RESEARCH ARTICLE

Image Quality Assessment of Digital Radiographs obtained with Photostimulable Phosphor Plate Systems

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ABSTRACT

Evaluation of image quality stands as a pivotal approach to understand specific characteristics of digital radiographic systems. Considering the lack of information regarding the image quality of photostimulable phosphor plate systems (PSP) systems, this study objectively evaluated the image quality of PSP systems at different spatial resolution modes and exposure times. Size-2 PSP of three digital systems had the sensitive surface covered with a 30 mm-thick polymethyl methacrylate block and radiographic acquisitions were performed with the Focus X-ray Intraoral unit adjusted at 70 kVp, 7 mA, and exposure times of 0.32; 0.63; 0.80 s. All PSP were read out using their corresponding scanners at two spatial resolution modes: low and high. The image quality of the images was objectively evaluated using ImageJ software for measurements of image noise, uniformity, and signal-to-noise ratio (SNR). The data were statistically compared by means of analysis of variance and Turkey post hoc test with a significance level of 5%.In general, noise, uniformity, and SNR values were not significantly different ($p>0.05$) between the resolution mode; uniformity values were significantly lower ($p\leq0.05$) for the lowest exposure time and SNR values were not significantly different ($p>0.05$) between the exposure time, in most of the conditions. In conclusion, the spatial resolution, exposure time, and PSP system have an irregular impact on the evaluated image quality, encompassing aspects such asnoise, uniformity, and SNR.

Key words: Radiography, Dental, Digital; Radiographic Image Enhancement; Radiography, Dental; Technology, Radiologic.

INTRODUCTION

Along the past years, film-based radiography has been replaced with digital radiography systems worldwide. Digital intra-oral receptors are currently divided into two types: photo stimulable phosphor (PSP) plates and solid-state sensors.[1,2]Among the advantages of PSP-based digital systems, the image receptors are relatively thin and reasonably flexible. Also, when compared to conventional film, PSP receptors are more sensitive to X-rays due to the increased exposure latitude,[3]which allows for the reduction of patient exposure while maintaining the diagnostic quality.

To produce a radiographic image using a PSP system, the image receptor is exposed to X-rays and, then, the absorbed energy is stored as a latent image. Finally, to visualize the image, the image receptor has to be scanned with a manufacturer-specific device following the photo stimulated luminescence principle.[4,5].

The final image quality of a given digital radiographic system is multifactorial and directly depends on inherent properties

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of the detector. Because manufactures may not disclose some basic information of their products, precise clinical application of exposure control aiming at dose optimization is a challenge. According to the American Association of Physicists in Medicine, among several checkpoints, image quality control should fundamentally consider the presence of artefacts, image uniformity and spatial resolution.[6]Image noise is a prominent artefact that can be quantified by the gray value standard deviation of a homogeneous object, image uniformity reveals the variability of gray values from different zones of the image, and signal-to-noise ratio (SNR),[7,8] which refers to the proportion between the signal intensity and the image noise.[9,10]

Exposure time and scanner resolution settings are acquisition parameters that may influence the final X-ray image; however, considering radiation protection principles, the selection of the exposure time should be made cautiously, as it directly affects the radiation delivered to the patient. Depending on the exposure latitude of the digital system, a lack of user information could result in unnecessary over exposure, which may occur in the search for improved image quality with reduced noise.[11,12]

Although the scientific literature reports numerous studies evaluating image quality of intraoral digital radiographic systems, little information is found regarding the effect of spatial resolution, exposure time and PSP system on the image quality. Therefore, the aim of this in-vitro study was to objectively evaluate the image quality of three PSP systems at two spatial resolution modes and three exposure times.

MATERIAL AND METHODS

PSP digital systems

Brand new size-2 PSP plates of three different digital systems were used in this study:Digora Optime (Soredex, Orion Corporation, Finland), Express (Dental Instrumentarium, PaloDEx Group Oy, Finland), and VistaScanPerioPlus (Durr Dental AG, Germany).

Image acquisition

A 30-mm-thick polymethyl methacrylate block was placed between the PSP plates and the X-ray source to induce slight X-ray attenuation and scattering[12,13]and ten repeated radiographic acquisitions were individually performed using the Focus Intraoralunit (Instrumentarium Dental, PaloDEx Group Oy, Finland)adjusted to 70kV, 7mA, and a focus-to-object distance of 40 cm. The exposure geometry followed the paralleling technique and the exposure times were 0.32, 0.63, and 0.80 s.

