental operatories. Three X-ray machines (Heliodent 70, Siemens Corporation) operated at 70 kVp and 7 mA. The measured kVp of all 3 units was within 5% of the nominal value. For all units, the CV of repeated exposures was <1.7%, the half-value layer of Al was ≥2.4 mm, and the ESE for the bitewing setting ranged from 50.8 to 95.7 mR. The timer on 1 X-ray unit was off by 20%, which could explain the large discrepancy. The phantom images produced at this setting resulted in only 5 visible steps for 1 unit; 6 steps were visible for the other 2 units. Altering the exposure times reduced the ESE by 30%-48% and produced phantom images with 7 steps, 7 line pairs/mm, 5 changing diameter wells, and 2 changing depth wells.

Offices using Dexis sensors

The 6 offices using Dexis sensors used Dentrix practice management software (Henry Schein Dental). All offices used Dexis proprietary image capture and viewing software.

The first Dexis office had 1 Dexis Platinum sensor and 1 operatory equipped with a Bel Ray II X-ray unit (Belmont Equipment) operating at 60 kVp and 7 mA. The measured kVp was 2% lower than the nominal kVp, while the CV of repeated exposures was <0.4%, and the

half-value layer of Al was 2.1 mm. The 132 mR ESE for the bitewing setting yielded a phantom image with 10 line pairs/mm, 5 changing diameter wells, and 4 changing depth wells. The ESE was reduced by 20% without degrading image quality.

The second Dexis office used a single Dexis Platinum sensor in 3 operatories. The first operatory was equipped with a Sanko X-ray unit (Sanko Co., Ltd.) operating at 70 kVp and 10 mA. The measured kVp was 7% higher than the nominal kVp, the CV of repeated exposures was 8.3%, and the recorded half-value layer of Al was 2.4 mm. Utilizing the bitewing setting, an ESE of 199.1 mR was recorded. The corresponding phantom image had 9 line pairs/mm, 6 changing diameter wells, and 4 changing depth wells. An optimized image was obtained with an ESE of 102 mR—a 51% reduction in patient exposure with no degradation in image quality. The second operatory utilized a Gendex 770, operating at 70 kVp and 7 mA. The measured kVp was 7% lower than the nominal value for this unit, the CV of repeated exposures was 1.2%, and the recorded half-value layer of Al was 2.3 mm. The ESE was 144.2 mR; the corresponding phantom image had 9 line pairs/mm, 6 changing diameter wells, and 4 changing depth wells. A 36% reduction in ESE (to 93 mR) was achieved with no degradation of image quality. The X-ray unit in the third operatory was a Dens-O-Mat (Phillips Scientific) operating at 65 kVp and 7.5 mA. The measured kVp was 4% lower than the nominal value, the CV of repeated exposures was 1%, and the half-value layer of Al was 1.9 mm. The bitewing setting produced an ESE of 367.7 mR and a phantom image showing 9 line pairs/mm, 6 changing diameter wells, and 4 changing depth wells. Due to the settings available for the Dens-O-Mat unit, it was impossible to reduce the ESE below 274.6 mR. The authors recommended discontinuing the use of this unit if the dentist is unable to produce an acceptable ESE level.

The third Dexis office used 3 Dexis Platinum sensors in 3 different operatories. The first operatory had a Gendex 765 DC, operating at 70 kVp and 6.5 mA. The measured kVp was 9% lower than the nominal kVp, the CV of repeated exposure was 0.5%, and the half-value layer of Al was 2.3 mm. The bitewing setting produced an ESE of 164.7 mR, with a phantom image showing 7 line pairs/mm, 6 changing diameter wells, and 2 changing depth wells. A 23% reduction in ESE to the patient was achieved without loss of image quality. The second operatory had a Planmeca Intra X-ray unit (Planmeca USA) operating at 63 kVp and 8 mA. The measured kVp of this unit was 3% lower than the nominal value. The CV of repeated exposures was 0.8%. The half-value layer of Al was 2 mm. The bitewing setting produced an ESE of 243.8 mR and a phantom image with 7 line pairs/mm, 6 changing diameter wells, and 3 changing depth wells. ESE was reduced by 38% without loss of image quality. The third operatory used a Heliodent MD operating at 70 kVp and 7 mA. The measured kVp was within 1% of the nominal kVp, the CV of repeated exposures was 0.1%, and the half-value layer of Al was 2.4 mm. The bitewing setting produced an ESE of 188 mR and a phantom image with 7 line pairs/mm, 6 changing diameter wells, and 3 changing depth wells. A 38% reduction in ESE was achieved without loss of image quality. It should be noted that in this office, the low resolution mode of software was selected. The authors recommended using the high resolution mode.

