The role of software in quality assurance for indirect digital intraoral imaging

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Objectives. The aim of this study was to evaluate inherent image quality and the effects of software changes on image quality by using photostimulable phosphor (PSP) plates.

Study Design. Six new DIGORA Optime PSP plates (Soredex/Orion Corp., Helsinki, Finland) were used to assess inherent image quality and the effect of software settings on image quality. Images of a radiographic phantom were exposed to evaluate dynamic range, spatial resolution, and contrast resolution. Varying sharpness filters and gamma values were adjusted to assess their effects on these parameters.

Results. Dynamic range was not affected by software settings. Spatial resolution varied among the raw (i.e., minimally processed) images and increased maximally with application of a sharpness filter of 30. Contrast resolution varied among the plates for the raw images. The gamma value of 0.8 was most consistent at increasing the detection of contrast wells.

Conclusions. The findings of our study suggest that the sharpness filter 30 and gamma value of 0.8 may increase the spatial and contrast resolutions of DIGORA Optime PSP images when applied during the scanning process. However, this increase was small. Our results also establish that software manipulation should not be used in an attempt to compensate for data that are not present in the image. (Oral Surg Oral Med Oral Pathol Oral Radiol 2020;130:313−321)

The importance of quality assurance (QA) measures in digital imaging has been recognized by the American Dental Association (ADA), which appointed a task force of experts to compose standards of practice for digital intraoral radiographic systems.[1] These standards include QA guidelines for the X-ray unit, the image display device, and the image receptor (to include acquisition software).[1] In accordance with these standards, the X-ray tube output should be measured at periodic intervals, the contrast and brightness of the computer monitor should be evaluated with an appropriate test pattern, and the proper dose to achieve the full diagnostic capability of the image receptor should be determined with an appropriate radiographic phantom.[1]

Udupa et al. proved that evaluating image receptors with an appropriate radiographic phantom is an essential component of the QA protocol.[2] Udupa et al. used a radiographic phantom to determine the radiation exposure required for optimal diagnostic yield of the image receptor.[2] Their results revealed wide variability among image receptors, which held true even for image receptors produced by the same manufacturer.[2] Olsson et al. found that 3 of 4 sensors operated within a similar limited exposure range, whereas 1 of the sensors performed optimally up to an exposure time of 1 second.[3] Therefore, it is not surprising that an evaluation of private practice offices found that the appropriate dose to achieve maximum diagnostic yield for the digital intraoral image receptor was rarely used and that most often, the dose that was being used was too high.[4]

Recently, Buchanan et al. reported on inherent artifacts present on the image receptor and the effects of software on radiographic image contrast.[5,6] These authors discovered that software filters had a significant effect on image contrast, resulting in nondiagnostic radiographs.[5] Given the multiple variables reported with digital imaging (varying physical sensor design, appropriate radiation exposure not being the same for all image receptors, inherent artifacts, and software effects), it is crucial to establish a comprehensive QA protocol for digital intraoral imaging that includes evaluation of software effects.

The purpose of this study was to compare the inherent image quality of radiographs acquired with photostimulable phosphor (PSP) plates to the image quality of radiographs acquired with the same PSP plates when 2 software enhancement options, the sharpness setting and the gamma value, were applied in different combinations. The inherent image quality (i.e., raw image/minimally processed image) is defined as the image quality produced when all software options controlla-

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Received for publication Aug 30, 2019; returned for revision Mar 5, 2020; accepted for publication Mar 14, 2020.

Published by Elsevier Inc.

2212-4403/$-see front matter

https://doi.org/10.1016/j.oooo.2020.03.043

Statement of Clinical Relevance

It is important to understand the effects of software enhancements of sharpness filters and gamma values on image quality. Operators must strive to select the optimal exposure factors and software settings to maximize the diagnostic benefits of radiographs.

ble by the user are turned off. The null hypothesis tested was that there are no differences in image quality (determined by using a radiographic phantom capable of measuring dynamic range, spatial resolution, and contrast resolution) between the images with no enhancement (i.e., raw images/ minimally processed images) and images produced when these 2 software enhancement options are applied in various combinations.

