Original Research
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Evaluation of the microstructure, chemical composition, and image quality of different PSP receptors

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Abstract: This study aimed to assess the microstructure, chemical composition, and image quality of different photostimulable phosphor plates (PSP). Four PSP systems, Express®, Digora®, VistaScan®, and Apixia,® were assessed. Five radiographs of a homogeneous acrylic phantom were obtained with the PSP of each system, to acquire a total of 20 images. The images were objectively evaluated for uniformity using mean grey and standard deviation (SD) of their grey values. PSP receptors were analyzed using scanning electron microscopy (SEM) to determine the thickness of the granule layer and the size of the granules. The chemical composition of the PSP receptors was analyzed using total reflection X-ray fluorescence (TXRF). VistaScan showed more uniform and higher density images than the other tested systems ($p < 0.05$), as well as the lowest SD of grey values ($p < 0.05$). Regarding the microstructure of the receptors, Digora and VistaScan had thicker granule layers than Express and Apixia, and VistaScan had smaller granules than Digora and Express ($p < 0.05$). Fourteen chemical elements were detected in the receptors, with barium being the element with the highest concentration in all PSP systems. The microstructure, chemical composition, and image quality varied among all four PSP receptors studied. VistaScan receptors showed the smallest variation in granule size, one of the thickest granule layers, and the most uniform and least noisy images.

Keywords: Radiography; Europium; Radiography, Dental, Digital.

Introduction

Photostimulable phosphor plates (PSP) are digital radiographic receptors coated with radiation-sensitive phosphors that store a latent image after exposure to X-rays. The PSP is then scanned using a high-speed laser, and the resulting light emitted by the stimulated phosphor is digitized and converted into a displayable image.[1] Historically, the first PSP was patented in 1975 (Eastman Kodak Co., Rochester, EUA), and the first PSP system was commercialized in 1981 by Fuji Photo Film (Tokyo, Japan).[2,3] However, PSP receptors were introduced in the dental field only in 1994 (Digora, Soredex Finndent, Orion Corporation Ltd, Helsinki, Finland),[4,5] emerging as an alternative to intraoral radiographic films[3] and solid-state detectors.[6] PSPs are similar in size and flexibility to conventional films, and demand lower radiation dose for image acquisition.[7-9] They are also better tolerated by patients than solid-state detectors because they are thinner and do not include a wire.[10]

The PSP receptors are malleable acrylic plates covered with crystals of phosphor.[11] Studies in the literature reported that these crystals of phosphor are responsible for storing the latent image because of the presence of an europium complex (EU^{3+}) or crystalline halide and europium-activated barium fluorohalide compounds ($BaFBr:Eu^{2+}$).[3,6,12] Phosphor crystals are host materials that usually contain traces of some activator material, which can be incorporated into the material matrix through temperature diffusion.[13] In the case of $BaFBr:Eu^{2+}$, the host material can be prepared by mixing barium fluoride (BaF2) and barium bromide (BaBr2), or BaF2 and ammonium bromide (NH4Br), using a manufactured phosphor-enriched base, which leads to improved image acquisition and scanning of PSP receptors.[13] Nevertheless, in the scanning process, the phosphor is optically stimulated[14] and the reduction in the interaction among the crystals of phosphor can affect the final image.[3,15]

To ensure adequate quality of the final radiographic image, the American Dental Association[16] published some recommendations for intraoral digital systems, such as periodic evaluations of the X-ray unit, imaging receptors, and devices in which the final image will be evaluated.[16] Previous studies evaluated the image quality from the perception of a particular group of observers concerning a specific diagnostic task.[11,17] However, some authors have performed quantitative analyses of image quality, evaluating the mean and standard deviation (SD) of grey values of the pixels in the image.[3,17-19] According to White & Pharoah, 2015[20], the image quality of radiographic films is associated with the exposure time for image acquisition, composition of the emulsion in the film, and the format and distribution of the silver halide grains. However, to our knowledge, no study has evaluated the composition of PSP receptors, the distribution and format of their granules, or their objective image quality considering these characteristics to date.

Thus, the present study aimed to assess the microstructure, chemical composition, and objective image quality of different PSP systems.

Methodology

In the present study, two unused receptors from four different PSP systems, totaling eight receptors, were employed. The tested systems were Express® (Instrumentarium Imaging, Tuusula, Finland), Digora® (Soredex, Tuusula, Finland), VistaScan® (Durr Dental, Bietigheim, Bissingen), and Apixia® (Digital Imaging, Industry, Jericho, USA). Three different evaluations were performed: one on the images acquired with the PSP receptors (objective evaluation of image quality) and two on the PSP receptors (microstructural and chemical composition analyses).