The fourth Dexis office had 1 Dexis Platinum sensor for 5 operatories. The first 3 operatories had a Trophy FU 47 X-ray unit (Eastman Kodak Company) operating at 70 kVp and 8 mA. In the first operatory, the measured kVp fluctuated randomly by as much as 16% from the nominal value, contrary to Texas state regulations. A CV of 1.7% was recorded for multiple exposures. The half-value layer of Al was 2.3 mm. The bitewing setting produced an ESE of 161.2 mR and a phantom image with 10 line pairs/mm, 5 changing diameter wells, and 3 changing depth wells. Decreasing the exposure time reduced patient ESE by 60% without loss of image quality. In the second operatory, the measured kVp was within 2% of the nominal value. A CV of 3% was recorded for multiple exposures, with a recorded 2.1 mm half-value Al layer. The bitewing setting produced an ESE of 94.1 mR and an image with 7 line pairs/mm, 6 changing diameter wells, and 1 changing depth well. A 23% reduction in ESE was achieved without loss of image quality. The third operatory was also equipped with a Trophy FU 47, operating at 70 kVp and 8 mA. This unit operated with a measured kVp 12% lower than the nominal value, greater than the 10% allowed by Texas regulations. A CV of 0.3% was recorded for multiple exposures, with a 2.2 mm half-value layer of Al. The bitewing setting produced an ESE of 151.1 mR and a phantom image with 8 line pairs/mm, 5 changing diameter wells, and 1 changing depth well. ESE was reduced by 31% without loss of image quality. The fourth operatory utilized a YOSHIDA X-70 X-ray unit (THE YOSHIDA DENTAL MFG. COMPANY, LTD) operating at 70 kVp with 15 mA. The measured kVp was 2% lower than the nominal value. A CV of 2.7% was recorded with multiple exposures and the half-value layer of Al was 2.3 mm. The bitewing setting produced an ESE of 93.2 mR and yielded an image with 7 line pairs/mm, 6 changing diameter wells, and 3 changing depth wells. ESE was reduced by 17% without loss of image quality. The fifth X-ray unit was a Bel Ray II operating at 70 kVp and 7 mA. The measured kVp was 3% lower than the nominal value, with a CV of 1.4% recorded for multiple exposures, and a 2.2 mm half-value layer of Al. The ESE from the bitewing setting was recorded at 61.4 mR. This exposure yielded an image of 8 line pairs/mm, 5 changing diameter wells, and 2 changing depth wells. An increase of 30% in the ESE was required to improve image quality to 9 line pairs/mm, 6 changing diameter wells, and 3 changing depth wells.

The fifth Dexis office used a single Dexis 601P sensor in 4 operatories. Three operatories were equipped with Heliodent DS X-ray machines operating at 60 kVp and 7 mA. For all units, the measured kVp was within 3% of the nominal value, with a CV ≤0.1% recorded with multiple exposures, and the half-value layer of Al was ≥2.1 mm. Utilizing the bitewing setting, ESE values ranged from 222.2-236.0 mR, producing an image with 7 line pairs/mm, 6 changing diameter wells, and 2 changing depth wells. An average ESE reduction of 63% was achieved without significant deterioration of image quality. The fourth operatory employed a Planmeca Intra X-ray unit operating at

63 kVp and 8 mA. The measured kVp was within 1% of the set value of this unit. For multiple exposures a CV of 0.7% was recorded, while the half-value layer of Al was 2.2 mm. The bitewing setting had an ESE of 78.9 mR that produced an image of 7 line pairs/mm, 4 changing diameter wells, and no changing depth wells. A 47% increase in ESE was required to produce an optimal image with 7 line pairs/mm, 6 changing diameter wells, and 1 changing depth well.

The sixth Dexis office had 3 Dexis 601P sensors in 4 operatories, equipped with Gendex 770 units operating at 70 kVp and 7 mA. The measured kVp of all units was within 12% of the nominal value for this X-ray machine, and 2 of the units differed from the nominal value by more than the 10% permitted by Texas regulations. A CV of ≤3.5% was recorded for multiple exposures. The bitewing setting in the various operatories produced ESE values ranging from 128.2 to 172.3 mR. Experience with similar sensors used in other dental offices suggests that patient exposure could be decreased significantly with no loss of image quality. Unfortunately, all 3 sensors produced a phantom image with an overlying honeycomb pattern that prevented the analysis of all the images (Fig. 1). This appeared to be a calibration error, and the doctor was notified.