MATERIALS AND METHODS

Radiographic technique and software conditions

Six brand new DIGORA Optime PSP plates (Soredex/ Orion Corp., Helsinki, Finland) were used to assess the inherent image quality and the effects of software changes on image quality. The Planmeca ProX constant potential X-ray unit (Planmeca Oy, Helsinki, Finland) was used to acquire all images. Before exposing the PSP plates, the X-ray exposure output and consistency was measured by using the Piranha 557 meter (RTI Electronics, Mölndal, Sweden). The exposure parameters required to achieve optimal diagnostic yield were determined by using the Digital Dental Quality Assurance (DDQA) radiographic phantom (Dental Imaging Consultants LLC, San Antonio, TX).[7] The exposure parameters of 63 kV, 8 mA, and 0.2 seconds provided visibility of all 7 steps in the stepwedge, confirming that adequate dynamic range was obtainable in each image. These exposure parameters resulted in an exposure output of 0.8 mGy, which was similar to that in the study by Udupa et al., in which the output measured was 0.74 mGy for the same imaging receptor and scanner resolution setting.[2] Additionally, 0.8 mGy is in compliance with the recommendation of 1.6 mGy by the National Council on Radiation Protection and Measurements for intraoral imaging.[8]

The DDQA phantom was imaged in all radiographs. The phantom allows for repeatable projection geometry (the X-ray beam is kept perpendicular to the image receptor); constant distance from radiation source to image receptor that is analogous to that used for intraoral imaging on patients (30.5 cm position indicating device [PID] + 6.55 cm distance from the PID to the image receptor = 37.05 cm total distance); and the assessment of dynamic range, spatial resolution, and contrast resolution. As mentioned previously, the DDQA phantom contains a stepwedge with 7 steps (5 aluminum steps of increasing thickness and lead and air steps) to measure dynamic range. To measure spatial resolution, the DDQA phantom contains 16 groups of line pairs that resolve from 5 to 20 line pairs per millimeter (lp/mm). To measure contrast resolution, there are 2 rows of 6 cylindrical contrast wells: 1 row consisting of 6 wells of different diameter with the same depth and 1 row consisting of 6 wells of the same diameter with varying depths. These features of our radiographic phantom are in agreement with those recommended by the ADA technical report No. 1094.[1]

Before any software adjustments, radiographs of the DDQA phantom were acquired on all 6 plates and were scanned as raw images. A raw image is created by turning off the enhancement options within the software (i.e., Sordex plugin). In reality, this creates a minimally processed image, rather than a raw image, because some of the software enhancements are imposed by the manufacturer with the end-user having no control over them.[5,9] Therefore, minimally processed images are created when all the enhancement options accessible to the end-user have been turned off within the software. Consequently, the displayed radiograph is a minimally processed image, rather than an actual raw image.

Next, varying sharpness filters and gamma values were used to assess their effects on image quality. All changes to sharpness filters and gamma values were made through the MiPACS Soredex plugin available in our institution's processing and viewing software MiPACS (Medicor Imaging, Charlotte, NC). Therefore, the software changes applied to sharpness filters and gamma values were adjusted before scanning the PSP plate. We used 0, 15, 30, 40, 50, and 60 sharpness filters. They were selected to test values that might be used clinically, such as 15 and 30, and are less likely to produce artifacts at restoration margins.[9-13] Selecting more aggressive filters, such as 50 and 60, and an intermediate filter of 40 helped test the validation of using a sharpness filter of 15 or 30. The gamma values used were 0.8, 1.0, and 1.3. The gamma settings were selected to simulate values that might be chosen clinically. Gamma values below 1 decrease the brightness of an image, whereas gamma values above 1 increase the brightness of an image. Gamma values that are too extreme in either direction run the risk of creating an image that is too dark or too light to be diagnostic. Three radiographs were exposed under each condition. This means that plates 1 to 3 were scanned under the following 9 software enhancement options (reported as sharpness filter/gamma value): 0/1, 0/1.3, 15/0.8, 30/1, 30/1.3, 40/1, 40/1.3, 50/0.8, and 60/0.8. Likewise, plates 4 to 6 were scanned under the following 9 software enhancement options (reported as sharpness filter/gamma value): 0/0.8, 15/1, 15/1.3, 30/0.8, 40/0.8, 50/1, 50/1.3, 60/1, and 60/1.3. Therefore, the total number of raw (1) and enhanced (9) images made on each of the 6 image receptors was 10, for a total of 60 images for evaluation (Tables I to IV). The PSP plates were scanned into our institution's MiPACS digital acquisition and viewing software, using the high-resolution scanning mode (DIGORA Optime provides two scanning mode options: high and super high).

Table I. Dynamic range results

Scanning Software	*Raw*	*0*	*0*	*0*	*15*	*15*	*15*	*30*	*30*	*30*	*40*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*
Settings		*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*
Plate 1*	7	7		7		7		7		7	7		7		7			7	
Plate 2*	7	7		7		7		7		7	7		7		7			7	
Plate 3*	7	7		7		7		7		7	7		7		7			7	
Plate 4*	7		7		7		7		7			7		7		7	7		7
Plate 5*	7		7		7		7		7			7		7		7	7		7
Plate 6*	7		7		7		7		7			7		7		7	7		7

Scanning software settings are reported as sharpness filter/gamma value.
*Dynamic range for the photostimulable phosphor (PSP) plates is reported as the number of steps visible out of the total of 7 available steps.

