RESEARCH ARTICLE

Can a high-density dental material affect the automatic exposure compensation of digital radiographic images?

Neiandro Santos Galvão, Eduarda Helena Leandro Nascimento, Carlos Augusto Souza Lima, Deborah Queiroz Freitas, Francisco Haiter-Neto and Matheus Lima Oliveira

Department of Oral Diagnosis, Division of Oral Radiology, Piracicaba Dental School, University of Campinas (UNICAMP), Sao Paulo, Brazil

Objectives: To investigate the influence of high-density dental material on the automatic exposure compensation of digital radiographic imaging systems.

Methods: Two radiographic phantoms were custom made to reproduce radiographic densities of the dental tissues: enamel, dentin and pulp chamber. The phantoms were X-rayed using the Digora Toto, Digora Optime and VistaScan systems for 0.063, 0.1 and 0.16 s. Radiographic acquisitions were repeated in the presence of a high-density material equivalent to a titanium implant, in the small and large sizes. Mean grey values of the dental tissue-equivalent regions were obtained with the Image J software, averaged and compared between the absence and presence of the high-density material using ANOVA for multiple comparisons and Tukey's test ($\alpha = 0.05$).

Results: The presence of a high-density material significantly ($p \leq 0.05$) decreased grey values of the dental tissue-equivalent images in the Digora Toto and VistaScan, regardless of the exposure time. For the Digora Optime, the high-density material decreased the pulp-equivalent grey values at all exposure times, the dentin-equivalent grey values significantly increased at exposure time of the 0.1 and 0.16 s, and the enamel-equivalent grey values significantly increased at the exposure time of 0.16 s ($p \leq 0.05$). In general, the size of the high-density material did not affect the grey values significantly ($p \leq 0.05$).

Conclusions: In general, the presence of a high-density dental material in digital radiographic systems influences the AEC by adjusting dental tissue-equivalent grey values.

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Introduction

Digital radiographic imaging systems present tools that allow for simple and quick image adjustment,¹ which may be automatic or manual. The automatic exposure compensation (AEC) is a non-linear enhancement of the image histogram that detects the lowest and highest pixel values and modifies the greyscale to increase image contrast.² Since AEC produces high-contrast images, it has brought advantages to clinical routine even with

variations of the X-ray exposure.³ Although it has been observed that the presence of materials with high physical density influences the AEC performance,⁴ this is not clear in the scientific literature yet.

The effect of AEC on image contrast and signal-to-noise ratio has been the subject of previous studies.^{2,5} It is a convenient and fast method when the exposure is not optimal, but it can mask excessive radiation dose in cases of overexposed images.² The AEC has been shown to reduce signal-to-noise ratio and not to produce pixel values proportional to X-ray exposure.^{2,5} When evaluating digital systems, a recent study found that

Correspondence to: Dr Matheus Lima Oliveira, E-mail: matheuso@unicamp.br
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high-density materials affect the performance of AEC in image contrast, however, the methodological design of the study did not evaluate this effect on grey values equivalent to the dental tissues.⁴

Substantial changes in radiographic density due to the presence of high-density materials during radiographic acquisition in modern digital systems have been observed by dentists in their clinical routine, however, no previous study has assessed the effect of the AEC on the grey values of dental tissues in the presence of a high-density dental material. Therefore, the aim of this study was to investigate the effect of AEC induced by high-density dental materials on dental tissue-equivalent grey values obtained with three digital radiographic systems.

Methods and materials

Radiographic phantom preparation

Two radiographic phantoms were custom-made for this study. They consisted of three polypropylene cylindrical tubes with an open top (6.7 mm in diameter x 35 mm in height) fixed next to each other and perpendicular to a glass slide. Each tube was filled with a radiopaque aqueous solution of dipotassium hydrogen phosphate (K_2HPO_4) at the concentration of 1000 mg mL⁻¹, and at different volumes (in µL), which were determined in a pilot study for presenting grey values with the same aluminium-equivalent thickness to those of the dental tissues. The corresponding heights of the solution within the tube to represent the enamel, dentin and pulp chamber were, respectively, 20, 15 and 8 mm.

In order to investigate the effect of the presence and the size of a high-density material on the AEC, a fourth cylinder was added to each radiographic phantom; one of them had 4.7 mm in diameter (henceforth, small size, S; [Figure 1e](#)) and the other had 9.7 mm in diameter (henceforth, large size, L; [Figure 1f](#)). Both tubes were filled with the same radiopaque solution at a height of 30 mm to represent the radiopacity of a titanium implant.

