The effects of physical photostimulable phosphor plate artifacts on the radiologic interpretation of periapical inflammatory disease

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Objective. To evaluate how physical photostimulable phosphor (PSP) plate artifacts, such as those created by scratches, phosphor degradation, and surface peeling, affect the radiologic interpretation of periapical inflammatory disease.

Study Design. A novel technique was developed to digitally superimpose 25 real PSP artifact masks over 100 clinical complementary metal oxide semiconductor (CMOS) periapical images with known radiologic interpretations. These images were presented to 25 general dentists, who were asked to state their radiologic interpretations, their confidence in their interpretations, and their opinions on whether the plates should be discarded. Statistical analyses were conducted by using random intercept mixed models for repeated measures and χ^2 tests of the pooled data.

Results. No statistically significant adverse effect on interpretation was seen, even at severe artifact levels. There was a statistically significant decrease in the clinicians' confidence and an increase in discard proportions when interpreting images with severe PSP plate artifacts ($P < .05$).

Conclusions. Although diagnostic efficacy was unaffected, clinicians' confidence decreased and proportionally more clinicians opted to discard sensors when interpreting images with severe artifacts. Future studies on the effects of artifacts on the efficacy of diagnosis of other dental diseases are recommended. Ultimately, these results can guide recommendations for PSP plate quality assurance. (Oral Surg Oral Med Oral Pathol Oral Radiol 2020;129:621−628)

Photostimulable phosphor (PSP) plates are a form of digital dental radiography widely used in modern dentistry. Although there are other forms of digital dental radiography, such as complementary metal oxide semiconductor (CMOS) sensors and charge-coupled devices (CCDs), PSP plates offer the advantages of being thin, flexible, and available in various sizes. PSP plates consist of a polyester base with an active surface made up of a delicate lattice of europium-doped barium fluorohalide. This means that excessive forces, such as scratches and bites, can result in damage to the active surface, resulting in an area of the plate that is no longer receptive to x-rays. This results in signal voids in the desired radiologic image that manifests radiologically as white/radiopaque artifacts. With continued use, damage accumulates and progressively degrades the quality of the radiologic image, which results in plates being discarded and replaced. It would be highly desirable for dental practitioners to have objective knowledge regarding when they should discard damaged PSP plates. To achieve this, the threshold of artifact for when radiologic interpretation is adversely affected needs to be determined.

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Physical PSP plate artifacts include cracking, scratching, peeling of the plate borders, bite marks, and crescent-shaped bending.[1] The reported prevalence of these artifacts varies in the literature. One study of 2000 PSP images reported that 53.4% of plates had peeling borders and 41.5% had scratches, whereas another investigation of 15,912 images found evidence of physical plate defects in only 0.4% of the images.[2] This discrepancy may be attributable to the lack of standardized quality assurance guidelines from dental regulatory agencies regarding when PSP plates should be discarded. Therefore, it is likely that the 2 research institutions had differing protocols for when to discard PSP plates. Many attempts have been made to create standardized quality assurance guidelines; however, these studies focused only on the degradation of objective imaging metrics, such as spatial or contrast resolution.[3-6] None of these studies assessed the clinical effects of physical artifacts on radiographic interpretation.

Periapical inflammatory disease is a common condition that dentists routinely diagnose and treat. This disease manifests when the tooth pulp undergoes necrosis caused by caries, trauma, or cracks.[7] The diagnosis of

Statement of Clinical Relevance

Photostimulable phosphor plates accumulate physical artifacts that degrade the quality of the desired radiologic image. These artifacts hinder the interpretation of periapical inflammatory disease by reducing clinicians' confidence levels, making clinicians more likely to discard damaged plates.

pulpal necrosis can be difficult because of its reliance on subjective clinical tests, especially in the presence of large coronal restorations. Therefore, radiography is a valuable supplemental test that dentists can use to assist in the diagnosis of pulpal necrosis. Accurate diagnosis is crucial because false-positive results lead to unnecessary root canal treatments and false-negative results lead to worsening patient symptoms and poorer prognosis.[8] For these reasons, periapical inflammatory disease is an ideal condition to be studied in the clinical setting.