Table II. Spatial resolution results

Scanning Software	*Raw*	*0*	*0*	*0*	*15*	*15*	*15*	*30*	*30*	*30*	*40*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*
Settings		*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*
Plate 1*	6	6		6		6		7		8	6		6		6			6	
Plate 2*	6	5		6		6		7		7	7		7		7			7	
Plate 3*	5	6		6		6		7		7	7		6		7			6	
Plate 4*	5		6		6		8		7			6		7		7	7		6
Plate 5*	5		5		7		6		8			7		6		7	7		6
Plate 6*	6		6		7		6		7			6		6		6	6		7

Scanning software settings are reported as sharpness filter/gamma value.
*Spatial resolution is reported as line pairs per millimeter (lp/mm).

Table III. Contrast resolution results: wells of different diameters

Scanning Software	*Raw*	*0*	*0*	*0*	*15*	*15*	*15*	*30*	*30*	*30*	*40*	*40*	*40*	*50*	*50*	*50*	*60*	*60*	*60*
Settings		*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*
Plate 1*	6	5		5		4		5		5	5		4		5			6	
Plate 2*	4	5		4		6		6		5	5		6		4			5	
Plate 3*	4	6,5,4†		4		5		5		5	4		4		6			6	
Plate 4*	5		5		5		6		5			5		4		4	5		5
Plate 5*	5		4		5		6,5,4†		6,4,5†			6		5		4	4		4
Plate 6*	5		6		4		5		6			5		5		5	5		5

Scanning software settings are reported as sharpness filter/gamma value.
*Contrast resolution for the PSP plates is reported as the number of contrast wells visible out of the total of 6 wells.
†Results reported at the consensus calibration session of both evaluators, subsequent independent reading by the oral and maxillofacial radiologist, and the subsequent independent reading by the dental student. In these cases the consensus was selected; however, choosing any of the 3 values would produce the same final results.

Table IV. Contrast resolution results: wells of the same diameter

Scanning Software	*Raw*	*0*	*0*	*0*	*15*	*15*	*15*	*30*	*30*	*30*	*40*	*40*	*40*	*50*	*50*	*50*	***60***	***60***	***60***
Settings		*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*	*1*	*0.8*	*1.3*
Plate 1*	3	3		3		4		3		3	4		3		3			4	
Plate 2*	3	3		3		3		3		3,2,4†	3		3		3			3	
Plate 3*	3	3		3		3		4		3	3		3		3			3	
Plate 4*	3		3		4,2,3†		3		3			4		3		3	3		3
Plate 5*	3		3		3		3		3			3		3		2	4		3
Plate 6*	3		3		3		3		3			4		3		3	4		3

Scanning software settings are reported as sharpness filter/gamma value.
*Contrast resolution for the PSP plates is reported as the number of contrast wells visible out of the total of 6 wells.
†Results reported at the consensus calibration session of both evaluators, the subsequent independent reading by the oral and maxillofacial radiologist, and the subsequent independent reading by the dental student. In these cases the consensus was selected; however, choosing any of the 3 values would produce the same final results.

Image analysis

The images were transferred as DICOM (Digital Imaging and Communications in Medicine) files directly from the digital viewing software to ImageJ (National Institutes of Health, Bethesda, MD) for all analyses (dynamic range, spatial resolution, and contrast resolution). DICOM is the international standard used to transmit imaging data and serves to make digital imaging data accessible from products of different manufacturers. The monitor calibration pattern, a variant of the SMPTE (Society of Motion Picture and Television Engineers) test pattern provided in our digital acquisition and viewing software, was used to confirm adequate contrast and brightness settings of the monitor before evaluating the images.

Visual analysis was used to assess the dynamic range and was completed by an evaluator who is a board-certified oral and maxillofacial radiologist with 9 years of experience. The dynamic range was determined by evaluating the number of steps visible in the stepwedge for each of the 60 radiographs.

