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TECHNICAL REPORT

Benefits of using a photostimulable phosphor plate protective device

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Objectives: To develop and test a protective device (PD) to increase the resistance of photostimulable storage phosphor (PSP) plate to compressive load, and assess the resulting image quality.
Methods: Two prototypes, polyvinylchloride sheets of 0.3 mm and 0.7 mm each, were developed for PSP plate size 2. The resistance to compressive load was tested using eight new PSPs divided into four test groups: (1) PSP, (2) PSP and paperboard protector, (3) PSP and 0.3 mm PD, and (4) PSP and 0.7 mm PD. The resulting images were analyzed by three oral radiologists, based on the consensus for image artifacts. Additionally, the objective image quality test was performed with four new PSPs, using an 8-step wedge aluminum scale. The mean gray values and standard deviation were measured in a total of 240 images, and the data were analyzed using analysis of variance with Bonferroni post-hoc test.
Results: Artifacts were seen in the PSP control group starting at 40 n, and at 150 n, 175 n and 300 n in 0.3 mm PD, paperboard protector and 0.7 mm PD, respectively. Although there was no statistical difference among groups, there were differences between exposure times (0.06–0.25 s, 0.06–0.40 s, and 0.10–0.40 s). Scanning resolution of 20 lp/mm showed higher mean gray value than 25 and 40 lp/mm ($p < 0.05$)
Conclusion: The developed PDs improved the PSP resistance to compressive forces, with low interference on the pixel gray values, regardless of exposure time and spatial resolution. Nevertheless, the 0.7 mm PD could withstand the maximum compressive load.
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Introduction

Digital radiographs with photostimulable storage phosphor (PSP) plates have been widely used in clinical practice owing to their convenience and lower radiation dose compared to conventional radiographs.[1,2] Among the currently used digital receptors, flexibility of PSP is considered an advantage compared to charge-coupled devices (CCD)[3]; however, these physical characteristics may be related to mechanical degradation of the phosphor layer, which has been described as the main reason for receptor replacement.[4] The reusable nature of the digital receptors has brought new challenges for the practitioner to overcome. Prevention of scratches, bending, and bite-marks that may induce artifacts and cause potential diagnostic errors, is still a matter of concern in the PSP system.[5,6] Bite-marks are encountered in intraoral radiography, either during occlusal examinations, or accidentally in periapical and interproximal radiographies. Some authors have described

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clinical techniques to reduce PSP damage and have highlighted some difficulties related to pediatric patients as well, who could have a harder conditioning because of age, restricted mouth opening, or limiting anatomical features, among others.[7] The mean bite force increases throughout human growth and development,[8] and the maximum bite force in children may range from 200 to 270 n according to age.[8,9] A resistance to these forces is anticipated from the image receptor. Over time, some authors have related a few aspects of image artifacts with indirect digital systems which are associated with operator error, scanning machine error, and mechanical damage to receptor.[5,10]

Recently, a dual-side reading technology was developed in an effort to reduce the image noise in PSP,[11] allowing the receptor to produce radiographic images on both sides. This feature is possible due to the absence of an opaque support on the back side of the PSP, with no lead foil as used in conventional films. Alternatively, some authors have tested other shielding materials to reduce the radiation dose in PSP-based radiography and have shown the efficacy of lead foil to reduce the residual radiation dose.[12] Besides the radioprotective feature, lead foil has the benefit of shielding scattered radiation with enhanced image quality even in PSP, as evidenced by Gomes AF. et al.[13] These previous studies showed that the addition of a lead foil during PSP-based radiography reduced the absorbed radiation dose and improved the image quality, producing a positive effect.

The PSP plate works on the principle of indirect image acquisition that requires additional scanner equipment to realize digital processing. Scanner functionality is a feature of every manufacturer that works in conjunction with PSP technology.[14] Therefore, any effort to increase the receptor's resistance to mechanical forces or reduce the residual radiation dose and improve the image quality, should not impair the functioning of the system.

The main purpose of this study was to develop a protective device (PD) for intraoral PSP, which provides resistance to compressive load, and patient radioprotection without interfering with the image quality. Furthermore, we evaluated the effects of the device on digital image quality under different exposure time settings and scanning protocols.

Methods and material

The Research Ethics Committee of the Dental School of the Federal University of Rio Grande do Sul approved this study under the protocol number 12127219.9.00005347.