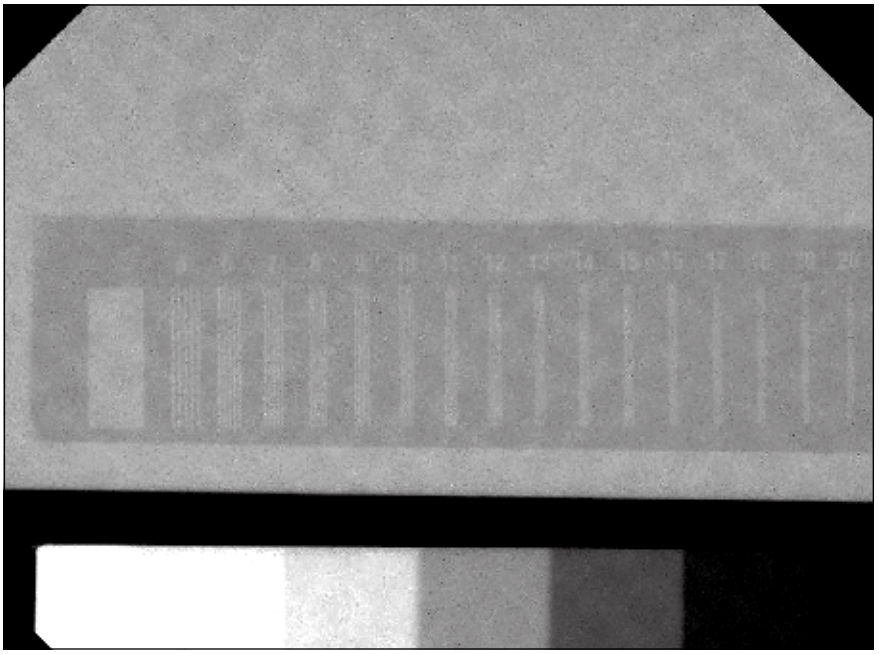


Fig. 1. An example of a phantom image with an overlying honeycomb pattern.

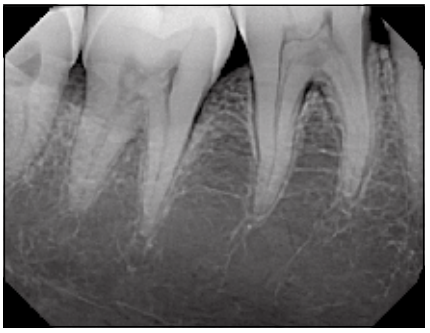


Fig. 2. Radiograph of a hemimandibular phantom taken at 367.7 mR exposure.

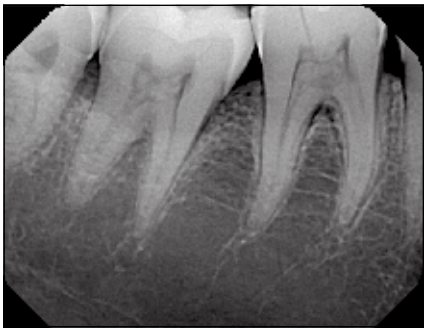


Fig. 3. Radiograph of a hemimandibular phantom taken at 96.7 mR exposure.

Discussion

Although they generally were not located in an ideal environment for diagnosis and treatment planning purposes, the operatory viewing monitors were for the most part consistent in their calibration quality, with only 2 needing adjustment. It would be convenient to have the medical viewing monitor SMPTE test pattern loaded onto every computer in the office so the calibration of a viewing monitor could be checked periodically.[16]

All X-ray units tested had a half-value layer that complied with Texas regulations. A total of 5 X-ray units had a kVp >10%, which was not acceptable per the manufacturers' stated values and Texas state regulations. Four X-ray units were found to be marginally within compliance boundaries.