Objective evaluation of image quality

Image acquisition

Radiographs of a homogeneous acrylic phantom (3 cm height × 4 cm width × 2 cm thickness) were obtained with a PSP receptor of each system and scanned with the respective dedicated software, following the same methodology employed in a previous study.[21] Five radiographs were obtained with a PSP of each system, totaling 20 images. All images were acquired using an X GE 1000® (General Electric Co., Milwaukee, USA) unit set at 70 kVp, 10 mA, and 0.10 s exposure time. An acrylic holder with a fixed locator bead was used to help position the image receptor and phantom and to reproduce the parallelism technique (focus-receptor distance of 40 cm, vertical angulation of 0°, and horizontal angulation of 90°). Each PSP receptor was processed using a dedicated scanner and the automatic exposure settings were disabled.

Image evaluation

All images were exported in tagged image file format (TIFF) (without compression), in 8-bits, and assessed using ImageJ software (National Institutes of Health, Bethesda, USA). The images were evaluated for uniformity and mean and SD of the grey values. To standardize the position of the regions of interest (ROI) to be evaluated, the macro function of the software was used. Uniformity was calculated as the average of the SD values of five different ROIs to analyze the entire image. One ROI (4 × 4 mm) was established at the center of the image, and four other ROIs (4 × 4 mm each) were symmetrically distributed in the upper and lower corners of the image. In a second moment, a square ROI covering 16% of the total image was placed at its central region to determine the mean of the grey values (image density) and the SD (image noise) restricted to this area (Figure 1).[21] A dentomaxillofacial radiologist experienced in the use of the software performed all analyses in a silent and dimmed-light room. Fifteen days after the analyses, the images were re-evaluated to verify intra-examiner agreement.

Microstructure analysis

The characteristics and sizes of the granules that were present in each PSP receptor were evaluated using a scanning electron microscope (SEM) (JEOL-JSM 5600LV, Tokyo, Japan). Each receptor was gold-sputter-coated and subjected to an electric current of 15 kV to evaluate the granule layer characteristics (active area) and size of the granules in each PSP. Figure 2 shows the thickness of the granule layer in each PSP, and Figure 3 shows the surface of the granule layer at 3000x magnification and a resolution of 5 μm.

Using a precision measuring tool, the thickness of the granule layer (Figure 2) and size of the granules (Figure 3) were measured for each of the eight PSP receptors. To measure the thickness of the granule layer, a parallel line was drawn in the upper border of the layer, and mean values of 10 measurements perpendicular to this reference line were recorded. To measure the size of the granules, three random areas were selected on the surface of the receptor, and the mean values of the measurements along the long axis of the granules (Figure 3) were recorded. All analyses were performed by the same dentomaxillofacial radiologist using ImageJ software.

Component analysis

Two PSP receptors were prepared separately for each digital system. The granule layer was scraped off, separated from the acrylic plate, and submitted to an acid digestion process using a conventional aqua regia solution (7.5 mL 1:1 v/v HNO_3 65% PA and 2.5 mL HCL). The solution was heated in a microwave (Milestone Ethos Easy) at 1800 W for 20 min until it reached 180 °C. The temperature was maintained for 20 min. Thereafter, the samples were cooled to room temperature (25 °C), and the volumes were made up to 25 mL with deionized water.[22]