Pilot study

The pilot study previously mentioned was based on obtaining radiographic images of an aluminium step wedge with either a molar tooth ([Figure 1a](#)), a titanium implant ([Figure 1b](#)) or multiple tubes filled with the solution of K_2HPO_4 ([Figure 1c](#)) using the VistaScan digital system (Dürr Dental, Beitigheim-Bissingen, Germany) under spatial resolution of 25 lp/mm and contrast resolution of 8 bits. After, for all radiographic images, grey values were obtained from each step of the step wedge using the ImageJ, a public domain software developed by the National Institutes of Health (NIH-USA), and plotted against the corresponding thickness in millimetre using Microsoft Excel. The equation of the trend line between these values ($y = 8.9826x + 132.26$ and $R^2 =$

0.98; where y = grey value and x = mm of aluminium) was used to establish accurate volumes of K_2HPO_4 to represent dental tissues ([Figure 1D](#)). Additionally, K_2HPO_4 is a salt of high solubility with an effective atomic number (15.58) close to that of hydroxyapatite (15.86), which makes similar the X-ray attenuation of both substances.⁶

Radiographic acquisition

After having the three standard-size cylinders filled with equivalent volumes to the same dental tissue (pulp, enamel or dentin), the two phantoms (S and L) were X-rayed with the fourth cylinder (high-density material) under two conditions: empty and filled. Three intraoral digital imaging systems were used: VistaScan (Dürr Dental, Beitigheim-Bissingen, Germany), Digora Optime (Soredex, Helsinki, Finland) and Digora Toto (Soredex, Helsinki, Finland) with the Focus dental X-ray unit (Instrumentarium Dental, Tuusula, Finland) operating at 70 kVp, 7 mA, 40 cm source-to-object distance and three exposure times: 0.063, 0.01, 0.16 s. The digital radiographic systems were operated using integrated imaging software packages: DBSWIN 5.2.0 (Build 9020) for VistaScan, and CliniView 10.1.0.9 (IAM v. 4.05.0009) for Digora Optime and Digora Toto.

This methodological design composed 108 experimental conditions: 3 dental tissues × 2 (presence and absence of a high-density material) × 2 high-density material sizes × 3 imaging systems × 3 exposure times. In order to evaluate the reproducibility of the grey values, each experimental condition was X-rayed for five times, resulting in a total of 540 radiographic images. [Table 1](#) shows cropped representative radiographic images of the phantom S at the exposure time of 0.063 s.

Image assessment

All radiographic images were exported in TIFF format with contrast resolution of 8 bits. Using the ImageJ software, a circular region of interest (ROI) of 2.0 mm in diameter was established on the centre of the images of the three standard size cylinders to obtain the mean grey values related to the dental tissue-equivalent regions.

Statistical analysis

Data were analyzed using SPSS v. 22.0 software (IMB Corp., Armonk, NY). ANOVA was used to compare the grey values between experimental groups of each radiographic system, followed by Tukey's test for multiple comparisons, at a level of significance of 5% ($\alpha = 0.05$).

Results

[Table 2](#) shows the distribution of the mean of grey values corresponding to the pulp, dentin and enamel, in the presence or absence of implant, in small and large sizes, in 0.063 s, 0.1 s and 0.16 s exposure times, distributed

Figure 1 Diagram illustrating the conversion of grey values into millimetres of aluminium (mmAl): (a) radiographic images of an aluminium step wedge with a molar tooth, (b) a titanium implant and (c) multiple tubes filled with the solution of K_2HPO_4 (C). Dotted areas represent the ROIs for grey value assessment. (d) Scatter chart, the resulting trend line and equation based on eight ROIs of the step wedge of a representative radiograph. (e, f) Schematic drawing of the final experimental setup. ROIs, regions of interest.

Table 1 Cropped representative radiographic images of dental tissues using three digital systems at the exposure time 0.063 s

Digital system	Equivalent dental tissue	High-density material-equivalent tube	
		Empty	Filled
Digora Toto	Pulp
	Dentin
	Enamel
Digora Optime	Pulp
	Dentin
	Enamel
VistaScan	Pulp
	Dentin
	Enamel

The rightmost cylinder of each image is the high-density material-equivalent tube of small size.

according to the Digora Toto, Digora Optime and VistaScan radiographic systems.