While the majority of X-ray units were compliant with state regulations, in many cases, the settings used for routine radiographs were not within NCRP-recommended diagnostic reference levels. One X-ray generator that had passed state certification 1 year earlier had an exposure of 367 mR for bitewing radiographs—twice the maximum recommended exposure of 183 mR.[10] Reducing the exposure time decreased patient exposure radically without affecting the image quality (Fig. 2 and 3). This is an example of the type of situation referred to by Lipoti that led to suggested changes in the New Jersey radiation control program.[13]

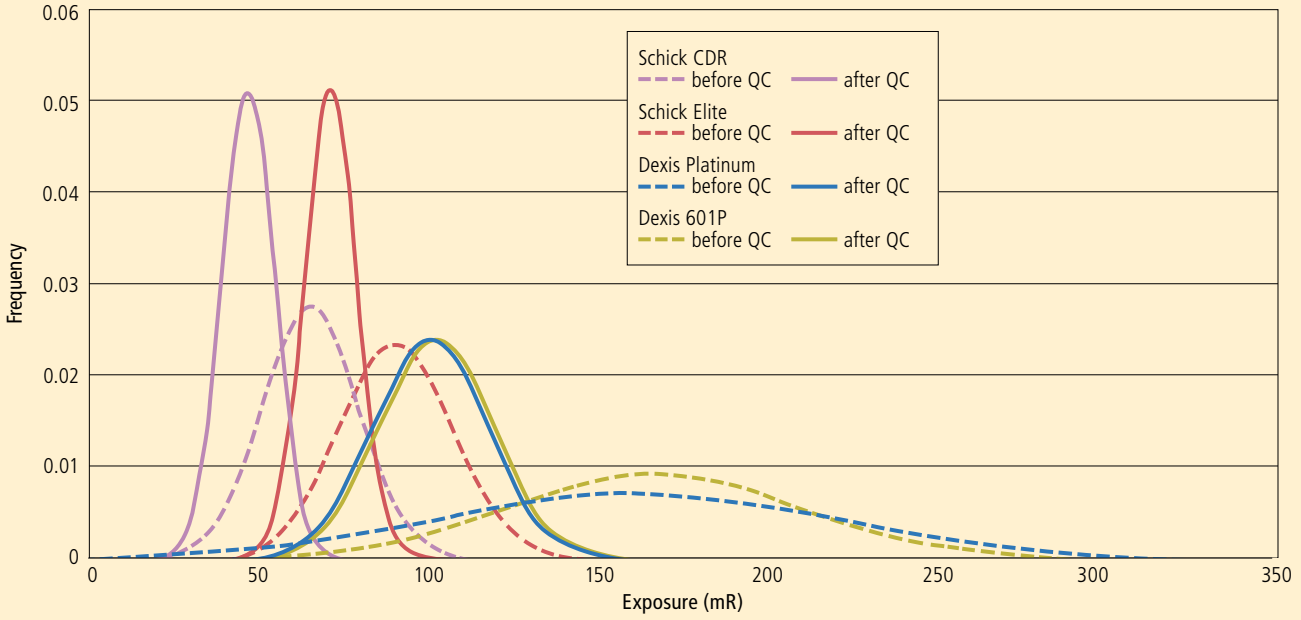
The DDQA phantom provides a means for selecting exposure settings that provide maximum image quality with minimal patient exposure. A phantom allows dentists to accurately evaluate dynamic range, contrast/detail resolution, and spatial resolution for all sensor/X-ray generator combinations and to select exposure settings based on these parameters.

Table 1 shows the values measured in a representative dental operatory. The gray-scale density values for the various steps of the wedge remain remarkably consistent for exposures ranging from 102.0 to 249.3 mR. These values demonstrate that a step wedge alone has no value for determining optimal exposure settings in digital imaging. The purpose of the step

Table 1. Image quality (grayscale density) data at different exposure settings.

Exposure (mR)	No. of visible steps	Line pair resolution (line pairs/mm)	Changing diameter wells	Changing depth wells	Step 1 (lead)	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7 (air)
102.0	7	10	6	4	233	198	168	116	62	17	0
150.3	7	10	6	4	235	200	171	117	61	16	0
206.9	7	10	6	4	234	198	168	113	56	14	0
249.3	7	10	6	4	230	193	161	103	47	11	0
302.2	6	9	6	4	225	181	143	78	27	8	1

Chart. Distribution of skin exposures using different sensors before and after quality control (QC).



wedge is to find a setting that allows for visualization of the entire range of patient (tissue) thickness encountered in routine practice. When exposures exceed this level, 1 or more steps of the wedge cannot be visualized. Having ensured that the entire dynamic range is registered, spatial and contrast resolutions are evaluated to determine a satisfactory exposure time. In Table 1, the original exposure setting in the dental office was 249.3 mR, with a line pair resolution of 10 line pairs/mm and a contrast resolution showing 6 changing diameter wells and 4 changing depth wells. An optimized setting was selected with a new ESE setting of 102.0 mR, producing an image with 10 line pairs/mm, 6 changing diameter wells, and 4 changing depth wells. A 60% reduction in ESE resulted, with no change in the radiographic image's diagnostic quality.

