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Quality assessment of digital images produced using handheld X-ray equipment

Avaliação da qualidade de imagens digitais produzidas com equipamento de raios X portátil

Evaluación de la calidad de las imágenes digitales producidas con equipos portátiles de rayos X

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Abstract
This study aimed at the assessment and monitoring of digital image quality parameters resulting from the use of portable X-ray equipment in clinical examinations. A multicentric study was conducted for quality assessment of images produced using the portable NOMAD® with the DIGORA® ™ Optime UV computed radiography (CR) system. The digital image quality was evaluated in terms of high- and low-contrast spatial resolution, contrast noise ratio (CNR), and signal-to-noise ratio (SNR). The samples comprised six biomaterials: zirconia (Zr), lyophilized bone (LB), photopolymerizable restorative resin (PRR), glass ionomer cement (GIC), GIC photopolymerizable (GICP), and double adhesive resin cement (DARC). The DICOM image (processed pixels) and raw data (without processing) were quantitatively analyzed. The qualitative visual analysis was performed in an adequately illuminated environment and then repeated in an environment equivalent to that of a clinical practice using conventional monitoring equipment. The relative biomaterial contrast was normalized by the high-contrast result of Zr. The Zr image demonstrated no noise because the standard deviation of the digital image biomaterial pixel mean was zero. In contrast, the relative SNR of the biomaterials was normalized by the DARC result. The relative CNR values according to different aluminum thicknesses were 0.11 for LB and 0.3–0.35 for PRR, GIC, and GICP. The spatial resolution was identical for both high-resolution and conventional monitors; however, for a 0.2-s clinical exposure, the resolution produced by the high-quality monitor increased. The quality control tests indicated the compatibility of the CR system-assisted portable X-ray equipment, verifying the status and image quality.
Keywords: Teaching; X-ray image; Quality control; Biocompatible materials; Radiography; Signal-to-noise ratio.

Resumo
Este estudo tem como objetivo avaliar e monitorar os parâmetros de qualidade da imagem digital quando o equipamento portátil de raios X é utilizado em exames clínicos. Foi realizado um estudo multicêntrico para avaliação da qualidade das imagens produzidas com o NOMAD® portátil e com o sistema de radiografia computadorizada (CR) DIGORA® Optime UV. A qualidade da imagem digital foi avaliada em termos de resolução espacial de alto e baixo

contraste, razão de ruído de contraste (CNR) e relação sinal-ruído (SNR). As amostras foram compostas por seis biomateriais comumente utilizados: zircônia (Zr), osso liofilizado (LB), resina restauradora fotopolimerizável (PRR), cimento de ionômero de vidro (GIC), cimento de ionômero de vidro fotopolimerizável (GICP) e cimento resinoso adesivo dual (DARC). A imagem DICOM (pixels processados) e os dados brutos (sem processamento) foram analisados quantitativamente, assim como a análise visual qualitativa. O contraste relativo do biomaterial foi normalizado pelo resultado de alto contraste do Zr. A imagem Zr não apresentou ruído porque seu desvio padrão foi zero. No entanto, a SNR relativa dos biomateriais foi normalizada pelo resultado DARC. Os valores relativos de CNR em relação a diferentes espessuras de Al foram 0,11 para LB e 0,3–0,35 para PRR, GIC e GICP. A resolução espacial foi idêntica para monitores convencionais e de alta resolução; no entanto, com uma exposição clínica de 0,2 s, a resolução do monitor de alta qualidade aumentou. Os testes de controle de qualidade estabeleceram a compatibilidade dos equipamentos de raios X portáteis assistidos pelo sistema CR.
Palavras-chave: Ensino; Raios X; Controle de qualidade; Materiais biocompatíveis; Radiografia; Relação sinal-ruído.