All PSP plates were read out using their corresponding scanners at two spatial resolution modes: low resolution (LR) and high resolution (HR). The LR mode produces images with a pixel size of 60 µm and 8-bit depth in the Digora Optime, 64 µm and 8-bit depth in the Express, and 50 µm and 8-bit depth in the VistaScan. The HR mode produces images with a pixel size of 30 µm and 8-bit depth in the Digora Optime, 35 µm and 8-bit depth in the Express, and 12.5 µm and 8-bit depth in the VistaScan. This resulted in a total of 180 radiographic images (10 repetitions × 3 digital radiographic systems × 3 exposure times × 2 spatial resolution modes) (Fig.1).

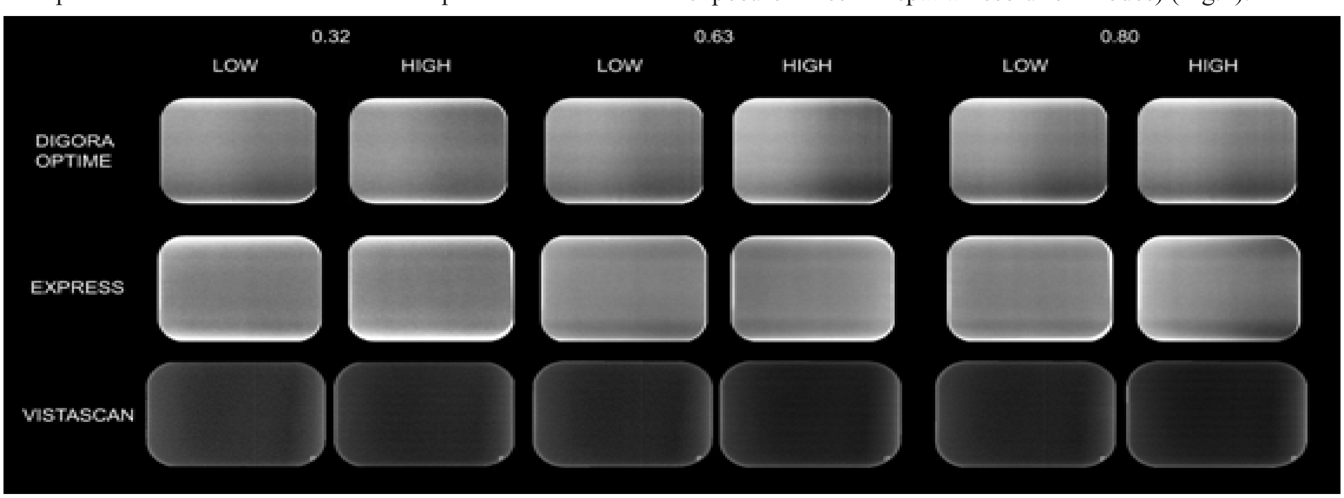

Figure 1. Radiographic images of the PSP digital systems Digora Optime, Express, and VistaScan at three exposure times (0.32, 0.63, and 0.80 s) and two spatial resolution modes (low and high).

The scanning of the PSP plates was performed in a room with subdued light to prevent the image from possible undesired degradation and the images were exported in RAW format to avoid the action of pre-processing filters automatically defined by the manufacturer.[12]

Image evaluation

Image noise, uniformity, and SNR were assessed in all images using the ImageJ software, version 32 (National Institutes of Health, Bethesda, MD, USA). First, as shown in Fig. 2, a rectangular region of interest (ROI) corresponding to 7.5% of the entire image was selected in four locations of the image to cover a broad area of the plate: top, bottom, right, and left. Then, mean values and standard deviation of gray values were collected. To assess image noise, the standard deviation values from the four ROIs were averaged. After, to assess image uniformity, the standard deviation of the mean gray values from the four ROIs was calculated.[13]Lastly, SNR was calculated by dividing the mean gray values from the four ROIs by image noise.[7]

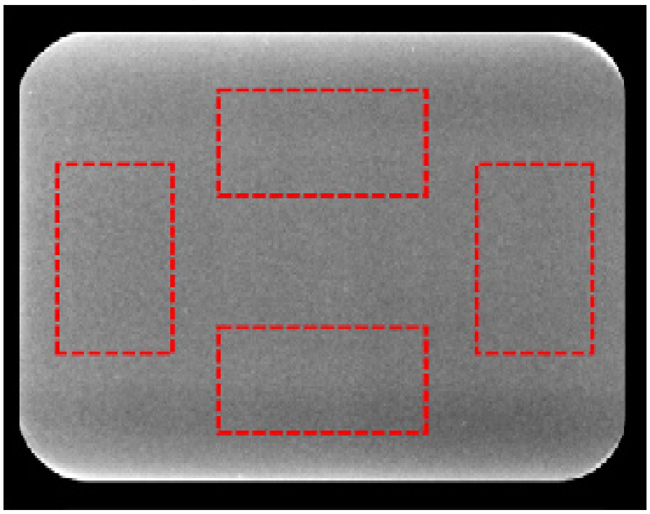

Figure 2. Illustration of the location of the regions of interest in the PSP-based radiographic image.