The purpose of this study was to determine how the radiologic interpretation of periapical inflammatory disease is hindered when interpreting images in the presence of PSP plate artifacts in comparison with artifact-free radiologic images. Specifically, we aimed to assess (1) the degree to which the radiologic interpretation was adversely affected, (2) how the presence of artifacts affected diagnostic confidence, and (3) when practicing dentists would discard PSP plates. We hypothesized that with increasing artifact severities (1) there would be a progressively adverse effect on diagnosis, (2) clinicians would lose confidence in their interpretation, and thus (3) clinicians would be more likely to discard damaged PSP plates. Ultimately, these findings will help inform the development of quality assurance guidelines for the dental community.

MATERIALS AND METHODS

Because it would not be ethical to expose a patient to ionizing radiation using a potentially undiagnostic PSP plate in the clinical setting, a novel technique was developed to study the effects of these artifacts. By using digital simulation, clinical images of *in vivo* periapical inflammatory lesions can be combined with artifact masks created from real PSP plates. This allows the resultant images to have both the subtle features of inflammatory diseases and authentic PSP plate artifacts. All procedures were approved by the University of Toronto Research Ethics Boards (Protocol Number 00035933).

Acquiring real PSP artifact masks

Carestream CS 7600 PSP plates (Carestream Dental, Rochester, NY) were acquired from the oral radiology clinic at the Faculty of Dentistry, University of Toronto (Toronto, Ontario, Canada). Plates were wiped (in accordance with the manufacturer's recommendations) by using a 0.6% weight by volume (w/v) sodium hypochlorite solution and then wrapped in thin plastic hygiene sheaths. Plates were subsequently exposed at a typical posterior periapical setting by using a Belmont PHOT-xIIs Intraoral X-Ray unit (Takara Belmont, Somerset, MA) with exposure parameters of 70 kV, 6.0 mA, 0.22 seconds exposure time, at the minimum exposure distance permitted by the long cone position indicating device. The hygiene sheathes were removed, and the plates were placed into the PSP scanner (Carestream Dental). The raw digital images were exported manually from the workstation in a lossless format (portable network graphics, *.png). These digital images were used as the PSP artifact masks because they contained authentic physical PSP artifacts that were created through routine clinical use.

Twenty-four PSP plate images were selected for analysis. Of these, 15 were deemed to have severe artifacts, 5 had intermediate artifacts, and 4 were brand new, unused PSP plates. An additional completely blank mask was added, and this plate, together with brand new plates, acted as negative controls. Images were characterized as having an intermediate level of artifact if the authors (T.T. and S.P.) deemed that a reasonable clinician would continue using the plate, whereas plates were characterized as having severe levels of artifact if it was deemed that no reasonable clinician would continue using these plates. Examples of these artifacts, including scratches, bends, and peeling of the plates, are shown in Figure 1.

Acquiring radiologic interpretations of in vivo artifact-free images

A total of 160 anonymized periapical images were acquired from the Faculty of Dentistry's MiPACS Imaging Picture Archiving and Communication System (Medicor Imaging, Charlotte, NC) in a lossless format (tagged image file, *.tif). The inclusion criteria were as follows: (1) the image had been acquired by using a size 2 Carestream RVG 6200 CMOS sensor; (2) the image was a posterior periapical radiograph of the maxillae or mandible; (3) the image adequately visualized the periapical region of a tooth of interest; and (4) the brightness and contrast of the images were adequate. To indicate the tooth of interest, a red asterisk was digitally placed over its crown, ensuring that this additional marking would not interfere with the diagnostic task. CMOS images were selected (over PSP images) to ensure that these basis images were artifact-free and devoid of scratches and mechanical abrasion.

Gold standard radiologic interpretations were acquired by expert consensus between 2 oral and maxillofacial radiologists. They were asked to review these images in their preferred viewing conditions and to indicate (1) the presence or absence of periapical inflammatory disease (binary decision) and, if periapical inflammatory disease was present, (2) the severity of the bone changes (ordinal scale of mild, moderate, and severe). Reference images were provided to calibrate the reviewers on bone change severity. A total of 100 images with uniform agreement in both interpretation and severity were selected for testing: 50 images were normal, 21 had mild pathologic changes, 15 moderate, and 14 severe.