Protection device development

Two PDs were developed for PSP plate size 2 from the VistaScan system (VistaScan, Dürr Dental, Bietigheim-Bissingen, Germany) using polyvinyl chloride (PVC). They were of the same size to involve a PSP plate on both the sides. One of the prototypes had a 0.3 mm sheet, and the other was thicker, with a 0.7 mm sheet (Bio-Art Dental Equipments Ltd., Brazil). PVC is a polymer, which is widely used in dentistry and presents physical properties such as toughness and elastic deformation, indicating its repetitive use in clinical practice. Furthermore, the prototype device was attached to a lead foil from a radiographic film, adapted to the thermoplastic sheet with a vacuum former machine (VH Essence Dental, Brazil), only on one side of the device, and was kept totally isolated (Figure 1a, 1b and 1c).

Mechanical compression test

Eight new PSP plates were used in this experiment, divided into four test groups: (1) PSP, control; (2) PSP with paperboard bite block protector (VistaScan, Dürr

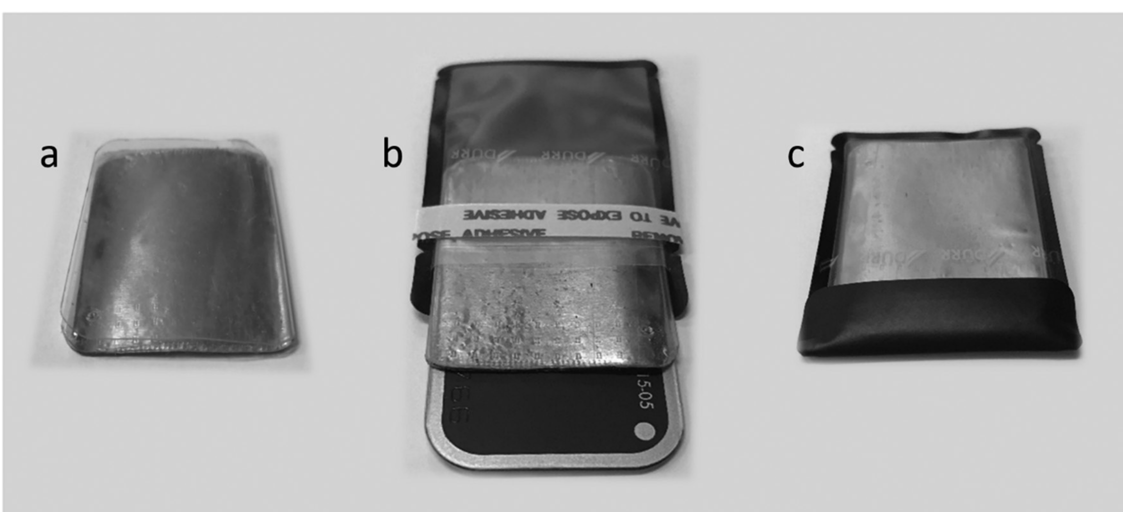

Figure 1 (a) 0.3mm protective device by itself, (b) Image of the PSP used with protective device, and (c) with light protection cover sealed

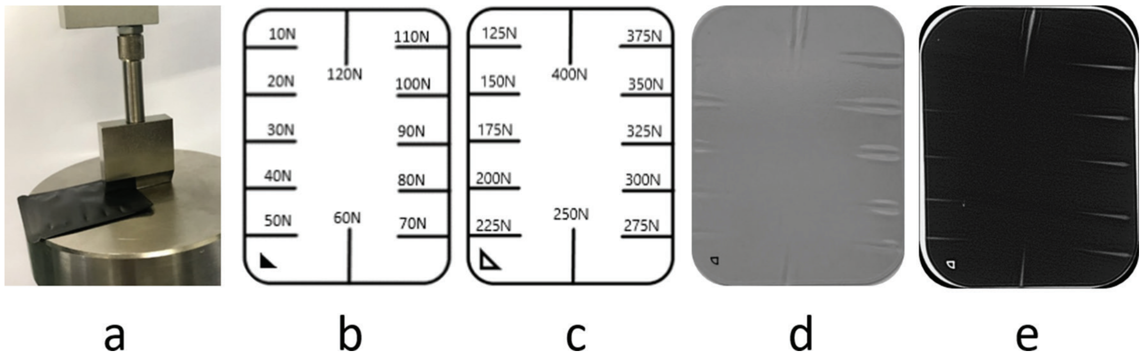

Figure 2 (a) Image of EZ Test machine used in the mechanical compression test, (b, c) sketch of applied forces at twelve different locations on the first and second PSP plates, respectively, (d) second PSP plate after use of 0.3mm PD (under load from 125 to 400N), and (e) the resulting image