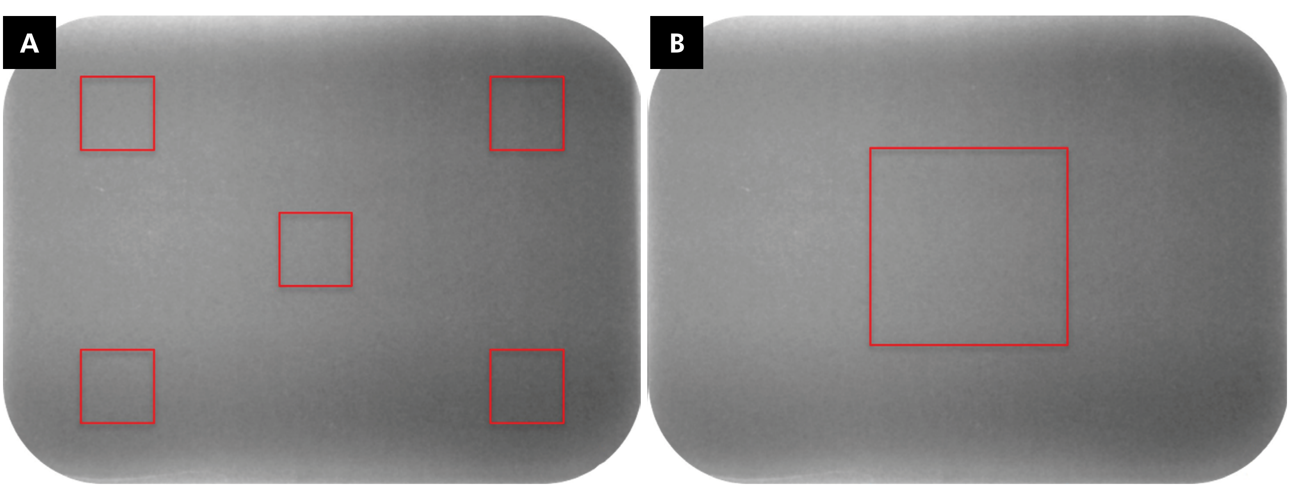

Figure 1. Objective analysis of image quality. Regions of interest (ROIs) are represented by red squares. 1A – Analysis of image uniformity: mean and standard deviation (SD) of grey values of the five ROIs. 1B – Central ROI to analyze the mean and SD of grey values.

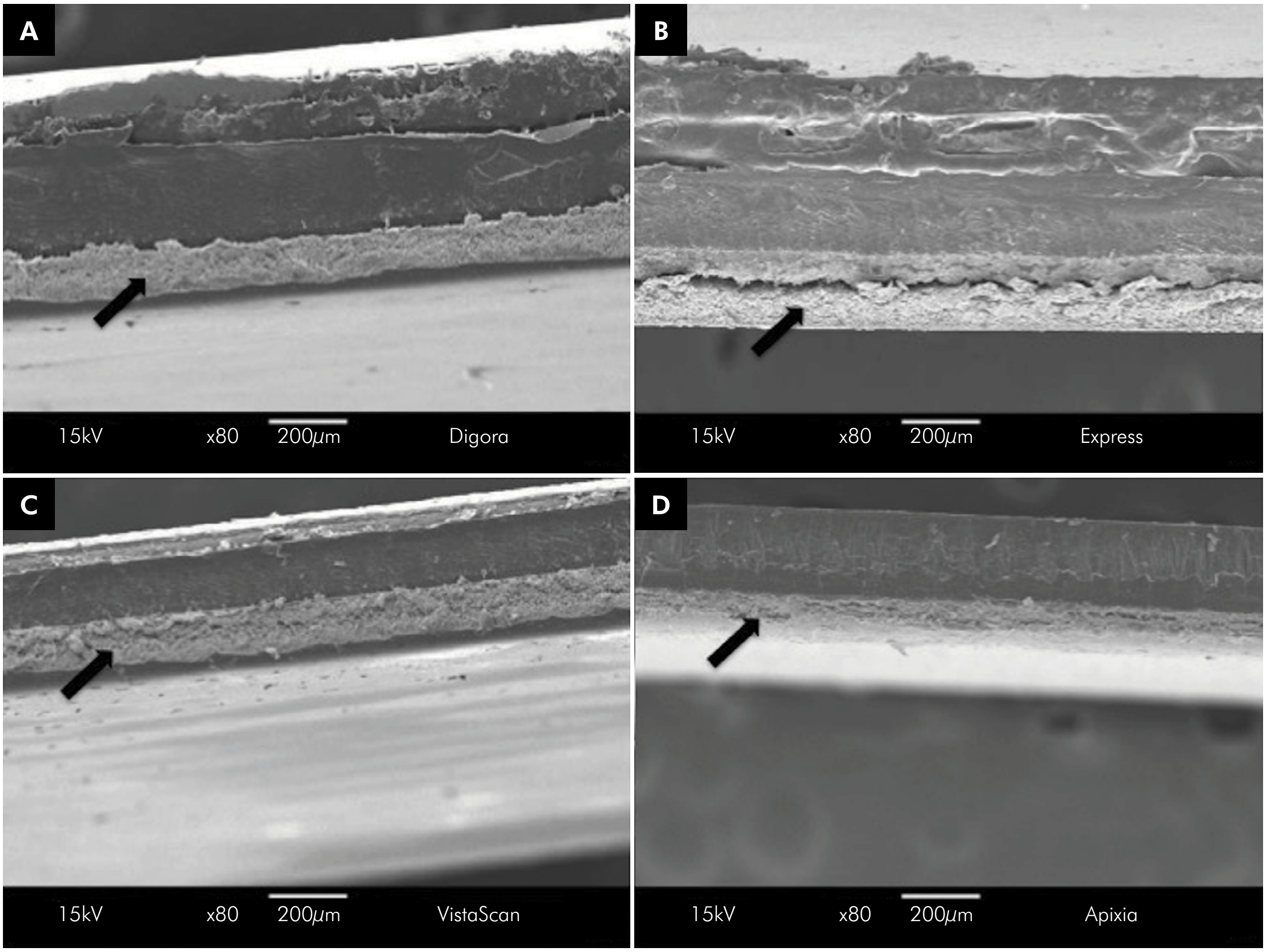

Figure 2. Scanning electron microscopy images, in a transversal view, of the PSP receptors, showing the granules' layer (black arrow). 2A. Digora, 2B. Express, 2C. VistaScan, and 2D. Apixia. 80x magnification, 15 kV and 200-µm proportion.