Resumen
El objetivo fue evaluar los parámetros de calidad de la imagen digital cuando se utiliza un equipo de rayos X portátil. Se llevó a cabo un estudio para evaluar la calidad de las imágenes producidas con el sistema portátil de radiografía computarizada (RC) NOMAD® y DIGORA® Optime UV. La calidad de la imagen digital se evaluó en términos de resolución espacial de alto y bajo contraste, relación de ruido de contraste (CNR) y relación señal-ruido (SNR). Las muestras estaban compuestas por seis biomateriales: zirconio (Zr), hueso liofilizado (LB), resina restauradora fotopolimerizable (PRR), cemento de ionómero de vidrio (GIC), cemento de ionómero de vidrio fotopolimerizable (GICP) y cemento adhesivo de resina dual (DARC). La imagen DICOM (píxeles procesados) y los datos sin procesar (sin procesamiento) se analizaron cuantitativamente, así como el análisis visual cualitativo. El contraste relativo del biomaterial fue normalizado por el resultado de alto contraste de Zr. La imagen de Zr no presentó ruido debido a que su deviación estándar fue cero. Sin embargo, la SNR relativa de los biomateriales fue normalizada por el resultado DARC. Los valores relativos de CNR en relación con diferentes espesores de Al fueron 0,11 para LB y 0,3-0,35 para PRR, GIC y GICP. La resolución espacial fue idéntica para los monitores convencionales y de alta resolución; sin embargo, con una exposición de 0,2 s, la resolución del monitor de alta calidad aumentó. Las pruebas de control de calidad establecieron la compatibilidad de los equipos de rayos X portátiles asistidos por el sistema CR.
Palabras clave: Enseñanza; Rayos-X portátil; Control de calidad; Biomateriales; Radiografía; Relación señal-ruido.

1. Introduction

The technological improvement of digital systems applied in digital imaging has led to the emergence of computed radiography (CR), which has replaced digital systems that produce analog videos. The CR technology employs photostimulable digitized phosphor plates, and the resulting clinical images can be displayed on any monitor (Alves et al., 2016; Hellén-Halme et al., 2016; Wrigley, 2004; van Langen & Castelijn, 2009).

Methods of X-ray exposure employed in analog systems have often been applied to digital systems; however, in such systems, there is little scope for the utilization of high-range dynamics owing to the absence of technical reviews, which hinders further high-quality enhancement of clinical images (Hellén-Halme et al. 2016; Oberhofer, et al. 2009; Don, et al. 2012; Williams, et al. 2007; Buchanan, et al. 2017).

The use of inappropriate types of monitors in clinical evaluations may further deteriorate the image quality. Additionally, inadequate illumination in a dentist's office may compromise the diagnosis based on the digital image recorded. Owing to delicate structures present in the stomatognathic system, such as periodontal bone (Abdinian et al., 2020; Hyer et al., 2021), periodontal bone level (Christiaens et al., 2018; Vandenberghe et al., 2011b; Restrepo-Restrepo et al., 2019), root canal (Vandenberghe et al., 2011a), dental calculus (Hyer et al., 2021; Christiaens et al., 2018; Vandenberghe et al., 2011b; Restrepo-Restrepo et al., 2019; Vandenberghe et al., 2011a; Joly et al., 2002), and the presence of different biomaterials along with the biological tissue (Hyer et al., 2021), the clinical conduct may be compromised (Cruz et al., 2014; Krupinski, 2017; Nejaim et al., 2016; Mah et al., 2011).

Considering the foregoing, this study aimed to evaluate the quality of digital images acquired by portable X-ray CR equipment.