Software analysis was used to assess the spatial resolution of each raw or enhanced image. The plot profile tool within the ImageJ software was used to objectively measure the highest number of line pairs per millimeter detectable in each image by producing a plot of intensity values (i.e., gray levels) for the line pairs per millimeter portion of the phantom. This method has been implemented by others when using the DDQA phantom.[7,9]

Visual analysis was used to measure contrast resolution. At times, it can be challenging to discern how many contrast wells are resolved in the radiograph; therefore, 2 evaluators (a third-year dental student and the oral and maxillofacial radiologist) analyzed these data to achieve more consistent, reliable results. The evaluators examined the contrast wells independently first and then together. Discrepancies in evaluation were resolved through discussion to achieve consensus. This also served as a calibration session for both evaluators. After this calibration session, each evaluator assessed the contrast wells again independently. The average of the values selected at the calibration session and the values selected at the subsequent evaluation sessions performed by each evaluator independently established the final results for the number of visibly detectable contrast wells.

This research study did not involve human patients, patient data, or human tissue, and therefore, institutional review board approval was not required.

RESULTS

Dynamic range

The sharpness and gamma settings did not affect the dynamic range. Seven steps were visible in all images (Table I; Figure 1).

Spatial resolution

The spatial resolution of the raw images varied among the different plates from 5 to 6 lp/mm (Table II and Figure 2). Spatial resolution increased maximally with application of a sharpness filter of 30. That is to say, there was an increase in spatial resolution for all readings (i.e., all gamma values) at the sharpness setting of 30. No other sharpness filters resulted in an increase in the spatial resolution for all gamma values. Although there was an increase to 8 lp/mm for 3 of the readings, for the overwhelming majority the spatial resolution increased to a maximum of 7 lp/mm (see Table II; Figure 3).

Contrast resolution: wells of different diameters

The number of wells of different diameters detected varied from 4 to 6 wells among the different plates for the raw images (Table III). Changing the gamma setting increased the number of wells detected. Relative to the raw images, the gamma value of 0.8 was most consistent at increasing the number of wells of different

Fig. 1. Dynamic range. Images demonstrate that the sharpness and gamma settings did not affect the dynamic range. Plate 2 *(left)* is a raw image with gamma value of 1. It shows full dynamic range (i.e., all 7 steps visible in the stepwedge). Plate 3 *(center)* was acquired with software settings of sharpness 60 and gamma 0.8. The full dynamic range is visible. Plate 6 *(right)* was acquired with software settings of sharpness 60 and gamma 1.3. The full dynamic range is visible. This figure also demonstrates how adjusting the gamma value affected the overall brightness of the image. Gamma values less than 1 produced darker images; gamma values greater than1 produced brighter images.

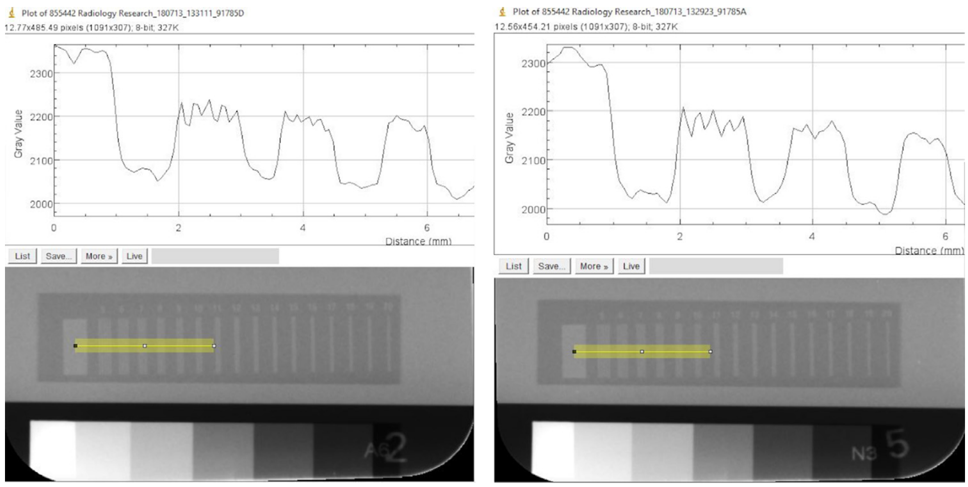

Fig. 2. Spatial resolution of raw images. The plot profile tool within the ImageJ software was used to objectively measure the highest number of line pairs per millimeter (lp/mm) detectable on each image by producing a plot of intensity values. The highest lp/mm value in which 5 spikes and 4 troughs were visible was used as the measure of spatial resolution. The line profiles demonstrate that the spatial resolution varied among the different plates. Plate 2 *(left)* resolved 6 lp/mm, and plate 5 *(right)* resolved 5 lp/mm.