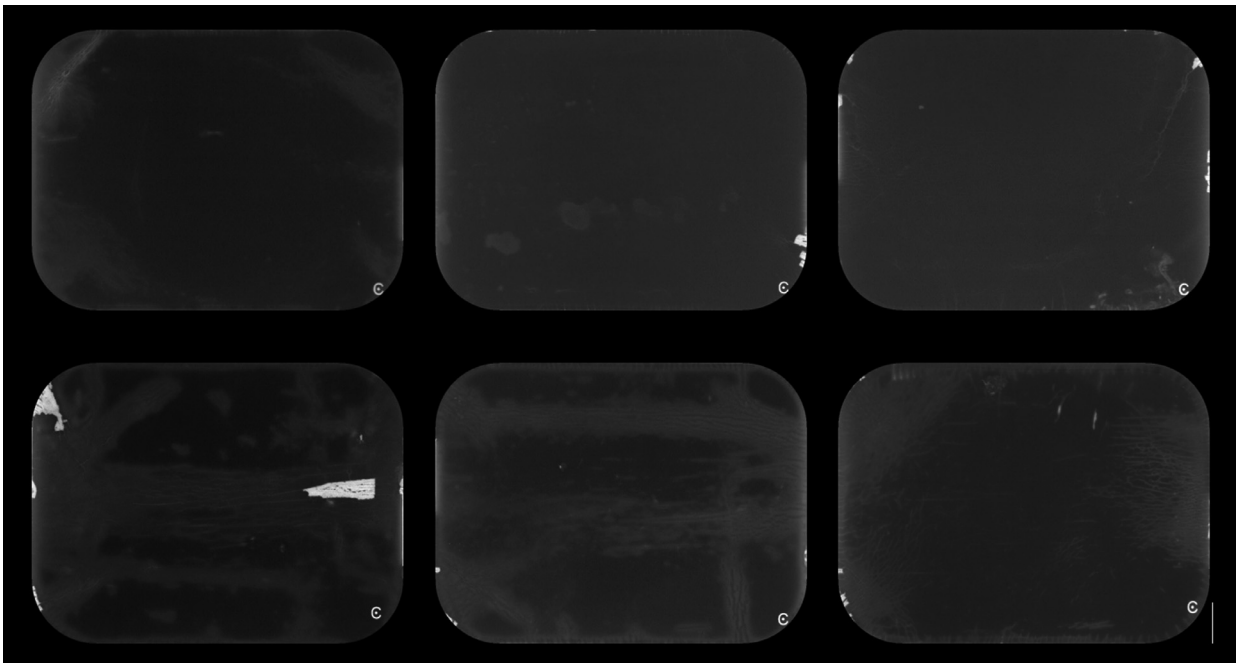

Fig. 1. Examples of photostimulable phosphor (PSP) plates with "intermediate" *(top row)* and "severe" *(bottom row)* artifacts. Scratches and bends of various severities are seen across all images. In addition to having an increased quantity of artifacts, additional types of artifacts, such as peeling of the active surface of the sensor *(bottom left)* and bite marks *(bottom right)*, are seen in the severe category.

Superposition of clinical and artifact images

To create the testing images, a custom python script was used to digitally combine the selected PSP artifact masks with the *in vivo* artifact-free images. The script summates corresponding pixel intensities after adjusting them by weighting factors to form the testing image. Through this process, the new image combines features of both basis images. This process is elaborated by Equations 1 and 2.

$$c_{ij} = w_{ij} \cdot a_{ij} + w_2 \cdot b_{ij} \quad (1)$$

where w_{ij} and w_2 represent the artifact and CMOS image weighting factors respectively, a_{ij} and b_{ij} represent the pixel gray-scale values from the artifact mask and the CMOS image respectively, and c_{ij} represents the gray-scale value of the combined image.

$$w_{ij} = A \cdot B^{a_{ij}} \quad (2)$$

where the weighting factor w_{ij} is an exponential transformation of the pixel intensity of a_{ij} with constants, A and B.

Weighting factors were selected through an integrative calibration process, comparing simulated images to real periapical images by using damaged PSP plates acquired on a DXTTR III Dental X-Ray Trainer dental radiographic phantom (DENTSPLY Rinn, York, PA) until the images were indistinguishable on visual inspection (Figure 2). The weighting factors that best simulated the real periapical images were $w_2 = 0.85$, $A = 0.08069$, and $B = 1.00718$. The maximum value of c_{ij} was set at the available bit depth of the image. The algorithm was applied for the 25 artifact masks onto the 100 CMOS images, creating 2500 new images with authentic PSP plate artifacts of various severities and known radiologic interpretations.