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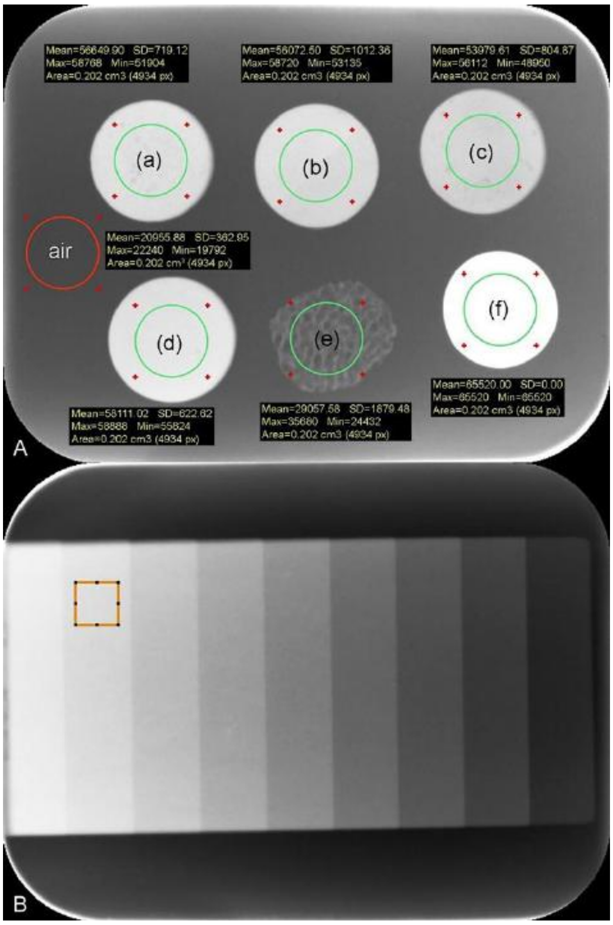
2. Methodology

Digital images were acquired using portable X-ray equipment (NOMAD® Aribex, Orem, Utah, USA) operating at 2.3 mA and 60 kV, and the CR data were collected using DIGORA™ Optime UV® (Soredex, Milwaukee, Wisconsin) (Nóbrega et al., 2012).

The biomaterials used were as follows: a) RIVA SELF CURE®—glass ionomer cement (GIC), b) RIVA LIGHT CURE®—GIC photopolymerizable (GICP), c) RELY X®—double adhesive resin cement (DARC), d) P60®—photopolymerizable restorative resin (PRR), e) ORTHOGEN®—lyophilized bone (LB), and f) PROCERA®—Zirconia (Zr). Figure 1 illustrates an image of the biomaterials and the aluminum wedge used to compare the results.

Figure 1. (A) Digital image of biomaterials and (B) aluminum wedge.



Source: Authors.

The digital image characteristics were evaluated according to the signal-to-noise ratio (SNR) of the biomaterials based on the contrast and contrast-to-noise ratio (CNR) for different aluminum-wedge thicknesses. The equations used to calculate the SNR, contrast between air and each biomaterial, and CNR of the digital images are expressed in Eqs. 1, 2, and 3, respectively:

$$SNR = \frac{\mu}{\sigma}, \tag{1}$$

where μ represents the mean pixel of the digital images, and σ denotes the standard deviation of the mean pixel value.