After acid digestion, 1 mL of the prepared sample was transferred to an Eppendorf tube, and 100 µL gallium solution (100 mg L-1) was added as an internal standard. Once the concentration of gallium was known, it was possible to calculate the concentration of the other elements through their relative intensities, eliminating any possible matrix effects. The internal standard was also important to compensate for any heterogeneity in the samples during the analyses. The samples were prepared in triplicate to minimize contamination errors.[22]

After this procedure, the final solution was stirred for homogenization, and 10 µL solution was pipetted into ultrapure quartz supports and dried using an infrared lamp under a laminar flow fume hood. After drying, the samples were stored in petri dishes to avoid contact with the external environment and possible contamination.

The samples were analyzed using a portable total reflection X-ray fluorescence (TXRF) system with a Si-PIN XR-100CR detector (Amptek) (multichannel analyzer MCA 8000) and an X-ray tube operating at 40 kV and 500 µA, with aluminum and copper filters. The acquisition time for each sample was 600 s. The spectra were subsequently analyzed using PyMCA software developed and distributed free of charge by the European Synchrotron Radiation Facility (ESFR) Software Group. The system was calibrated using multi-element solutions with known concentrations. All samples were measured in triplicates. After spectrum analysis, the X-ray fluorescence intensity was obtained to calculate