Clinical testing

Twenty-five dentists were recruited for testing. Inclusion criteria for dentists were (1) being registered and in good standing with the Ontario dental regulatory body, as either a full member or a graduate student member and (2) having a minimum of 1 year of clinical dentistry experience after dental school that involved interpreting periapical lesions on radiologic images. Each dentist analyzed all of the 100 selected CMOS images. Oral and maxillofacial radiology specialists were not eligible to participate because their expertise in interpreting radiographs could potentially confound the results and would not be representative of general dentists.

All testing was done in the oral radiology clinic under standardized viewing conditions—that is, a Dell P2417H 24" LED monitor (Dell, Round Rock, TX) with a 1920 x1080 pixel display, 60 Hz, brightness: 75%, contrast: 75%, using Windows Photo Viewer (Microsoft, Redmond, WA) with dim ambient lighting.[9] Verbal and written instructions were given, and written informed consent was obtained before testing.

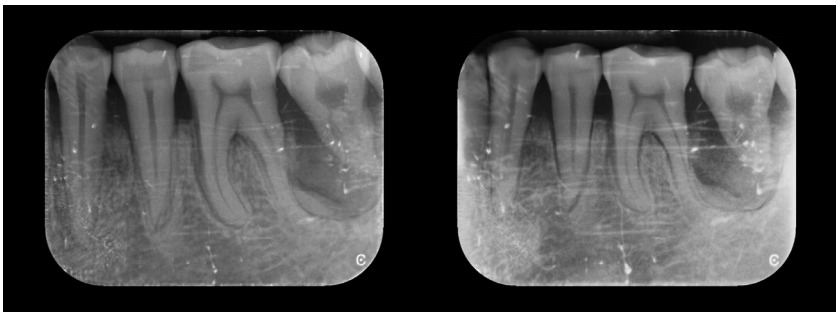

Fig. 2. Comparison of a computer-simulated image *(left)* and a real photostimulable phosphor (PSP) image *(right)*.

Participants reported their evaluations of each of the 100 images in a Microsoft Excel spreadsheet. To prevent recall bias of the interpretation, it was ensured that the underlying CMOS image was not repeated for any participant. The brightness and contrast of the images could not be altered. Participants were asked to report (1) their radiologic interpretation of the tooth of interest (pathologic vs normal); (2) the confidence level of their interpretation on a 5-point Likert scale anchored between "not confident" and "very confident"; and (3) whether they would discard PSP plates (yes vs no). When deciding if a plate should be discarded, participants were asked to consider whether these artifacts would adversely affect their radiologic interpretations on a typical day in their private practices.

Statistical analysis

Commercially available software (Prism version 7.05 for Windows, GraphPad Software, San Diego, CA; and SAS version 9.4 for Windows, SAS Inc., Cary, NC) was used for statistical testing. Interrater agreement was determined for the gold standard interpretations through Cohen's kappa coefficient statistic (κ). The responses from the 25 participants were collected and pooled for statistical analysis. Interpretative sensitivity, specificity, and accuracy; average clinicians' confidence levels in their interpretation; and discard proportion for each plate severity category were calculated. Descriptive statistics were performed for each response variable.

Random intercept mixed models were used to assess interpretative results, clinicians' confidence levels, and discard proportions by considering participants as clusters and artifact severity as the explanatory variable (with "Brand New/Blank" as the reference group). Specifically, an ordered logit model was used to analyze the clinicians' confidence levels. χ^2 tests were conducted to test for associations between the 3 response variables. Bonferroni corrections were performed to account for multiple tests. Statistical significance was set at $P < .05$.

RESULTS

Gold standard interpretations of artifact-free images

When determining the gold standard radiologic interpretations for the original 160 images through expert consensus, the interobserver agreement between the 2 oral and maxillofacial radiologists was "substantial" for the radiologic interpretation ($\kappa = 0.80$; 95% confidence interval [CI] 0.71−0.89) and "moderate" for the severity of osseous changes (weighted $\kappa = 0.60$; 95% CI 0.45−0.75). Of the 160 images reviewed, there was 90% (144 of 160) agreement of interpretation. Of the images with periapical inflammatory disease (73 of 144), there was agreement in severity in 70% (51 of 73) of the cases. Only images (n = 100) with agreed-upon interpretations were selected for further testing.