Statistical analysis

The data were statistically analyzed with analysis of variance (two-way ANOVA) in a factorial scheme 3 × 3 × 2 (digital radiographic system × exposure time × spatial resolution). Furthermore, multiple comparisons were performed with Tukeypost hoc test. All statistical analyses were conducted using the SPSS software, version 25 (SPSS, Chicago, IL, USA) witha significance level of 5% ($\alpha = 0.05$).

RESULTS

Noise

Noise values were significantly higher ($p \leq 0.05$) in HR mode than in LR mode only at 0.8 s for Express. Regarding the exposure time, noise values were significantly higher ($p \leq 0.05$) at 0.63 s and 0.8 s in HR mode for Digora Optime and at 0.32 and 0.8 s in LR and HR modes for Express. VistaScan did not present significant differences of noise values between spatial resolution modes and exposure times ($p > 0.05$) (Fig.3).

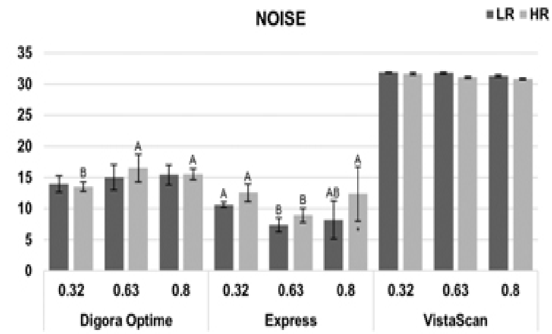

Figure 3. Noise mean values as a function of the PSP system, exposure time (in seconds), and spatial resolution modes (LR, low-resolution; HR, high-resolution). *Significantly greater than LR for the same PSP system and exposure time. Distinct letters on the bars differ significantly from each other ($p \leq 0.05$) for the same exposure time and resolution mode. Error bars represent the standard deviation.

Uniformity

Uniformity values were not significantly different between HR and LR modes for Digora Optime and Express ($p > 0.05$), but, for VistaScan, LR mode was significantly higher at 0.32 and 0.8 s and lower at 0.63 s ($p \leq 0.05$). When comparing the exposure times, DigoraOptime presented significantly higher ($p \leq 0.05$) values at 0.63 and 0.8 s in LR mode and, for VistaScan and DigoraOptime, the values were significantly higher ($p \leq 0.05$) at 0.63 s in HR mode. Express did not present significant differences of uniformity values between the exposure times ($p > 0.05$) (Fig.4).

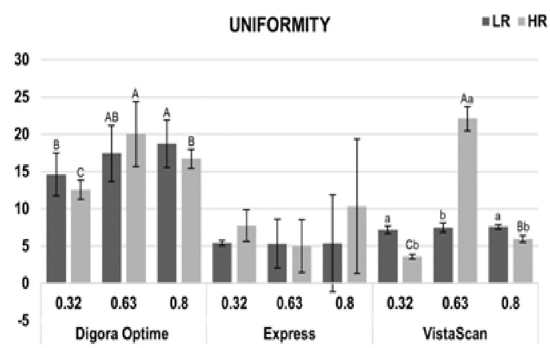

Figure 4.Uniformity mean values as a function of the PSP system, exposure time (in seconds), and resolution mode (LR, low-resolution; HR, high-resolution). Distinct letters on the bars (upper case for the same exposure time and lower case for the same resolution mode) differ significantly from each other ($p \leq 0.05$). Error bars represent the standard deviation.

SNR

SNR values were significantly higher ($p \leq 0.05$) in LRmode than in HR mode for Express. Regarding the exposure time, the values were significantly higher ($p \leq 0.05$) at 0.63 and 0.8 s. in LRmode and at 0.63 s in HRmode for Express. Digora Optime and VistaScan did not present significant differences of SNR values between spatial resolution modes and exposure times ($p > 0.05$) (Fig.5).

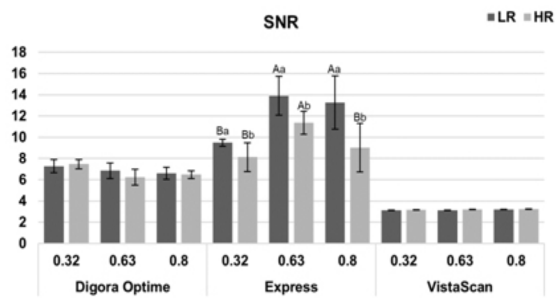

Figure 5.Signal-to-noise ratio (SNR) mean values as a function of the PSP system, exposure time (in seconds), and resolution mode (LR, low-resolution; HR, high-resolution). Distinct letters on the bars (upper case for the same exposure time and lower case for the same resolution mode) differ significantly from each other ($p \leq 0.05$). Error bars represent the standard deviation.