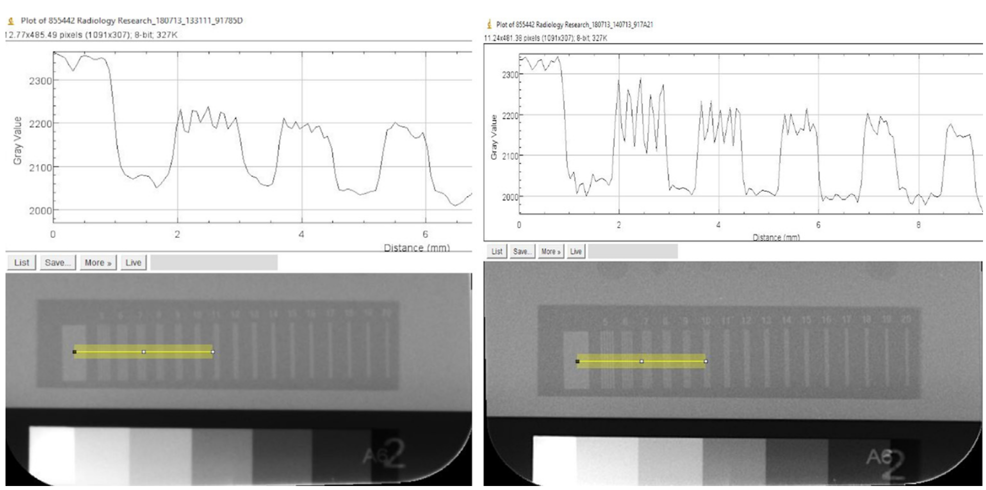

Fig. 3. Spatial resolution of an image enhanced with the sharpness filter. The image on the left is a raw image of plate 2 demonstrating a resolution of 6 line pairs per millimeter (lp/mm). The image on the right was captured on plate 2 with software settings of sharpness 30 and gamma 1. This image shows an increase in spatial resolution to 7 lp/mm.

diameters detected (see Table III; and Figure 4). Moreover, the gamma value of 0.8 produced the most total images that resolved all 6 of the contrast wells of different diameters (see Table III; Figure 5). Additionally, relative to the raw images, the sharpness setting of 30 produced the largest number of images with an increase in detectable wells, albeit the increase in the number is small (see Table III; Figure 6). Of the total 60 images, there were only 3 in which the consensus calibration session and the subsequent readings of each examiner differed, so finding an average was not possible; however, this did not affect the final results (see Table III and Figures 4, 5, and 6). Figure 7 provides an example of the increasing detectability of the wells of different diameters.

Contrast resolution: wells of the same diameter

Three wells were resolved on all raw images. Software adjustments in sharpness setting and gamma value did not improve visual detection of wells of the same diameter. Table IV demonstrates that although a few of the readings resolved 4 wells and 2 wells, the overwhelming majority of the readings resolved 3 wells. Of the total 60 images, there were only 2 in which the consensus calibration session and the subsequent readings of each examiner differed, so finding an average was not possible; however, this did not affect the final results.

DISCUSSION

Before establishing appropriate software settings, the X-ray exposure factors that produce optimal image

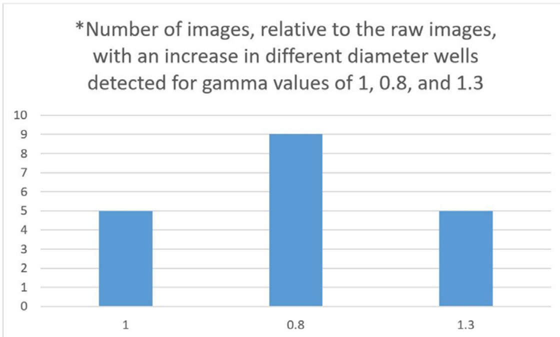

Fig. 4. Bar graph demonstrating that relative to the raw images, the gamma value of 0.8 produced the most total images with an increase in the number of detectable different diameter contrast wells. *The consensus value reported in Table III was selected; however, choosing any of the 3 values would not have changed the fact that relative to the raw images, the gamma value of 0.8 produced the most images with an increase in the number of detectable contrast wells of different diameters.

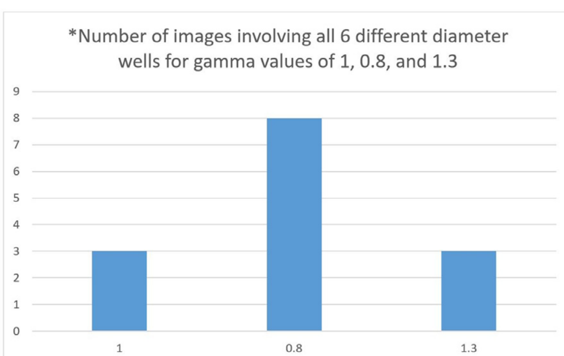

Fig. 5. Bar graph demonstrating that the gamma value of 0.8 produced the most total images that resolved all 6 of the contrast wells of different diameters. *The consensus value reported in Table III was selected; however, choosing any of the 3 values would not have changed the fact that the gamma value of 0.8 produced the most images in which all 6 of the contrast wells of different diameters were resolved.