Clinical testing

The pooled values for sensitivity, specificity, and accuracy; average clinicians' confidence levels in their interpretation; and discard proportions when using brand new/blank plates (negative control), plates with intermediate artifacts, and plates with severe artifacts (mean ± standard error of the mean) are reported in Tables I and II. No statistically significant differences were discovered in the interpretative parameters of periapical inflammatory disease when using plates with various artifact severities, even when stratified based on different severities of osseous changes ($P \geq .41$). Significant differences were found in confidence levels between images on brand new/blank plates or plates with intermediate artifacts versus images with severe artifacts ($P < .0001$). Significant differences were identified in discard proportions between images with each level of artifact severity ($P < .0001$).

Frequency distributions for sensitivity, specificity, and accuracy; average clinicians' confidence levels in their interpretation; and discard proportions are shown in Figures 3 and 4. Clinicians' confidence level is reported as the average confidence level percentage (mean confidence score divided by the maximum

Table I. Descriptive statistics (mean ± standard error of the mean) for the interpretative efficacy of periapical inflammatory disease when using plates with various degrees of artifact

	Sensitivity	*Specificity*	*Accuracy*	*P value*
Brand New/Blank	84.4 ± 2.29%	77.2 ± 2.65%	80.8 ± 2.17%	Reference
Intermediate	89.2 ± 1.96%	76.4 ± 2.69%	82.8 ± 3.03%	.41
Severe	86.9 ± 1.23%	76.7 ± 1.54%	81.8 ± 2.34%	.61
Overall	86.9 ± 2.95%	76.7 ± 3.21%	81.8 ± 2.43%	–

P values from the random intercept mixed models compare the accuracy of interpretation at various severity levels to the negative control.

Table II. Descriptive statistics (mean ± standard error of the mean) for subjective metrics for the clinical impact of interpreting periapical inflammatory disease when using plates with various degrees of artifact

	Confidence levels	*P value*	*Discard proportions*	*P value*
Brand New/Blank	86.0 ± 1.05%	Reference	5.0 ± 1.0%	Reference
Intermediate	86.1 ± 0.71%	.80	35.2 ± 10.2%	< .0001
Severe	80.1 ± 1.08%	< .0001	88.2 ± 3.17%	< .0001

P values from the random intercept mixed models compare the confidence level and discard proportions at various severity levels to the negative control.

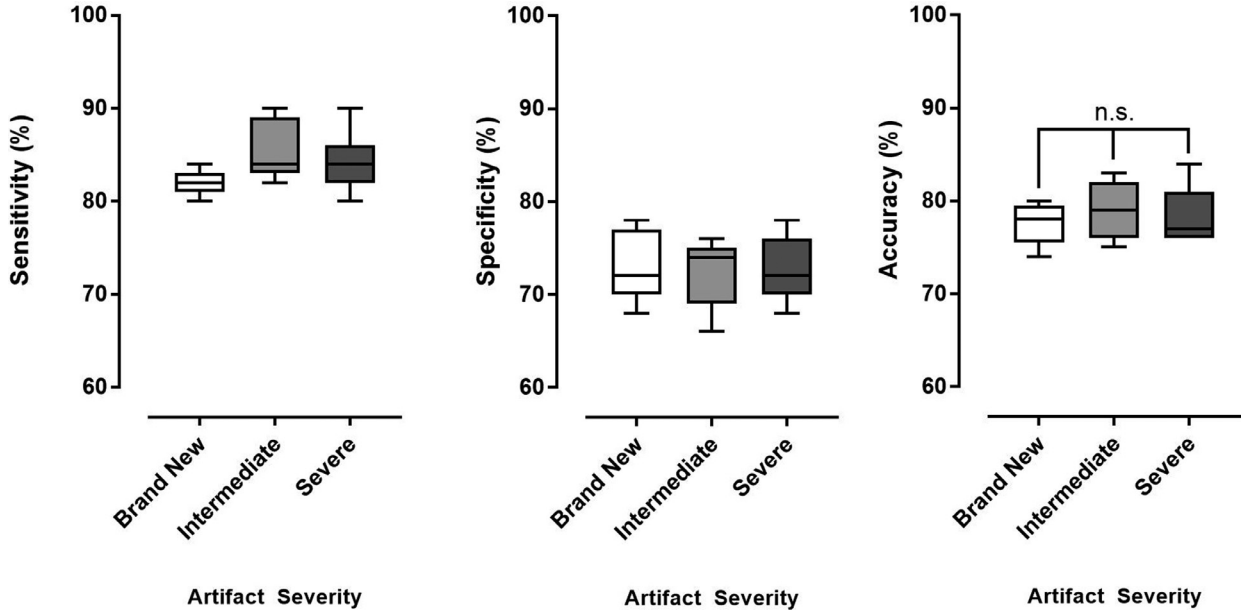

Fig. 3. Box-and-whisker plots for the interpretative efficacy of periapical inflammatory disease. Distributions for the sensitivity, specificity, and accuracy for each artifact plate categorized by artifact severities are shown. No statistically significant differences were seen in the interpretative results of periapical inflammatory disease under different artifact severities. The horizontal line, the box, and the whiskers represent the median, the middle 50%, and the outer 50% of the data, respectively.