Dental, Bietigheim-Bissingen, Germany); (3) PSP with 0.3mm PD; and (4) PSP with 0.7mm PD, with two PSPs for each group. The capacity to resist mechanical forces was measured on PSP plates, using a tabletop universal tester (EZ Test EZ-SX, Shimadzu Scientific Instruments, Kyoto, Japan) (Figure 2a). This device uses a toothed pushrod (30mm wide ×1mm thick) and a lower compression plate having a diameter of 118mm. This jig is designed to simulate the shape of the teeth and is used to test the compressive, shear and tensile strengths including other characteristics of the material. Compressive forces were applied at 12 different sites on the first PSP plate (10 to 120n) and the second PSP plate (125 to 400n) (Figure 2b and c, respectively). All PSPs were exposed to a dental X-ray equipment [Timex 70c X-ray generator (GNATUS, Barretos, São Paulo, Brazil)] operating at 70 kVp and 7 mA in a standard position with a focus-to-film distance of 30cm, and an exposure time of 0.16s. The plates were scanned under VistaScan Mini View with a 20 lp/mm setting, using an automatic exposure control (AEC). Prior to the experiment, the receptors were checked to verify the presence of any scratches or other defects, and all the experiments were performed with a light protection cover. Three experienced oral radiologists evaluated the eight images on the same monitor and workstation and were blinded to the image data. The images were evaluated based on the consensus for presence or absence of image artifacts.

Image quality test

This experiment included four new PSP plates. All were used in the same four groups: (1) PSP, control (2) PSP with paperboard (3) PSP with 0.3mm PD and (4) PSP with 0.7mm PD. The images were acquired using the parallel technique with the same X-ray equipment, operating at 70 kVp and 7 mA, with a focus-to-film distance of 30cm, in a standard position. The radiographs were taken above an 18 mm-thick plastic platform, with an incidence of the vertical radius in relation to the ground, with the support being 1 m from the ground. All radiographic exposures included an 8-step wedge aluminum scale (each step of a thickness of 5mm), and a 1.5cm thick dental wax, located in front of the phantom, as a soft tissue equivalent attenuator.

The exposure parameters were determined based on the manufacturer's instructions for interproximal radiographs in adults, with a deviation of two doses on either side of the prescribed dose of exposure, and were calculated to be 0.06, 0.10, 0.16, 0.25, and 0.40s. Following image acquisition, the plates were scanned in the VistaScan Mini View device with three scanning protocols: 20 lp/mm, 25 lp/mm, and 40 lp/mm, all of which were generated using AEC. Four groups consisting of four plates each, with five different exposure times, and three scanning protocols resulted in 240 digital images (Figure 3). These images were transferred as 8-bit tagged image file format (TIFF) to a desktop computer [Intel Duo Core 2 Ghz CPU, 4GB RAM, Windows 7 Pro operating system, 19" monitor, with 1,280 × 1,024 screen resolution, 32-bit color mode, complies with IEC 60950–1 (International Electrotechnical Commission Co., LTD., Geneva, Switzerland) Dell Inc., Texas] and evaluated using ImageJ software (v. 1.52q; National Institute of Health, Bethesda, MD). The radiodensity of the 8-bit digital images is expressed by a grayscale ranging from 0 (black) to 255 (white).[14] The gray value was measured in nine rectangular (3.7.×1.5mm) regions of interest (ROIs) in each image. It consisted of a region in the background (ROI 0) by the right side of the scale, with the other regions being the centers of each of the eight steps of the aluminum phantom (ROI 1 to ROI 8). Figure 4 shows the ROI placement in an image sample.

Statistical analysis

The data of the image quality test were analyzed using the SPSS software v. 18.0 (IMB. Corp., Armonk, NY) using an analysis of variance (ANOVA). Normal distribution data and variance homogeneity were tested using the Shapiro-Wilk test and Levene's test, respectively. Additionally, bootstrapping was employed as a method for estimating the sampling distributions followed by the Bonferroni post-hoc test to verify differences in gray values among groups for different exposure times and