$$Contrast = 100\% \times \frac{\mu_{air} - \mu_{bio}}{\mu_{air}}, \tag{2}$$

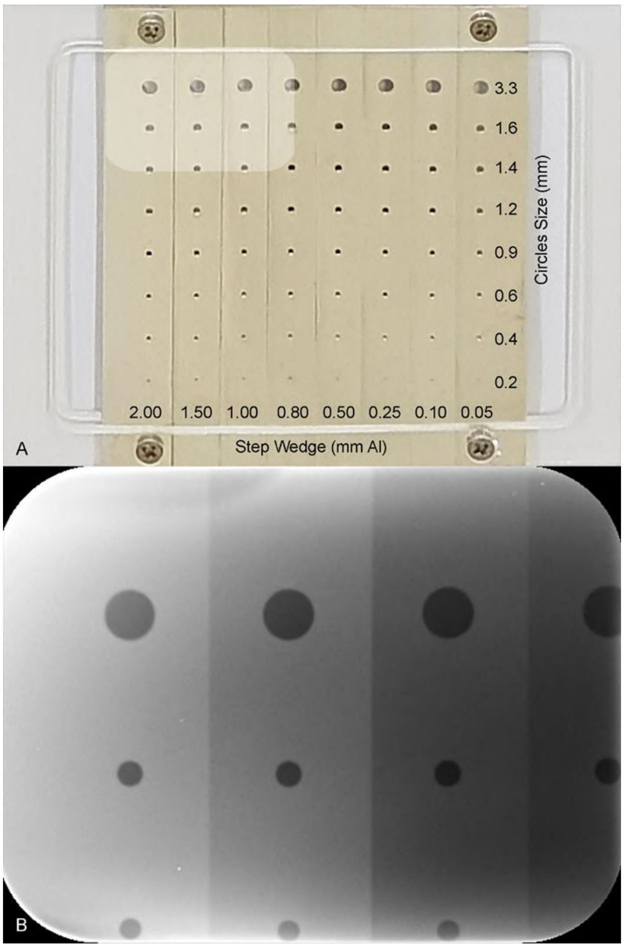
$$CNR = \frac{\mu_{air} - \mu_{bio}}{\sqrt{\frac{\sigma^2_{air} + \sigma^2_{bio}}{2}}}, \quad (3)$$

where μ_{air} and μ_{bio} represent the mean pixel values of air and biomaterials in the digital image, and σ_{air} and σ_{bio} indicate the standard deviations of the mean pixel value of air and biomaterials in the digital image, respectively.

A quantitative analysis of the DICOM pixel-processed image and unprocessed data was performed using the RadiAnt® software. An evaluation of the monitor and illumination in the room was performed using a luminance meter (Light-O-Meter®, Unfors Instruments, Billdal, Sweden) and a monitor screen (Barco® 3 MP, model E-3620, Kortrijk, Belgium).

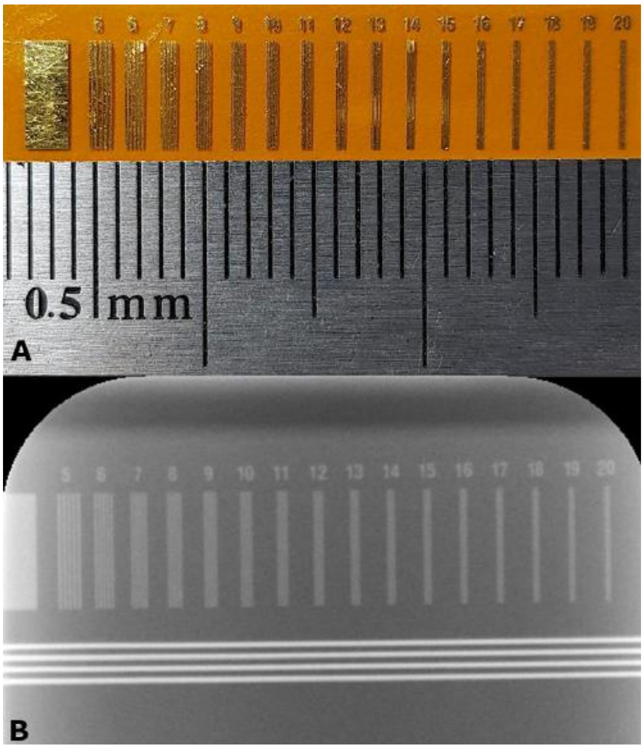
The digital image quality was evaluated based on low-contrast visualization and spatial resolution. The low-contrast visualization was assessed using a calibration aluminum wedge for radioscopy (Shimadzu Company®, Japan) with thicknesses varying from 0.05 to 2.00 mm and empty circular regions with diameters varying from 0.2 to 3.3 mm (Figure 2). The equipment was operated at clinically employed specifications of 60 kV and 0.2 s. The spatial resolution was demonstrated with patterns using a dedicated mammography test with model 18-251-2000 (Nuclear Associates®, Cleveland, Ohio), as shown in Figure 3. The patterns were exposed to values of spatial resolution above 10 mm, which is the value for equivalent polymethylmethacrylate tissue attenuators, and the digital images were acquired with different exposure times at 2.3 mA and 60 kV.