possible confidence score) for each plate. Odds ratios from the random intercept mixed analyses are shown in Table III. Statistically significant odds ratios were identified between "brand new/blank" and "severe" artifact groups in clinicians' confidence levels. The discard proportions for the 3 artifact severity groups were statistically different from each other.

Decreased clinician confidence was associated with an increased discard proportion ($\chi^2 = 41.79$; $P < .01$) (see Table III). The odds ratio for discard proportions was 1.73 (95% CI 1.46−2.04) when clinicians had below-average confidence compared with above-average confidence. An association between interpretative results and clinicians' confidence levels was also found ($\chi^2 = 174.9$; $P < .01$). There was an odds ratio for an accurate interpretation of 4.12 (95% CI 3.31−5.77) when clinician confidence was above average compared with below average.

Sample images of those with intermediate discard proportions are presented in Figure 5. These images illustrate the tipping point at when the artifacts started to influence most clinicians to discard damaged plates.

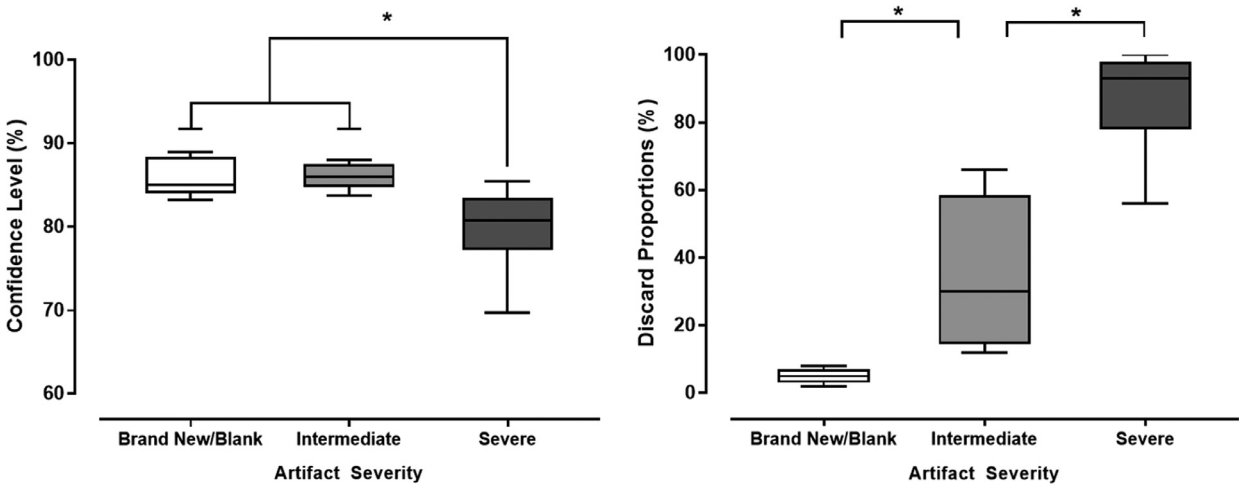

Fig. 4. Box-and-whisker plots for the clinicians' confidence levels and the discard proportions of photostimulable phosphor (PSP) plates when interpreting periapical inflammatory disease. Distributions for the confidence levels and discard proportions for each artifact plate categorized by artifact severities are shown. Statistically significant differences are indicated with an asterisk (*). The horizontal line, the box, and the whiskers represent the median, the middle 50%, and the outer 50% of the data, respectively.