The presence of a high-density material significantly ($p \leq 0.05$) decreased grey values of the dental tissue-equivalent images in the Digora Toto and VistaScan, regardless of the exposure time. For the Digora Optime, the grey values were affected differently in the presence of a high-density material, such that, the pulp-equivalent grey values decreased at all exposure times, the dentin-equivalent grey values significantly increased at exposure time of the 0.1 s and 0.16 s, and the enamel-equivalent grey values significantly increased at the exposure time of 0.16 s ($p \leq 0.05$).

In general, the size of the high-density material did not affect significantly ($p \leq 0.05$) the grey values of dental tissues, except for the pulp in 0.16 s on the Digora Toto and VistaScan, when the small size presented greater reduction ($p \leq 0.05$) of the grey values in relation to the large size, and for the dentin in 0.16 s on the Digora

Optime, when the large size presented greater reduction ($p \leq 0.05$) of the grey values in relation to the small size.

Discussion

The presence of high-density material during radiographic acquisition automatically changes the grey values of the image in systems with AEC.⁴ However, to the best of the author’s knowledge, no previous studies have demonstrated the influence of the presence of high-density dental materials on the grey values of dental tissues. In general, the present study showed that the action of the AEC varies depending on the radiographic system.

In most cases, the presence of a high-density material decreased the grey values of dental tissues in the Digora Toto, Digora Optime and VistaScan. In specific cases in the Digora Optime at the exposure times of 0.1 s and

Table 2 Mean and SD of grey values corresponding to the dental tissues in the presence (with Ti) or absence (w/o Ti) of a high-density material in two sizes and at three exposure times

		Exposure time					
Digital system	Dental tissue	0.063 s		0.1 s		0.16 s	
Digora Toto		w/o Ti	with Ti	w/o Ti	with Ti	w/o Ti	with Ti
Small	Pulp	156.5 (2.9)*c	89.6 (0.6)c	130.1 (2.8)*c	88.7 (0.7)c	129.3 (2.6)*c	88.3 (0.4)d
	Dentin	195.7 (1.6)*b	150.9 (0.6)b	184.2 (0.1)*b	151.5 (0.2)b	184.0 (0.1)*b	151.3 (0.4)b
	Enamel	201.7 (0.2)*a	186.9 (1.1)a	202.7 (0.9)*a	187.6 (0.9)a	202.6 (1.0)*a	187.6 (0.9)a
Large	Pulp	156.5 (2.9)*c	90.9 (2.8)c	130.1 (2.8)*c	90.7 (2.4)c	129.3 (2.6)*c	91.3 (2.8)c
	Dentin	195.7 (1.6)*b	151.5 (1.6)b	184.2 (0.1)*b	151.6 (1.4)b	184.0 (0.1)*b	151.8 (1.5)b
	Enamel	201.7 (0.2)*a	185.7 (1.3)a	202.7 (0.9)*a	186.2 (1.3)a	202.6 (1.0)*a	186.3 (1.5)a
Digora Optime							
Small	Pulp	253.3* (2.3)*	220.8 (11.8)b	155.8 (9.2)*c	126.2 (16.8)c	54.3 (8.2)*c	40.5 (10.3)d
	Dentin	255.0 (0.0)	255.0 (0.0)a	199.4(10.3)#b	227.7 (5.6)b	101.4 (10.9)#b	134.7 (2.9)b
	Enamel	255.0 (0.0)	255.0 (0.0)a	254.2 (1.1)a	255.0 (0.0)a	185.7 (9.0)*a	213.4 (8.3)a
Large	Pulp	253.3 (2.3)*	215.6 (4.7)b	155.8 (9.2)*c	116.1 (8.0)c	54.3 (8.2)#c	33.2 (7.0)d
	Dentin	255.0 (0.0)	255.0 (0.0)a	199.4 (10.3)#b	216.2 (6.2)	101.4 (10.9)	120.9 (7.2)
	Enamel	255.0 (0.0)	255.0 (0.0)a	254.2 (1.1)a	255.0 (0.0)a	185.7 (9.0)#a	203.2 (7.4)a
VistaScan							
Small	Pulp	149.6 (0.4)*c	137.1 (0.1)c	141.3 (0.4)*c	135.9 (2.2)c	142.0 (0.5)*c	135.3 (1.2)d
	Dentin	189.5 (0.5)*a	180.4 (0.3)a	183.7 (0.1)*a	180.3 (0.1)a	183.9 (0.9)*b	179.6 (0.6)b
	Enamel	209.6 (0.8)*a	204.7 (0.8)c	206.5 (0.2)*a	204.4 (0.2)a	207.2 (0.2)*a	204.0 (0.4)a
Large	Pulp	149.6 (0.3)*c	137.3 (1.1)c	141.3 (0.4)*c	135.6 (1.3)c	142.0 (0.5)*c	136.6 (0.9)c
	Dentin	189.5 (0.6)*	180.8 (0.8)b	183.7 (0.1)*b	179.6 (1.1)b	183.9 (0.9)*b	179.7 (1.0)b
	Enamel	209.6 (0.1)*a	203.8 (0.4)a	206.5 (0.2)*a	203.9 (0.6)a	207.2 (0.2)*a	205.1 (0.4)a