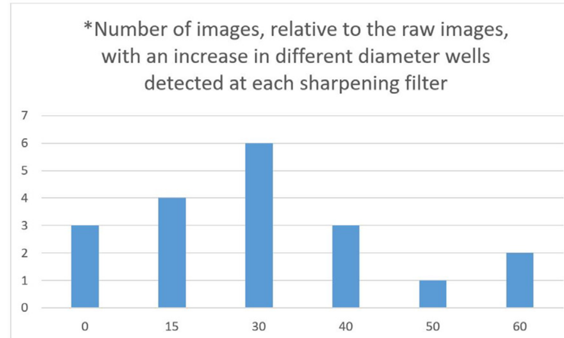

Fig. 6. Bar graph demonstrating that relative to the raw images, the sharpness filter of 30 produced the most total images with an increase in the detectability of contrast wells of different diameters, albeit a small increase. *The consensus value reported in Table III was selected; however, choosing any of the 3 values would not have changed the fact that, relative to the raw images, the sharpness setting of 30 produced the most images with an increase in the number of detectable wells of different diameters.

quality should be determined by using the least amount of image manipulation by the software.[11] To accomplish this, all accessible software enhancements must be turned off to produce a raw (i.e., minimally processed) image. This image ensures that no diagnostic information is lost through future software manipulation. It must be stressed that software manipulation cannot create data in the image that do not exist. For this reason, software manipulation should not be used in an attempt to compensate for an incorrectly exposed radiograph. One must start with a properly exposed radiograph to benefit from software adjustments.[11]

Determining the appropriate X-ray exposure also ensures that the necessary wide dynamic range needed for caries and periodontal disease interpretation is achieved.[1] *Dynamic range* is defined as the range of X-ray intensities that an image receptor can capture

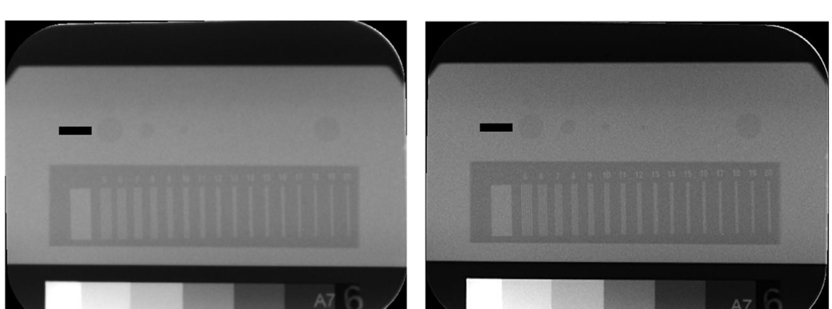

Fig. 7. Contrast resolution. The image on the left is a raw image of plate 6. The image on the right is plate 6 with the software settings of sharpness 30 and gamma 0.8. This image demonstrates resolution of all 6 of the 6 wells of different diameters (contrast wells are indicated by the black lines on the images).

simultaneously.[1] Using a radiographic phantom that spans the entire gray scale ensures that a wide dynamic range is available in the radiographic image.[1,7]

Measuring the dynamic range for each radiograph also determines the exposure range of the image receptor. This range is referred to as latitude and is a property of the image receptor. Latitude represents the range of exposures, from the lowest to the highest, that the image receptor can accept while still producing a diagnostic radiograph.[2] The latitude is determined by evaluating the dynamic range in each image as follows: The exposure resulting in loss of differentiation between the steps on the light (radiopaque) end of the stepwedge indicates underexposure, and the exposure resulting in loss of differentiation between the steps on the dark (radiolucent) end of the stepwedge indicates overexposure. The most appropriate exposure to use is the lowest exposure that will provide the highest diagnostic yield, which, when using the DDQA phantom, is defined as visibility of all steps in the stepwedge with maximum spatial and contrast resolutions.[2]