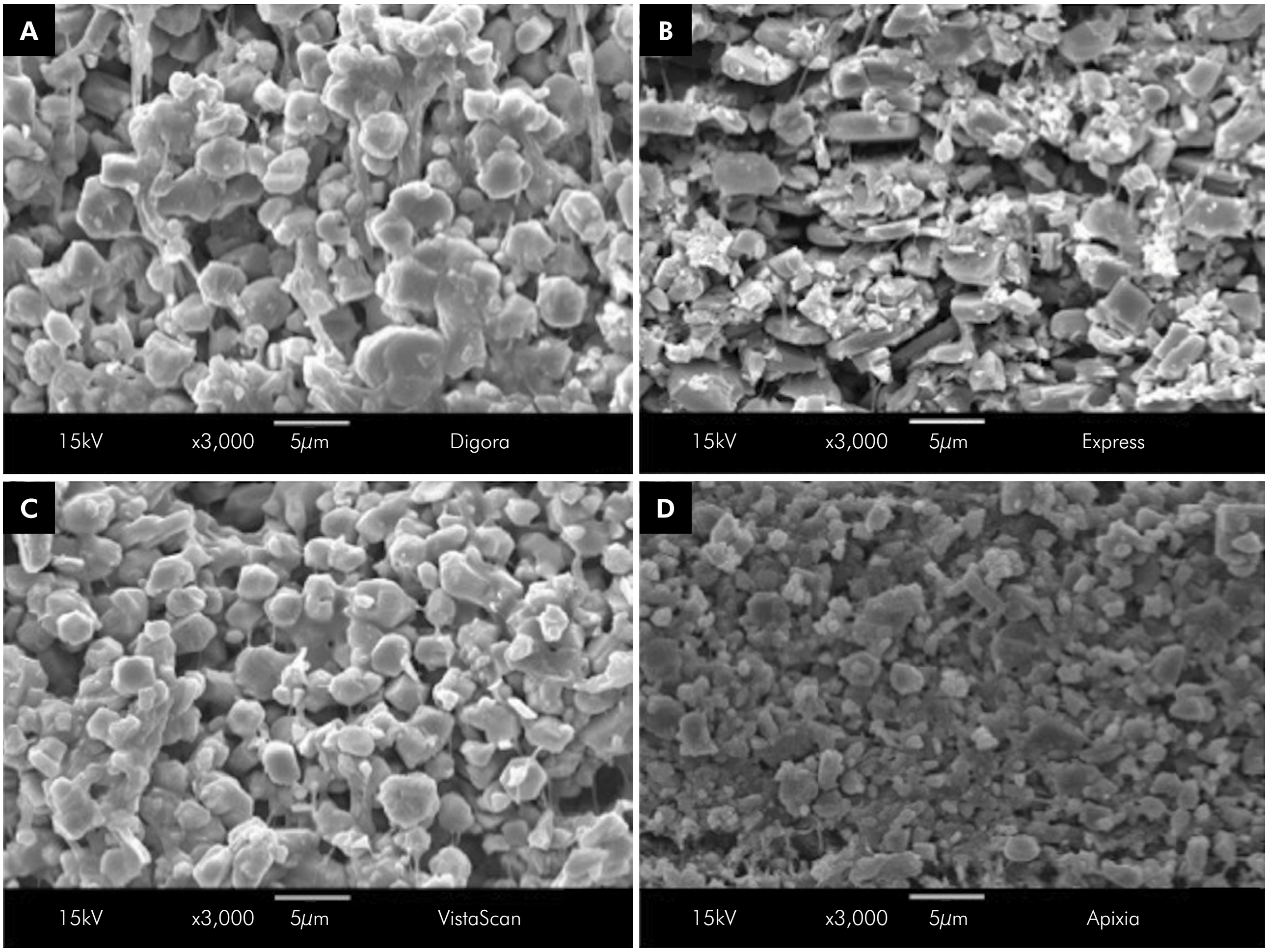

Figure 3. Scanning electron microscopy images obtained to assess the size of the granules of the photostimulable phosphor plate (PSP) receptors. 3A. Digora, 3B. Express, 3C. VistaScan, and 3D. Apixia. 3000x magnification, 15 kV and 5-µm proportion.

the concentration of each element present in the sample.

Statistical analysis

The results for the objective evaluation of image quality (image uniformity, mean and SD of greys values) and granule size were compared among the PSP systems using one-way analysis of variance (ANOVA) and post-hoc Tukey's test. The intraclass correlation coefficient was used to evaluate the intra-examiner agreement for the objective analysis. Statistical analysis was performed using the SPSS software (version 24.0; IBM Corp., Armonk, USA), with the significance level set at 5%. Additionally, a descriptive analysis (mean, SD, and median values) was performed for the microstructural evaluation of the receptors.

Results

Objective analysis of the image

The results of the objective analysis of the four PSP systems are listed in Table 1. Intra-examiner agreement for the objective analysis was excellent (0.99).[23] The VistaScan system showed the lowest mean and SD of the five ROIs ($p < 0.05$), which indicates a more uniform image; conversely, of the five ROIs, Digora Optime and Express had the highest mean and SD values ($p < 0.05$), indicating less uniform images when compared with the other evaluated systems. Regarding the mean grey values (central ROI), each system differed significantly from each other, and the VistaScan system showed significantly lower values, which implies higher

Table 1. Mean and SD for the uniformity of grey values, mean of grey values, and SD of the central region of interest.

Radiographic system	Uniformity	Mean of grey values	SD
	(mean [SD] of the five ROIs)	(Central ROI)	(Central ROI)
Apixia	7.28 (0.19) B	45.34 (6.40) C	11.37 (0.44) C
Digora optime	8.84 (0.05) A	142.98 (0.34) A	22.72 (0.64) A
Express	8.86 (0.04) A	131.26 (0.18) B	12.68 (0.12) B
VistaScan	1.85 (0.06) C	4.67 (0.24) D	2.36 (0.07) D
p-value	< 0.0001	< 0.0001	< 0.0001

Different capital letters indicate significant differences ($p < 0.05$) between the radiographic systems within each analysis. SD: standard deviation.

Table 2. Mean, SD, minimum, and maximum of the granule size from three randomized areas of the PSP (in µm).

Variable	Apixia	Digora	Express	VistaScan
Mean	1.61 AB	1.93 A	1.98 A	1.38 B
SD	1.42	1.85	1.73	1.08
Minimum	0.52	0.79	0.53	0.35
Maximum	3.37	3.97	4.75	3.05

Different capital letters indicate significant difference ($p<0.05$) among the radiographic systems. $p = 0.0114$. SD: standard deviation.

density images when compared with the other systems, while Digora Optime had significantly higher values ($p < 0.05$). Likewise, VistaScan showed the lowest SD values for the central ROI, whereas Digora Optime had the highest values for this quantity ($p < 0.05$).

Microstructural analysis

The Digora system presented the greatest thickness of the granule layer, with a mean of 112 µm, followed by the VistaScan (109 µm), Express (83 µm), and Apixia (56 µm) systems. The mean, SD, minimum, and maximum sizes of the granules are shown in Table 2. VistaScan showed statistically lower mean and SD and lower minimum and maximum values of the granule size when compared with those of Express and Digora ($p < 0.05$).

Chemical Composition

The chemical composition and concentration of the components of PSP receptors are shown in Table 3. None of the receptors showed significant concentrations of europium and fluorine. Barium was the most prevalent component in all PSP systems: VistaScan (219.79 mg/g), Express (215.80 mg/g), Apixia (146.53 mg/g), and Digora (56.01 mg/g). Tin was the least prevalent component in the receptors: Express (0.55 mg/g), VistaScan (0.48 mg/g), and Digora (0.12 mg/g). Tin was not detected in the Apixia system.

Discussion

To our knowledge, there are no studies in the literature that have evaluated the microstructure and chemical composition of PSP receptors, unlike conventional films, which have been broadly studied. Therefore, considering that this information would be relevant for a better understanding of this type of receptor and technology, the present study assessed the microstructure, chemical composition, and objective image quality of four PSP systems.