DISCUSSION

Objective and quantitative evaluation of image quality stands as a pivotal approach to understand specific characteristics of different digital radiographic systems. Each step of the radiographic acquisition process must be carefully considered to achieve satisfactory image quality associated with high diagnostic accuracy.[12] Therefore, the present study measured noise, uniformity, and SNR of radiographic images obtained with three PSP systems. Overall, the resolution mode and exposure time affect the three systems differently.

Noise values assessed in Express were higher at 0.32 and 0.80 s, differing from those in Digora Optime and VistaScan that, in most conditions, were not significantly influenced. When different exposures times lead to constant response, the operator should select the shortest one to follow the ALADA (As low As Diagnostically Acceptable) principle and avoid unnecessary overexposure of the patient.[14]Previous studies have revealed that the PSP plate in DigoraOptime is pre-scanned such that a numerical value of the amount of energy stored on the PSP plate is set and, during the actual scanning, the digital system takes it into account depending on the exposure level. As a consequence, any relationship between exposure and gray value is lost.[9,15]Unfortunately, to the best of the authors' knowledge, no similar information is disclosed about Express and VistaScan, which partially limits the present discussion.

Uniformity is a fundamental parameter to assess image quality considering that a uniform X-ray exposure should deliverer a uniform response to the image system.[16] In this study, the exposure time did not affect uniformity for Express system. However, for Digora Optime and VistaScan, the image was more homogeneous at the lowest exposure time tested at the same spatial resolution mode. Interestingly, a previous study[12]assessing eight solid-state sensors from six manufactures also showed diverging uniformity outcomes. It is important to consider that sensor-based systems have different image processing technology from the one employed in the present study. Additionally, the mentioned study[12] measured the uniformity from five circular ROIs, each with 25% of diameter of the sensor, while this study measured it from four rectangular ROIs, each with 7.5% of the total area of the PSP plate. However, the authors do not believe this methodological difference between both studies could differently affect the outcomes.

The spatial resolution of PSP plates can be influenced by scattering and absorption properties of the PSP layer thickness, laser dimensions, and scanning settings of each individual system.[9] According to the manufacturers, the maximum theoretical spatial resolution of the PSP systems used in this study is 14.3 lp mm-1in Digora Optime and Express and 22.0 lp mm-1in VistaScan, depending on the resolution mode selected for plate scanning.[2]Previous studies have shown that higher exposure times generate higher X-ray dose and, consequently, increased signal and decreased noise in the image.[17,18]However, considering the large number of manufactures of digital systems and the technology improvement over the years, this study analyzed the image noise of three PSP systems and showed that SNR values is not influenced by the exposure time and spatial resolution mode in Digora Optime and VistaScan systems. Thus, in a clinical situation, a radiographic acquisition with lower X-ray dose may not affect SNR. Conversely, the Express system showed lower SNR values at lower exposure times and higher values at LR, under most conditions.

In the present in-vitrostudy, all the images were produced having only a 30mm polymethyl methacrylate block in front of the PSP plate, which is a homogeneous object with low density, in accordance with the study methodology of Hellén-Halme et al.[12]and Farias-Gomes et al..[13]This was done in an endeavor to isolate and analyze the image quality characteristics of the different PSP systems without influence of the physical aspects of the study object, such as composition, density, and thickness.

Also, it is important to highlight that when using 70 kV and 7mA for radiograph acquisition, the PSP system's manufacturers suggest an exposure time between 0.12-0.33s, depending of the region of interest, and resolution mode between 50-64µm, in accordance with each specific system. However, the present study used an exposure time and resolution mode between 0.32-0.80s and 12.5-64.0µm, respectively. This methodology design was chosen in endeavor to analyze the effects of different exposure times and resolution modes on image quality, similarly to the study of Olsson et al.[11]which used exposure times between 0.02-1.00s.Since the results of the present study did not show a proportional relationship between image quality and exposure time and resolution mode, caution should be taken regarding unnecessary exposure time during image acquisition.

Because of inherent specifications of different radiographic imaging systems, it is important to highlight that the present results are specific for the digital systems used. Also, for being a technical in-vitro study, caution is needed when translating the present outcomes to a clinical situation. Considering that digital system manufacturers may not provide all proprietary information about their products, the scientific literature should continue to approach the characteristics of different systems.

CONCLUSION

The spatial resolution, exposure time and PSP system have an irregular impact on the image quality evaluated, including aspects such as noise, uniformity, and signal-to-noise ratio. This underscores the importance of conducting further studies on the inherent characteristics of multiple digital radiographic systems, as well as the necessity for manufacturers to provide more detailed information about their systems.

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