The distribution of exposures corresponding to the original settings used in the 12 offices were calculated and compared to the distributions of exposures at the optimized settings. The results, segregated by sensor model, are shown in the Chart. In each case, an overall reduction in the mean ESE was achieved, as was a narrowing in exposure range. One-way ANOVA was used to compare changes to the QC for exposures and deviation from the mean exposure for each of the 4 types of sensors. There were significant reductions in exposure for all 4 types of sensors (average reduction = 34.6 mR, $P < 0.05$) after QCs were instituted. The Dexis 601P and Dexis Platinum had significantly higher reductions ($P < 0.01$) than the Schick CDR and Schick Elite. There was a significant reduction in terms of deviance from the average exposure for each instrument; averaging a reduction in spread of 53.2 mR. The Schick CDR demonstrated the greatest reduction in spread, followed by the Dexis 601, Dexis

Platinum, and Schick Elite. In every case, the mean optimized exposure was less than the 183 mR diagnostic reference level recommended by the NCRP, and the recommended 137 mR Achievable Dose for intraoral radiography.[10]

The mean optimized results for each sensor model are summarized in Table 2. While the exposure required for optimal image quality varies from sensor to sensor, all exposures were less than the NCRP Achievable Dose value of 137 mR. A 2007 study by Hellen-Halme et al concluded that a QA protocol was necessary for digital imaging in dentistry.[20] The present study confirms this need.

Intraoral digital radiography is increasing and proper QA and QC protocols need to be developed and implemented. It will be necessary to strike a balance between the dose reduction and adequate image quality.[13] As ICRP Report No. 73 states:

…it is not acceptable to compromise image quality to the point that it may have deleterious effects on clinical effectiveness in order to reduce patient radiation doses." [21]

In 2001 the state of New Jersey changed their state's X-ray inspection program to include ESE and image quality; a 5-year follow-up study reported significant ESE reduction and an increase in image quality.[13] The results of the present study support this approach.

Table 2. Mean optimized results by sensor.

	Exposure (mR)	No. of visible steps	Line pair resolution (line pairs/mm)	Changing diameter wells	Changing depth wells
Schick CDR	48.6	7	8	4	1
Schick Elite	73.3	7	6	4	1
Dexis Platinum	103.5	7	8	6	2
Dexis 601P	115.7	7	7	5	1

Conclusion

The ADA stated in a 2006 update that:

Dentists should consider developing and implementing a radiation protection program in their offices. In addition, practitioners should remain informed on safety updates and the availability of new equipment, supplies and techniques that could further improve the diagnostic ability of radiographs and decrease exposure.[8]

The present study sought to present the available techniques and tools for implementing a QA program that includes image optimization. This pilot study was able to evaluate a number of intraoral digital radiographic systems in a private practice setting in addition to new QA and QC tools and procedures. In the course of this study, steps were taken to identify faulty equipment, increase image diagnostic quality, and in many cases, reduce ESE.

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Disclaimer

Drs. Mah, Dove, and McDavid are joint developers and inventors of the intraoral imaging phantom known as the Digital Dental Quality Assurance (DDQA) phantom (US Patent No. US8308362) by Dental Imaging Consultants, LLC, San Antonio, Texas. Dr. Mah serves as president of the company.

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Manufacturers

Belmont Equipment, Somerset, NJ
800.223.1192, dental.takarabelmont.com

Dental Imaging Consultants, LLC, San Antonio, TX
210.347.7091, www.dentalimagingconsultants.com

Eastman Kodak Company, Rochester, NY
800.698.3324, www.kodak.com

Gendex Dental Systems, Hatfield, PA
800.323.8029, www.gendex.com

Henry Schein Dental, Melville, NY
800.372.4346, www.henryschein.com

ImageWorks, Elmsford, NY
800.592.6666, www.imageworkscorporation.com

Microsoft, Redmond, WA
425.882.8080, www.microsoft.com

Patterson Dental Supply, Inc., Wood Dale, IL
630.616.8202, www.pattersondental.com

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201.934.8015, www.phillipsscientific.com

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877.544.9672, www.progenydental.com

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