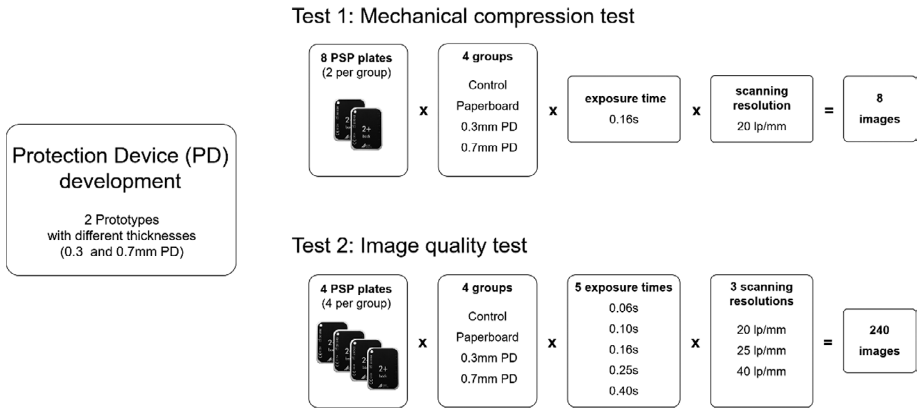

Figure 3 Study flowchart

scanning protocols. The level of significance adopted for all tests was $p < 0.05$.

Results

Mechanical compression test
Artifacts were seen in the PSP's control group starting at 40 n, in the 0.3 mm PD at 150 n, (Figure 2d and e) and in the 0.7 mm PD at 300 n. The paperboard protector offered resistance up to 175 n, which was larger than the 0.3 mm PD.

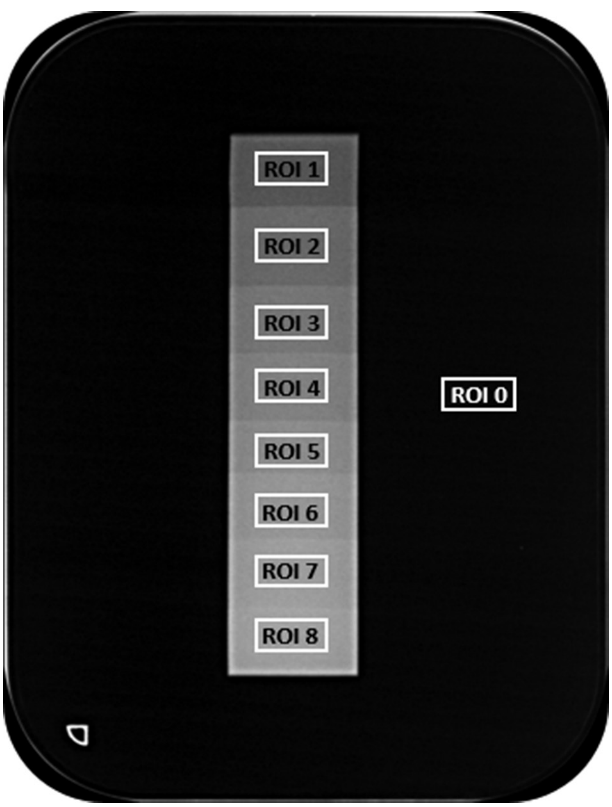

Figure 4 Sample image used for MGV measurement and the ROIs placement

Image quality test
The MGVs and standard deviations (SD) from the nine ROIs at different exposure times, and scanning resolutions are displayed in (Figures 5 and 6) respectively. Overall, there was no statistical difference among groups; however, there were differences between exposure times (0.06–0.25 s, 0.06–0.40 s, and 0.10–0.40 s). In addition, scanning resolution of 20 lp/mm showed higher MGV than 25 and 40 lp/mm ($p < 0.05$) (Table 1).

Discussion

There is scarce information on the physical resistance of PSP in the literature; we found a single study published by Borch et al,[15] which assessed the occurrence of damage in PSPs from four different manufacturers. The study employed application of pressure at different dots using tweezers, starting with a load of 10 g and subsequently increasing the load by 10 g at each dot. The phosphor plate was attached to a trolley with tape, and the pressure was kept constant. The trolley was pulled away under the tweezers, creating an imaginary line next to every dot. On scanning the plate under VistaPerio scanner (Dürr Dental, Bietigheim-Bissingen, Germany), scratches were not observed until a load application of 100 g. In the present study, although the plate was not tested for surface hardness, the plate's resistance to compressive forces and the first artifact on the VistaScan PSP was observed at a load of 40 n. Among the test groups, the 0.3 mm PD showed a lower resistance to compressive forces, when compared to the paperboard protector. The 0.7 mm PD showed the highest resistance, with the first artifact seen at 300 n, proving the ability to withstand the maximum occlusal bite force of a child in a clinical scenario. Although it is unlikely for pediatric patients to bite with the maximum occlusal force, which ranges from 200 to 270 n according to age,[8,9] it would be prudent to consider this possibility, and give a scientific background to the practitioner to choose the best approach, especially in less co-operative patients.