Dynamic range was unaffected by the software adjustments made in this study (gamma values of 0.8, 1.0, and 1.3 and sharpness filters of 0, 15, 30, 40, 50, and 60). This demonstrates that as long as the proper exposure factors are used, the sharpness and gamma settings, within the changes made in this study, do not affect the dynamic range. It makes sense that adjusting the sharpening filter would not affect dynamic range. Similar findings were reported by Clark.[9] However, why would changing the brightness of the image through gamma manipulation not affect the dynamic range? First, we must consider the process of determining the appropriate exposure output that results in optimal image quality for the specific image receptor. The exposure that produces optimal image quality is defined as the lowest exposure within the latitude of the image receptor where maximum spatial and contrast resolutions are obtained.[2] The dynamic range is maintained throughout the latitude of the image receptor. Therefore, if software changes are not altered drastically, then the dynamic range would not be expected to be affected. In our study, we selected the gamma values that are more likely to be implemented in a clinical setting and, therefore, did not represent drastic changes; this explains why the dynamic range was not affected. It must be stressed that more aggressive changes to the gamma setting may result in loss of differentiation of the steps in the stepwedge and, therefore, loss of a wide dynamic range. Additionally, our findings validate the significance of using a suitable radiographic phantom to determine the appropriate exposure factors for the image receptor.[1,11]

Unlike dynamic range, we found that spatial resolution was affected by software changes. We found a consistent increase in spatial resolution at the sharpness filter setting of 30 (see Table II). The line pair phantom is a high-frequency component of the radiograph, so applying edge enhancement through the use of a sharpening filter can serve to increase spatial resolution by making the edges of the lines in the line pair phantom more defined.[14,15]

We found that the sharpening filter effect on spatial resolution was limited to 7 lp/mm (see Table II and Figure 3). Why did the spatial resolution stabilize at a sharpness setting of 30? This may be explained by the inherent spatial resolution capability of the PSP plates themselves. The DIGORA Optime PSP plate system has been reported to resolve 6 lp/mm at the "high" scanning resolution setting, as used in our study, and 8 lp/mm at the "super high" scanning resolution setting.[2] Therefore, 8 lp/mm is the highest possible spatial resolution with the DIGORA Optime PSP system, and it is achieved by increasing the scanning resolution setting, not through software changes.

Moreover, the sharpening filter serves to highlight the edges of high-frequency objects in an image, such as that of the line pair phantom, but if the data are not there to begin with (i.e., the highest spatial resolution of the scanner is not used), then this effect may have limitations. For example, when applying a moderate sharpening filter to PSP images acquired in the middle of the PSP plate's exposure range, Clark[9] found that the spatial resolution improved an average of 0.909 lp/mm.[9] In a study of the effect of the sharpening filter on detection of subtle enamel demineralization by using DIGORA Optime PSP plates, Belem et al. found no difference between sharpened and nonsharpened images.[16] By the same token, when testing the Schick 33 intraoral sensor, Gaalaas et al. found that the image sharpening filter resulted in reduced caries sensitivity relative to phosphor plate images with no sharpening filter.[17] Although Belem et al. evaluated the effect of sharpening filters on a different diagnostic task—caries detection, rather than spatial resolution—their investigations and Clark's study suggest that the effects of sharpening filters are limited. This demonstrates that although software is capable of making changes to an image, these changes are limited in their diagnostic capability; this emphasizes the importance of determining the appropriate X-ray exposure for maximum diagnostic performance of the image receptor.

We also found that software changes affected contrast resolution. Hayakawa et al. discovered that gamma values below 1.0 clarified panoramic images.[18] The reason may be that adjusting the gamma value will change the average brightness of an image and can affect the perception of contrast.[5,19] Baksi et al. recommended using a sharpening filter to improve the perception of low contrast structures when using a PSP system for panoramic imaging.[20] Our results showed that the gamma value of 0.8 provided the most consistent increase in contrast resolution for the wells of different diameters, but no improvement for wells of the same diameter (see Tables III and IV; Figures 4 and 5). Additionally, we found that the sharpness setting of 30 produced the largest number of images with an increase in the number of detectable wells of different diameters, although the increase in number was small (see Table III and Figure 6).

Why was contrast resolution affected for wells of different diameters but not for wells of the same diameter but different depths? Not only the software filters but also the diagnostic task at hand may need to be taken into account. It has been shown that PSP plates detect more wells of different diameters than wells of the same diameter with the DDQA phantom.[2] Udupa et al., evaluated 4 PSP plate systems and found that although 5 to 6 of the wells of different diameters were resolved, typically only 0 to 3 of the wells of the same diameter were resolved.[2] Likewise, 9 of 15 sensors resolved from 0 to 3 of the contrast wells of the same diameter.[2] These same 9 sensors resolved from 4 to 5 of the wells of different diameters.[2] Because both sets of contrast wells measure low-contrast resolution, this suggests that detection of wells of the same diameter is a more challenging diagnostic task than the detection of wells of different diameters. Therefore, more substantial adjustments may be required than the changes made in this study to enhance the detection of wells of the same diameter.