SD, standard deviation.

*Significantly higher than “with Ti” under the same conditions. #Significantly lower than “with Ti” under the same conditions. (a) Significantly greater than “b” and “c” in the same column and digital system. (b) Significantly greater than “c” in the same column and digital system.

0.16 s, the high-density material increased the grey values of dental tissues, which reveals that this system presents a bidirectional function that increases or decreases the grey values to improve the image contrast.^{3,7} For Digora Optime, longer exposure times produced a greater variation on the grey values. The other systems did not vary the results as a function of the exposure time.

With regard to the exposure time, attention should be paid to the fact that excessive underexposure produces extremely low-signal images, i.e. grey values concentrated at the upper limit of the greyscale (histogram shifted to the right). When looking at our results (Table 2), this is more evident for the Digora Optime at 0.063 s, which limits the assessment of the action of AEC in the presence of a high-density material and reveals that the inherent sensitivity of the imaging systems plays a critical role in the comparative evaluation of grey values. However, it is important to mention that the exposure times used in this study were determined based on the clinical routine of the authors, in which diagnostically acceptable periapical radiographic images are obtained using the three digital radiographic imaging systems associated to a high-frequency intraoral unit.

For the Digora Toto and VistaScan, the size of the high-density material, i.e. the coverage area on the radiographic image, did not influence the grey values

of dental tissues, with the exception of the pulp-equivalent grey values at the exposure time of 0.16 s, which reduced significantly for the small size. The Digora Optime was not affected by the size of the high-density material. This finding is in agreement with the scientific literature, considering that AEC detects the maximum and minimum grey values of the image and automatically adjusts these values to increase the image contrast.² Although the authors did not expect to find significant differences related to the size of the high-density dental material, this analysis was important to rule out such possibility when interpreting the results. The assessment of the size of high-density dental materials is new in the scientific literature, which limits direct comparison of the current results with those of similar studies. Additionally, each digital radiographic system presents inherent characteristics that can influence the final grey values of the image, such as contrast resolution, dynamic range and integrated imaging software, and this should be taken into account.

Dashpuntsag et al⁴ investigated the effects of AEC on the grey values of an aluminium step-wedge in the presence of lead and at different exposure times and, as in our study, the addition of high-density material increased and decreased grey values for the Digora Optime, and slightly increased for the VistaScan. The

non-linear behaviour of Digora Optime in relation to the physical density of the material and grey value was also observed. Dashpuntsag *et al.*⁴ also indicated that structures of higher grey values are more sensitive to changes in AEC.

Based on the results found in this study, it could be verified that the presence of a high-density material, such as an implant, adjusts the grey values, which could reflect on the diagnostic accuracy of discrete lesions. In the study of Yoshiura *et al.*,³ the effect of AEC on the diagnosis of proximal caries was evaluated, and the authors concluded that the AEC increased diagnostic accuracy in sub- and superexposed images, indicating its usefulness use for this diagnostic task. This is observed when the radiation exposure does not comply with the radioprotection principle of keeping the exposure factors as low as diagnostically acceptable. However, the influence of the presence of high physical density material was not investigated.

This being an *in vitro* study, the current methodology could accurately isolate the study object, avoiding bias from additional interferences. However, limitations

related to the positioning and distribution of the dental tissue- and implant-equivalent materials, and the background area during radiographic acquisition should be considered. Studies that simulate clinical conditions to evaluate the influence of the AEC on the diagnostic accuracy in the presence of high-density dental materials, as well as the effect of post-image processing are indicated to validate the results of this study.

Conclusion

In general, AEC is influenced by the presence of a high-density dental material in the digital radiographic systems tested, regardless of the X-ray exposure time and the size of the high-density material.

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