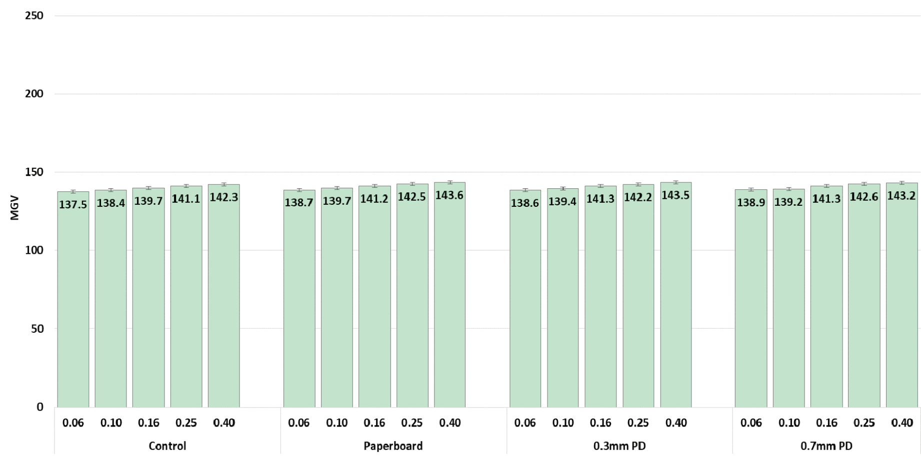

Figure 5 Mean grey value (MGV) and standard deviation (SD) in overall ROIs in the different exposure times

Nejaim et al[12] investigated the radioprotective effect of the use of a lead foil on the back side of the VistaScan PSP. They found a reduction of 32% in the radiation absorption by anatomical sites of the head and neck during intraoral radiographic exams. The presence of lead in both the PDs follows the ALARA principle (as low as reasonably achievable),[16] and increases patient radioprotection, which is most desirable for examining pediatric patients, the target population of these devices. According to Gomes et al,[13] addition of a lead foil to VistaScan PSP produces positive effects on image quality as well, by resulting in more uniform pixel values that is attributed to a decrease in fog formation. Compared to the control group, the MGV was larger in the PD group, and in the paperboard group. At higher exposure times of 0.25 and 0.40s, the noise (expressed by SD) of ROIs was consistently higher with PD. This could be attributed to the PVC material in front of the PSP. However, there was no difference among the groups with respect to different ROIs. In Figure 6, a higher difference between scanning protocols can be seen, whereas there is no such difference between the groups.

The PSP system has a wider dynamic range among radiographic receptors.[2,17] This feature allows it to produce an acceptable image with a large variation in radiation dose. The five exposure times tested in this study demonstrated a direct relationship between increased exposure time and MGV, except in ROI 0 (background), independent of the tested group. This behavior is probably an interference of the AEC of the VistaScan system that performs an image pre-processing to obtain the optimum contrast after data acquisition, before displaying the final image.[18] This interaction between the radiation dose and the MGV has already been described as a characteristic of the PSP system.[19] Dasputsag et al[20] reported the linearity response of the current VistaScan system, which elevates the image gray values in order to retain the best contrast to diagnosis purposes, and thus establishes a wider dynamic range. However, it is not possible to extrapolate these results to other manufacturers' indirect systems, since