Figure 2. (A) Shimadzu® aluminum wedges with varying thicknesses and circular regions with varying diameters and (B) demonstration of the site of digital image analysis, with the simulation of low contrast intraoral clinical situations.



Source: Authors.

Figure 3. (A) Pattern test of dedicated mammography and (B) example of a digital image with an exposure time of 0.20 s.



Source: Authors.

Low-contrast evaluation was performed on both monitors based on the visibility of the maximum and minimum contrasts of the circles. By comparing the ideal situation with the clinical reality, the conventional monitor presented adequate visualization of the minimum low-contrast condition. The qualitative visual analysis was performed in a suitable room with an illuminance of 8.11 lx, using a 3 MP HR monitor. The analysis was repeated in a simulated clinical environment, that is, a room with 892.9 lx illuminance, using a conventional monitor.

3. Results and Discussion

The relative contrast of the biomaterials analyzed was normalized using the highest contrast value, which was obtained for Zr (Figure 4A). The Zr image exhibited no noise because the corresponding σ_{bio} value was zero. However, the relative SNR of the biomaterials was normalized by the SNR of DARC, which exhibited the highest SNR (Figure 4B). The CNR values relative to different thicknesses of aluminum, normalized using the CNR of the 9-mm aluminum equivalent of Zr, were 0.11 for LB and 0.3–0.35 for PRR, GIC, and GICP (Figure 4C).

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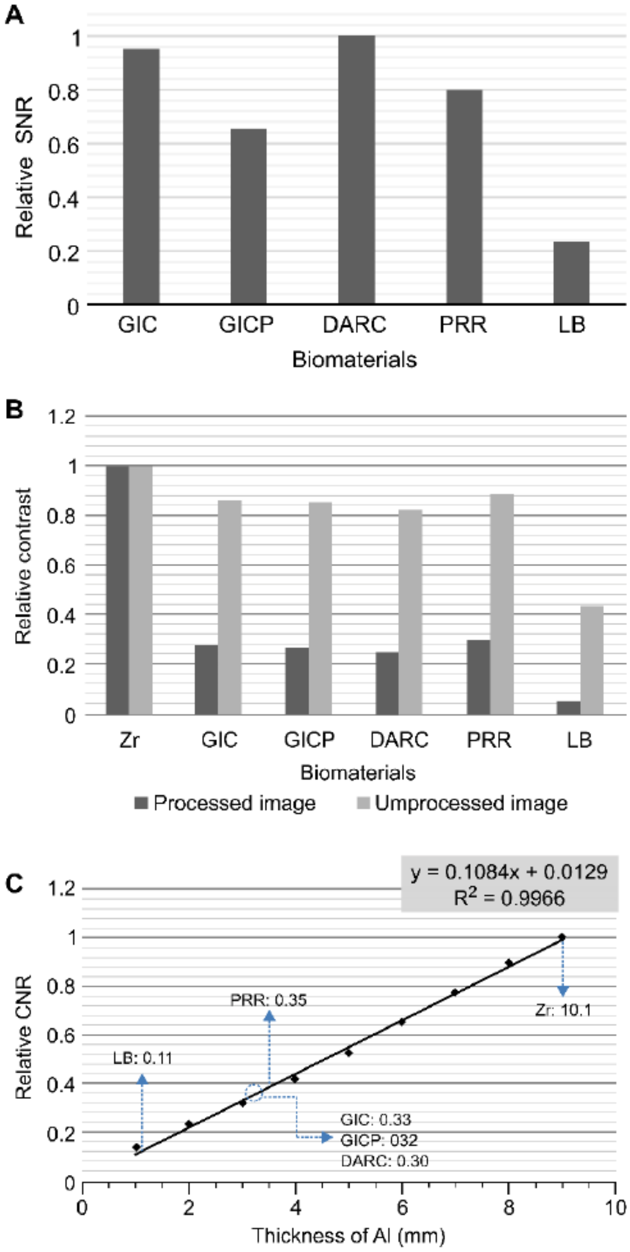
Figure 4. (A) Relative contrast of the biomaterials normalized using the highest contrast value exhibited by Zr. (B) Relative SNR of the biomaterials normalized by the SNR of DARC. (C) CNR relative to the different thicknesses of aluminum, normalized by the CNR of aluminum with a thickness of 9 mm .