In addition to the diagnostic task at hand, perhaps the inherent capability of the image receptor should be considered. In the study by Udupa et al., DIGORA Optime PSP plates resolved 5 of the wells of different diameters and only 2 of the wells of the same diameter.[2] These results held true for both spatial resolution scanning settings.[2] Therefore, DIGORA Optime PSP plates are capable of resolving 5 of the wells of different diameters. In our investigation, we started with a contrast resolution ranging from 4 to 6 for the contrast wells of different diameters (see Table III). Therefore, although the gamma value of 0.8 and the sharpness setting of 30 produced the highest number of images with an increase in detection of contrast wells of different diameters, this effect was small. Because our baseline of raw (minimally processed) images to change was small and our PSP plates were already performing close to the values reported in the literature, the smaller changes, such as those made in this study, were adequate to enhance the contrast resolution of wells of different diameters, even though that change was small. Similarly, for contrast wells of the same diameter, it has been shown that DIGORA Optime resolves 2 of the 6 wells.[2] Therefore, it is possible that the maximum contrast resolution achieved with the DIGORA Optime PSP plate for contrast wells of the same diameter is 2 to 3 wells. Because our plates were already performing at this level, no further improvement occurred. This also suggests that within the changes made in this study, the maximum performance in the detection of wells of the same diameter is accomplished through appropriate exposure settings and not software manipulation. As with our findings regarding dynamic range and spatial resolution, this validates the significance of using a suitable radiographic phantom to determine the appropriate exposure factors for the image receptor.[1,11]

A potential limitation of our study is that only 1 PSP plate imaging system was tested. Therefore, conclusions can only be based on this particular system. Another potential limitation is that we did not evaluate the effect of the sharpness setting of 30 on restoration margins. It has been reported that sharpness filters can produce a radiolucency adjacent to the margins of restorations.[9-13] Another potential limitation is that we only tested the effects of 2 software applications, sharpening filter and gamma value, and the gamma values tested were within a limited range. It is possible that more aggressive changes in the gamma value would produce different results, such as decreasing the dynamic range or changing the low contrast detectability of the image. Yet another potential limitation is that we only evaluated the effects of software changes made within the MiPACS Soredex plugin. Therefore, the software changes we made were adjusted before scanning the PSP plates and, thus, the software effects were applied to the scanned and subsequently displayed image. It is also possible to make software changes to an image after it has been scanned and displayed. Examples of software algorithms that can be applied to an image after it has been acquired include brightness and contrast changes, histogram manipulation, and the application of sharpening filters. Therefore, it is possible to make software changes that affect the contrast and spatial resolution of the image both before and after acquisition of the image. Software changes made to an image before scanning result in permanent changes that become part of the saved and displayed image, whereas software changes made after the image is scanned can be reversed. Because these software changes are applied at different times in the imaging chain (during initial processing of the scanned image and after the image has been scanned and displayed), different plugins within the software are used. Consequently, it is possible that they do not produce the exact same changes to the image. As a result, it is possible that the software changes affecting the contrast/brightness and sharpness of an image that are applied after the image has been scanned and displayed (not done in this study) could produce different effects on the dynamic range, spatial resolution, and contrast resolution of the image. Nevertheless, it should be stressed that software changes, whether applied during image scanning/acquisition or after scanning and displaying of the image, should not be used in an attempt to compensate for an incorrectly exposed radiograph. One must start with a properly exposed radiograph to benefit from software adjustments.[11]

CONCLUSIONS

The results of our study reject the null hypothesis and suggest that the sharpness filter of 30 and gamma value of 0.8, when applied during the scanning process, may improve the diagnostic accuracy of DIGORA Optime PSP plates by increasing spatial and contrast resolutions. However, it should be noted that the increase in both spatial and contrast resolutions in our study was small; therefore, our results also establish that software manipulation should not be used in an attempt to compensate for data that are not present in the image as a result of improper X-ray exposure or manipulation with improper software settings. X-ray exposure factors that produce optimal image quality should be determined by using the least amount of image manipulation by the software. The results of our study also validate the significance of using a suitable radiographic phantom to determine the appropriate exposure factors for the image receptor.

Additional research is needed to evaluate the effect of the sharpness setting of 30 on restoration margins before its implementation in the clinic. However, it is notable that Clark[9] found that a sharpening filter of 50 produced only a 3% fluctuation in gray levels for a PSP plate.[9] Consequently, implementing a sharpening filter of 30 may improve the spatial resolution of images acquired with DIGORA Optime PSP plates with no appreciable negative effect on restoration margins.

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