For the objective analysis of image quality, an acrylic block was used because theoretically, it has a homogeneous interaction with the X-rays, resulting in a homogeneous image.[21] Although the heel effect cannot be avoided in this type of experimental design, to prevent possible negative interference or bias in the evaluations, the acquisition of the images was standardized by adopting the same geometric

Table 3. Analysis of the concentration (mg/g) of chemical elements in each PSP system.

Chemical element	Apixia	Digora	Express	VistaScan
Europium (Eu)	-	-	-	-
Fluorine (F)	-	-	-	-
Sulfur (S)	-	1.18	1.93	0.67
Potassium (K)	0.37	6.42	6.50	4.33
Calcium (Ca)	0.93	10.52	43.77	15.93
Titanium (Ti)	0.69	2.44	9.30	9.97
Vanadium (V)	5.81	1.59	7.16	7.31
Manganese (Mn)	0.46	0.24	1.22	1.01
Iron (Fe)	-	1.94	2.10	3.64
Zinc (Zn)	-	-	27.49	30.31
Bromine (Br)	1.08	0.62	2.11	2.12
Strontium (Sr)	14.31	9.78	-	-
Silver (Ag)	17.51	-	16.91	-
Tin (Sn)	-	0.12	0.55	0.48
Antimony (Sb)	-	0.61	1.24	1.55
Barium (Ba)	164.53	56.01	215.80	219.79

parameters for all of them. Therefore, the images of all systems were evaluated under the same conditions, which allowed us to compare them. By measuring the SD of different areas in the image (SD of five ROIs), we aimed to evaluate the uniformity of the PSP receptors, as it is expected that uniform plates will have low SD values throughout the whole image (low variation in grey values). Additionally, to verify whether the systems were compared under the same conditions, we analyzed the background pixel values of the receptors. To achieve this, the receptors were scanned without prior X-ray exposure. On scanning not exposed receptors, homogeneously bright were obtained with the same pixel value (255) for all pixels. Therefore, it was ascertained that the receptors with the same background pixel values were compared. After exposure to X-rays, the VistaScan system showed images with significantly greater uniformity (i.e., more uniform pixel values) than the other PSP systems tested. VistaScan also showed less noisy images, which was reflected by a significantly lower mean and SD of the central ROI, and "darker," *i.e.*, higher density images, than the other systems. These results are in agreement with those of a previous study.[21]

In the present study, the mean size of the granules in the PSP receptors ranged from 1.38 μm to 1.98 μm. The mean and SD of the granule size of VistaScan were the smallest, demonstrating smaller and more standardized granules compared with the other systems. In addition, the VistaScan system showed one of the thickest granule layers. Therefore, we believe that the VistaScan receptors may have a greater number of granules than the receptors of the other systems evaluated. Based on this information and the better image quality demonstrated by VistaScan, we believe that there may be a relationship between the granule size and thickness of the granule layer and the image quality.

According to the manufacturers of the INSIGHT and Ultra-Speed intraoral films (Carestream Dental, Division of Carestream Health, Inc., Rochester, USA), their emulsion layers have flat, tubular, and distantly arranged halogenated silver crystals, with an area of 1.8 μm. Thus, compared to the granules in these films, the digital systems analyzed in the present study showed larger and more closely arranged granules. According to White & Pharoah, 2015[20], the more juxtaposed and the larger the area of contact between the granules and X-rays, the shorter the exposure time needed for image acquisition and, therefore, the lower the radiation dose exposed to the patient. Therefore, the larger size and closer distribution of the granules in PSP may be related to the lower radiation exposure needed for image acquisition by these digital receptors when compared with conventional films.[24,25]

Several authors[3,6,14,20] have suggested that europium is part of the storage process of the latent image and is an active participant in PSP scanning. According to Shalaev and Radzhabov, 2005,[14] europium actively participates in PSP receptor scanning, in which the phosphor is optically stimulated with a 633-nm wavelength laser, causing the activated Eu^{2+} to emit waves at 390 nm. Previous studies have suggested that PSP receptors include europium and fluorine in their composition.[6,13,14] However, there are no studies in the literature reporting the concentration of the chemical components of PSP receptors. In the present study, europium and fluoride were not detected in the PSP receptors evaluated. We do not rule out the presence of europium in PSP receptors, but we believe that if it is present, it is present in very low concentrations.