Table III. Odds ratios for response variables compared with "brand new/blank" plates

Response variable	*Brand New/Blank*	*Intermediate*	*Severe*
Diagnostic efficacy	1.0 (reference)	1.15 95% CI 0.83−1.60; $P = .41$	1.07 95% CI 0.82−1.34; $P = .61$
Confidence levels	1.0 (reference)	0.97 95% CI 0.75−1.24; $P = .80$	1.71* 95% CI 1.40−2.10; $P < .01$
Discard proportions	1.0 (reference)	14.8* 95% CI 9.12−24.01; $P < .01$	393.0* 95% CI 236.01−654.45; $P < .01$

No statistically significant differences detected in diagnostic efficacy. Differences in clinicians' confidence levels were detected between brand new/blank vs severe artifacts, showing that images with severe artifacts are 1.71 times more likely to result in lower confidence levels compared with controls. With regard to discard proportions, statistical differences were seen among all artifact severities.
*Statistically significant results ($P < .05$).

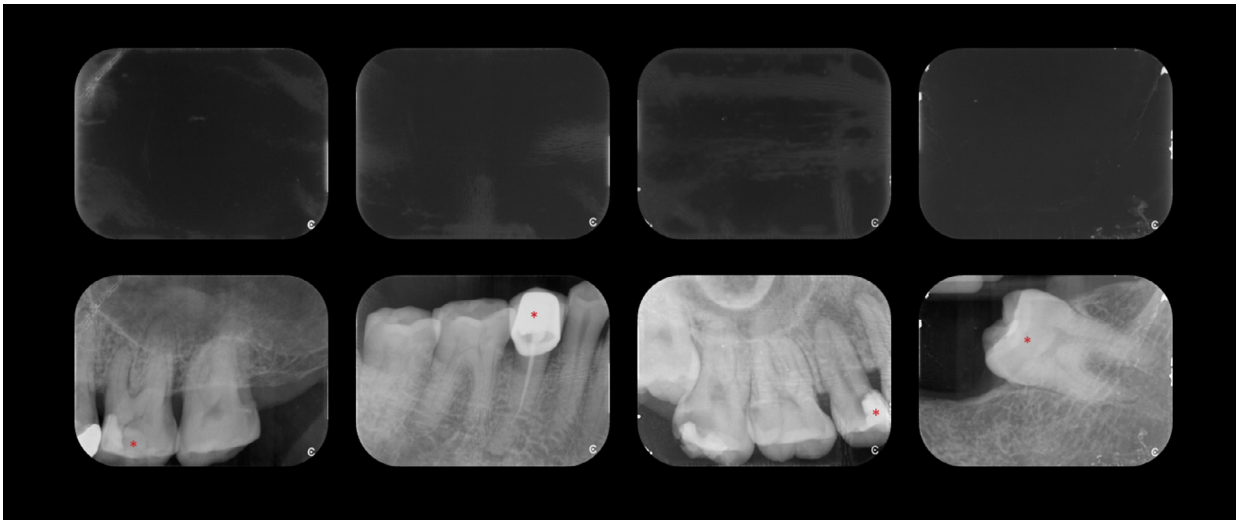

Fig. 5. Sample images with intermediate discard proportions. The top row of images shows the artifacts as they would appear if the photostimulable phosphor (PSP) plates were blank exposures, whereas the bottom row represents the corresponding artifacts digitally superimposed over a dental radiograph. The discard proportions for the following PSP plates were *(from left to right)*: 30%, 51%, 56%, and 66%.

DISCUSSION

Understanding the impact of PSP plate artifacts on diagnostic accuracy is a necessary step to determine their significance and to ensure adequate maintenance of PSP plates. It is easy to assume that artifacts adversely affect the efficacy of diagnosis; however, this present study does not support this notion. There was no significant difference in efficacy of interpretation between artifact-free and damaged PSP plates. Accurate interpretations require the visualization of a sufficient number of radiologic features to lead a clinician to an interpretation. Therefore, if a sufficient area of the region of interest is unobscured by artifacts, an accurate interpretation can still be made. For instance, in periapical inflammatory disease, the clinician presumably looks for osseous rarefaction and sclerosis as well as features supporting a pulpal etiology, such as widening of the periodontal ligament space, loss of the lamina dura, or a large coronal restoration. Thus, one inference from the data is that periapical inflammatory diseases can elicit changes across a sufficiently large area of the image, and therefore, PSP artifacts cannot significantly hinder the clinician's visualization of these features. However, it is believed that these artifacts may be able to obscure diseases with more subtle radiographic presentations, such as enamel interproximal caries. It is hypothesized that future studies assessing these more subtle diseases will show an adverse effect of artifacts on interpretation. Another possibility is that the artifacts selected for this study were not large enough to obscure the region of interest and, thus, hinder the interpretation. However, we believe that at the artifact severity levels tested in this study, common wisdom would suggest that no reasonable clinician would continue using these plates. Figure 1 shows examples of the level of PSP plate artifacts that are representative of the severe artifact category.