Source: Authors.

Low-contrast visual analysis demonstrated the contrast for all structures at their designated sites on both monitors. The results of the qualitative analysis considering a high spatial resolution are presented in Table 1.

Table 1. Visual analysis under high spatial resolution.

Time of exposure (s)	Conventional Monitor (lp/mm)	3 MP HD Monitor (lp/mm)
0.10	7	8
0.20	8	9
0.30	7	8

Source: Authors.

New radiology technologies have expanded to the odontological field; however, knowledge regarding the quality of existing imaging systems remains insufficient. In Brazil, instruments dedicated to quality control of intraoral images are not typically utilized. A combination of quality assessment of the radiological contrast produced by biomaterials and a digital system capable of identifying possible injury is vital for diagnosis.

In terms of the contrast of biomaterials, the comparative analysis indicated improved results for Zr. The analysis of other individual materials revealed different SNRs. The contrast, SNR, and CNR values of the digital images indicated that GIC, GICP, DARC, and PRR exhibited similarities in the processed images. This suggests that distinguishing these individual biomaterials in intraoral images when they are presented together during clinical imaging evaluation may be difficult. However, this is not the case when Zr and LB are present in the image.

The evaluation of the efficiency of mammography systems and radioscopy is similar to that of odontological systems; the use of a high spatial resolution and low-contrast instrument assists in verifying the ability of the system to identify injuries related to GIC, GICP, DARC, and PRR.

Herein, the low-contrast visual analysis provided the same results for both monitors. For a clinical exposure of 0.2 s, the spatial resolution increased on the 3 MP HD monitor. In the previous assay, however, the monitor and luminescence of the environment did not influence the image quality for clinical application. Therefore, it can be concluded that a conventional monitor can be used in a dental office. Consequently, the characteristics evaluated, which are often provided by the manufacturer, can be deemed appropriate for the applications suggested in this study (Pereira et al., 2018; Estrela, 2018; Koche, 2011; Ludke & Andre, 2013; Yin, 2015; Severino, 2018).

4. Conclusion

The quality control tests conducted and the instruments used in this study demonstrated that a compatibility between portable X-ray equipment and CR could be established. Moreover, the status and quality of images were verified. Future studies should focus on characterizing the image quality, improving the diagnosis and prognosis, and estimating the best exposure time values for identifying biomaterials, anatomical structures, and pathological findings. In addition to identifying the biomaterials used in daily clinical practices, we envision the possibility of studying the anatomy of the face, along with pathological changes that may affect it.

In the present study, the exposure time was limited to 0.2 s, thereby producing inadequate results for an accurate comparison between methods; however, it cannot be denied that the results produced are, indeed, promising. Changing the exposure time may demonstrate optimal protocols for clinical studies utilizing X-ray handheld devices in combination with CR and digital radiology technologies to establish a comparison between these technologies.

Future studies must focus on characterizing the image quality, improving the diagnosis and prognosis, and estimating the best exposure time values for identifying biomaterials, anatomical structures, and pathological findings. In addition to identifying the biomaterials used in daily clinical practices, studying the face anatomy and pathological changes affecting it is also a promising domain.

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