TXRF analysis showed the presence of 14 components, including barium, bromine, sulphur, potassium, calcium, titanium, vanadium, manganese, iron, zinc, strontium, silver, tin, and antimony in the PSP receptors evaluated in this study. Previous studies reported the presence of barium and bromine only.[3,6,12] The higher number of elements found in our study may be related to the evaluation techniques employed. The use of TXRF to detect chemical elements was previously reported by other authors.[26-29] Because of its capacity to detect chemical elements, this technique was chosen over energy dispersive spectroscopy (EDS); however, TXRF detection technique depends on the atomic number and concentration of the elements. Europium has an atomic number of 63 and according to the manufacturer of the TXFR equipment[30], its presence can be detected through such technology; however, its concentration is essential for this detection. Thus, it is possible that the PSP receptors evaluated in this study had chemical components other than those detected, but not in sufficient concentrations to be detected by this method. Although the authors believe that there may be an influence of the type and concentration of the chemical elements present in the PSP receptors on the final image, we did not aim to establish such a correlation, but to assess the chemical composition of these receptors, since this information was not disclosed by the manufacturers and was not evaluated in the previous studies. Further research is recommended on this possible correlation evaluating which of these elements are involved in the sensitization of the receptors by X-rays.

According to previous studies, the composition of the emulsion and the format and distribution of the silver halide grains in conventional films are associated with image quality[20]. Although some hypotheses correlating the findings regarding the microstructure of PSP receptors and objective image quality were raised in the present study, we did not aim to directly correlate the composition, microstructure, and image quality of PSP receptors. As little information about the characteristics of PSP receptors is available, this preliminary study aimed to disclose such characteristics. However, future studies correlating the composition and microstructure of PSP receptors with their possible influence on diagnostic tasks are recommended.

Conclusion

The microstructure, chemical composition, and image quality vary among the four PSP receptors evaluated in this study. The VistaScan system presented the smallest granules and variation in granule size. VistaScan also demonstrated better image quality, objectively reflected by greater image uniformity and lower SD of grey values, when compared with those of the other tested systems. For all PSP systems tested, Barium was the chemical element found in greater quantities.

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References

1. Nascimento HA, Visconti MA, Ferreira LM, Suarez MA, Haiter Neto F, Freitas DQ. Effect of delayed scanning on imaging and on the diagnostic accuracy of vertical root fractures in two photostimulable phosphor plates digital systems. Int Endod J. 2016 Oct;49(10):973-9. https://doi.org/10.1111/iej.12547
2. Schaetzing R, Whiting BR, Lubinsky AR, Owen JF. Digital radiography using storage phosphor. In: Newell JD Jr, Kelsey CA, editors. Digital imaging in diagnostic radiology. New York: Churchill Livingstone; 1990. pp. 107-38.
3. Ang DB, Angelopoulos C, Katz JO. How does signal fade on photo-stimulable storage phosphor imaging plates when scanned with a delay and what is the effect on image quality? Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2006 Nov;102(5):673-9. https://doi.org/10.1016/j.tripleo.2005.11.002
4. Sanderink GC, Stelt PF, Velders XL. Image quality of a new indirect digital intraoral x-ray sensor system: the Digora system compared to direct digital systems and film in assessing root canal length. In: 10th Congress of the International Association of Dento-Maxillo-Facial Radiology; June 1994; Seoul, Korea. p. 117.
5. Velders XL, Sanderink GC, Stelt PF. The effect of different exposure times on the detectability of endodontic files in the new Digora indirect digital oral X-ray system. In: 10th Congress of the International Association of Dento-Maxillo- Facial Radiology; June 1994; Seoul, Korea. p. 73
6. Borg E, Attaelmanan A, Gröndahl HG. Image plate systems differ in physical performance. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2000 Jan;89(1):118-24. https://doi.org/10.1016/S1079-2104(00)80026-8
7. Udupa H, Mah P, Dove SB, McDavid WD. Evaluation of image quality parameters of representative intraoral digital radiographic systems. Oral Surg Oral Med Oral Pathol Oral Radiol. 2013 Dec;116(6):774-83. https://doi.org/10.1016/j.oooo.2013.08.019
8. Ludlow JB, Mol A. Digital imaging. In: White SC, Pharoah MJ, editors. Oral radiology: principles and interpretation. St. Louis; Mosby, Elsevier; 2014. p. 41-62.
9. Gulsahi A, Secgin CK. Assessment of intraoral image artifacts related to photostimulable phosphor plates in a dentomaxillofacial radiology department. Niger J Clin Pract. 2016 Mar-Apr;19(2):248-53. https://doi.org/10.4103/1119-3077.164338
10. Vandenberghe B, Bud M, Sutanto A, Jacobs R. The use of high-resolution digital imaging technology for small diameter K-file length determination in endodontics. Clin Oral Investig. 2010 Apr;14(2):223-31. https://doi.org/10.1007/s00784-009-0285-1
11. van der Stelt PF. Filmless imaging: the uses of digital radiography in dental practice. J Am Dent Assoc. 2005 Oct;136(10):1379-87. https://doi.org/10.14219/jada.archive.2005.0051
12. Lakshmanan P. Radiation induced defects and photostimulated luminescence process in BaFBr: Eu2+. Phys Status Solidi, A Appl Res. 1996;153(1):3-27. https://doi.org/10.1002/pssa.2211530102
13. Leblans P, Vandenbroucke D, Willems P. Storage Phosphors for medical imaging. Materials (Basel). 2011 Jun;4(6):1034-86. https://doi.org/10.3390/ma4061034
14. Shalaev AA, Radzhabov EA. Single crystal growth of BaFBr:Eu storage phosphor with alkali impurities. J Cryst Growth. 2005;275(1-2):e775. https://doi.org/10.1016/j.jcrysgro.2004.11.092
15. Souza-Pinto GN, Santaella GM, Coli AA, Oenning AC, Haiter-Neto F. Analysis of the deterioration of photostimulable phosphor plates. Dentomaxillofac Radiol. 2020 Sep;49(6):20190500. https://doi.org/10.1259/dmfr.20190500
16. American Dental Association. Quality assurance for digital intra-oral radiographic systems. Chicago: ADA; 2017. (Technical Report, v. 1094).
17. Ergün S, Güneri P, Ilgüy D, Ilgüy M, Boyacioglu H. How many times can we use a phosphor plate? A preliminary study. Dentomaxillofac Radiol. 2009 Jan;38(1):42-7. https://doi.org/10.1259/dmfr/61622880
18. Akdeniz BG, Gröndahl HG, Kose T. Effect of delayed scanning of storage phosphor plates. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2005 May;99(5):603-7. https://doi.org/10.1016/j.tripleo.2004.10.021
19. Martins MG, Haiter Neto F, Whaites EJ. Analysis of digital images acquired using different phosphor storage plates (PSPs) subjected to varying reading times and storage conditions. Dentomaxillofac Radiol. 2003 May;32(3):186-90. https://doi.org/10.1259/dmfr/24355220
20. White SC, Pharoah MJ. Oral radiology: principles and interpretation. St. Louis: Mosby/Elsevier; 2015.
21. Farias Gomes AF, Nejaim Y, Fontenele RC, Haiter-Neto F, Freitas DQ. Influence of the incorporation of a lead foil to intraoral digital receptors on the image quality and root fracture diagnosis. Dentomaxillofac Radiol. 2019 Sep;48(6):20180369. https://doi.org/10.1259/dmfr.20180369
22. Canteras FB, Oliveira BF, Moreira S. Topsoil pollution in highway medians in the State of São Paulo (Brazil): determination of potentially toxic elements using synchrotron radiation total reflection X-ray fluorescence. Environ Sci Pollut Res Int. 2019 Jul;26(20):20839-52. https://doi.org/10.1007/s11356-019-05425-2