This study showed a significant relationship between the severity of PSP plate artifacts and clinicians' confidence levels and discard proportions. As plate artifacts increased, clinicians lost confidence in their radiologic interpretation and, thus, were more likely to discard plates. This aligns with the progressive nature of how plate artifacts accumulate and cause progressive degradation of image quality.

Lack of clinical confidence can adversely affect trust in the patient−dentist relationship and hinder delivery of optimal dental care. Although subjective, these factors ultimately limit the effectiveness of a dental practice. This lack of clinical confidence in radiologic interpretation commonly results in acquiring a "re-exposure," or a repeat image, to clarify the confusion. Unfortunately, this unnecessarily increases radiation burden to the patient. Another potential consequence of lack of confidence is delay in treatment until other signs, symptoms, and tests are more convincing for a positive diagnosis. Unfortunately, delaying the treatment of periapical inflammation is not benign, because the inflammatory response can spread into the surrounding structures, resulting in osteomyelitis or cellulitis.[10] Treatment for these conditions is significantly more difficult once the infection has spread outside of the tooth-bearing regions, increasing patient morbidity.

The most striking relationship was observed between the severity of PSP plate artifacts and the collective discard proportions. We found that as the severity of PSP plate artifacts increased, dentists were more likely to discard PSP plates. Our results are more compelling than those from similar investigations, which utilized only 1 expert opinion[3,11]; our study presents the collective opinion of 25 dentists. To ensure that the sampled participants were representative of the community, we compared their results with those in the reported literature. A meta-analysis conducted by Dutra et al. found that the specificity for periapical inflammatory disease on digital periapical images had a pooled value of 78% (range 42%−100%).[12] The pooled specificity of our study participants was 76.7% (range 38%−96%), which falls within the reported range. This suggests that the dentists participating in this study were a representative sample of the dental community.

As with any clinical study, variability is expected in each participant's interpretative skills and experiences with interpreting PSP plate artifacts. This limitation is hard to overcome, given the study design. A possible alternative study design would be to use each participant as his or her own control by presenting each clinician with both original and degraded images. However, this potential study design would introduce recall bias for the interpretation.

To avoid unnecessary irradiation of patients, simulated images were created to act as a proxy for clinical images acquired by using damaged PSP sensor images. Therefore, an assumption is made that the results from the simulated images in this study are comparable with the results expected from clinical PSP plate radiographs. Despite using real PSP images to optimize the weighting factors used in superimposition simulation, the final algorithm was established by our visual calibration. There could potentially be subtle, yet clinically significant, features of PSP sensors that were not accurately replicated through the simulation. To our knowledge, this is a novel method with no alternative technique to accomplish this simulation reported in the literature.

Quality assurance protocols for PSP sensors should be founded on knowledge of how PSP artifacts affect the interpretation of common dental diseases. Although there are known differences between digital sensors,[4] at this time, there are no other articles in the scientific

literature examining the effects of PSP artifacts on diagnosis. Thus, these results represent the sole data on this issue. Given this, we recommend that dentists seeking to ensure the quality of their PSP plates refer to the reference images in Figure 5 for comparison with their own radiologic images. These images represent PSP plates with intermediate discard proportions. Using these images as a reference, sensors that appear to have less severe artifact than the reference images may be kept, whereas those with more severe artifacts should be discarded. Until a more rigorous and reproducible approach to quality assurance is developed, these images can be used as a guide for when PSP plates should be discarded. Future investigations should be designed to (1) study the effect of PSP artifacts on the radiologic diagnosis of other common dental diseases and (2) determine a way to quantify artifacts.

CONCLUSIONS

This study presented a novel technique to study the clinical impact of PSP sensor artifacts on interpretation of periapical inflammatory disease, without requiring any additional patient exposure. No statistically significant adverse effects on interpretation were discovered, even at severe artifact levels. Clinicians' confidence decreased, and proportionally more clinicians opted to discard sensors, when interpreting images with severe artifacts. Future studies on the effect of artifacts on other dental diseases are recommended to determine the effect on diagnostic efficacy. Ultimately, these results can guide recommendations for PSP plate quality assurance.

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