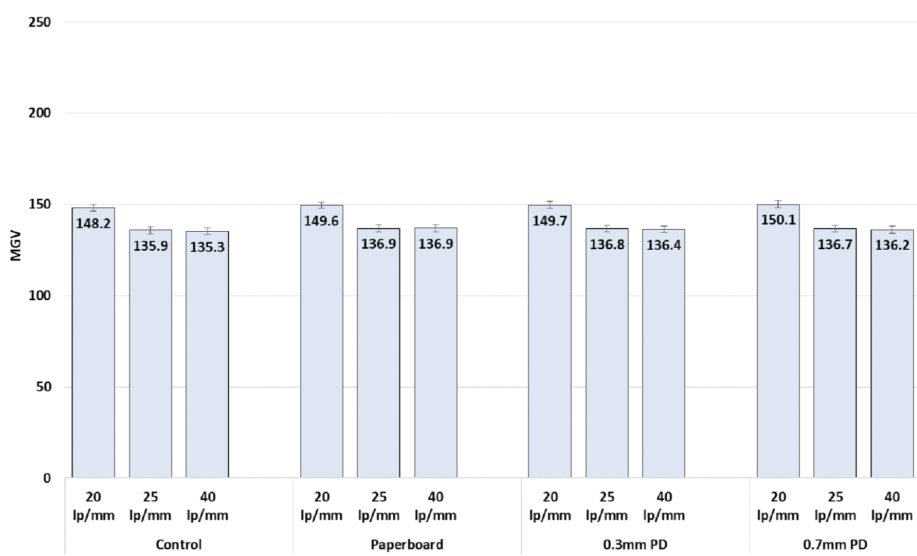

Figure 6 Mean grey value (MGV) and standard deviation (SD) in overall ROIs in the different scanning resolutions

Table 1 Differences between groups, scanning resolution, and exposure time

	ANOVA (p-value)	*Bonferroni (p-value)*
Groups	0.641	
Scanning resolution	0.000*	
20–25 lp/mm		0.000*
20–40 lp/mm		0.000*
25–40 lp/mm		0.676
Exposure time	0.001*	
0.06 – 0.10 s		1.000
0.06 – 0.16 s		0.544
0.06 – 0.25 s		0.044*
0.06 – 0.40 s		0.003*
0.10 – 0.16 s		1.000
0.10 – 0.25 s		0.257
0.10 – 0.40 s		0.025*
0.16 – 0.25 s		1.000
0.16 – 0.40 s		0.802
0.25 – 0.40 s		1.000

ANOVA, analysis of variance.
*statistically significant

different findings were related to PSP Digora Optime (Soredex, Tuusula, Finland).[21]

With solid-state digital imaging systems, the theoretic resolution limit is determined by the pixel size: the smaller the size of the pixel, the higher the maximally attainable resolution. However, in practice, actual detector resolution is lower than these theoretical limits for a variety of reasons. Resolution in PSP systems is influenced by thickness of the phosphor material, and the diameter of laser beam. Likewise, slow scan motion influences resolution by the increment of plate advancement. This increment may be adjusted to increase or reduce resolution in some systems.[14] In the present study, the scanning resolution was the tested factor with the most significant difference, where 20 lp/mm had whiter images than 25 and 40 lp/mm. In digital radiography, the SD of the pixel values is used in metrics to evaluate image noise, which can affect the diagnostic quality of image.[20–22] The low-contrast resolution is perhaps the most important quality parameter for intraoral radiographic imaging, at least for the detection of caries and periapical bone resorption.[22] The present study did not test the effects of modification of MGV and SD on image contrast and diagnostic quality of the image. However, Berkhout et al[17] demonstrated that even without loss of diagnostic quality, whiter images with higher noise can unfavorably influence practitioner's preference to use higher radiation doses.

The influence of spatial resolution *per se* on digital imaging diagnosis has been studied and is still a matter without consensus.[23,24] However, the reduced scanning time and less storage space may be a benefit to the dentist in daily work, and influence his/her choice.[23] Given our findings and the small differences in these functional characteristics between the resolutions 20 and 25 lp/mm, we suggest the use of 25 lp/mm in the VistaScan system, as a general recommendation for an improved image quality. It would be prudent to establish scanning resolution configuration protocols for specific diagnostic purpose, for every digital system. In addition, it should be taken into account that manufacturers of digital radiographic systems make adjustments and improvements over time, and this would require a constant update of acquisition protocols.

Till date, no previous study utilizing paperboard protector has been reported in literature. The VistaScan supplementary protector employed in our study is only available to plate size 4 and has been shown to increase the PSP resistance to compressive forces by more than four times. However, this device had the largest difference in MGV compared to the control group.

Conclusion

In conclusion, both developed PDs (0.3 and 0.7 mm) improved the PSP resistance to compressive forces and provided radioprotection to the patient, with low interference on the pixel gray values, regardless of exposure time. Nevertheless, the 0.7 mm PD was the only device capable of withstanding the simulated maximum bite force. The VistaScan system has a characteristic feature of elevating the gray values with an increase in exposure time, therefore, a resolution of 20 lp/mm showed whiter images than 25 and 40 lp/mm. In future, further studies are mandated to analyze patient comfort, professional usability, and subjective image quality before fully indicating the use of the newly developed PD.

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