23. Cicchetti DV. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. Psychol Assess. 1994;6(4):284-90. https://doi.org/10.1037/1040-3590.6.4.284
24. Wenzel A, Møystad A. Experience of Norwegian general dental practitioners with solid state and storage phosphor detectors. Dentomaxillofac Radiol. 2001 Jul;30(4):203-8. https://doi.org/10.1038/sj.dmfr.4600613
25. Berkhout WE, Beuger DA, Sanderink GC, Stelt PF. The dynamic range of digital radiographic systems: dose reduction or risk of overexposure? Dentomaxillofac Radiol. 2004 Jan;33(1):1-5. https://doi.org/10.1259/dmfr/40677472
26. Chimidza S, Viksna A, Lindgren ES. EDXRF and TXRF analysis of aerosol particles and the mobile fraction of soil in Botswana. XRay Spectrom. 2001;30(5):301-7. https://doi.org/10.1002/xrs.502
27. Towett EK, Shepherd KD, Cadisch G. Quantification of total element concentrations in soils using total X-ray fluorescence spectroscopy (TXRF). Sci Total Environ. 2013 Oct;463-464:374-88. https://doi.org/10.1016/j.scitotenv.2013.05.068
28. Santos FR, Almeida E, Kemerich PDC, Melquiades FL. Evaluation of metal release from battery and electronic components in soil using SR-TXRF and EDXRF. XRay Spectrom. 2017;46(6):512-21. https://doi.org/10.1002/xrs.2784
29. Marguí E, Hidalgo M, Migliori A, Leani JJ, Queralt I, Kallithrakas-Kontos N, et al. A first evaluation of the analytical capabilities of the new X-ray fluorescence facility at International Atomic Energy Agency-Elettra Sincrotrone Trieste for multipurpose total reflection X-ray fluorescence analysis. Spectrochim Acta B At Spectrosc. 2018;145:8-19. https://doi.org/10.1016/j.sab.2018.03.016
30. S2 PICOFOX total reflection X-ray fluorescence spectroscopy: working principles Berlin: Bruker Nano GmH; 2007. (Report nº XRF 426).