RESEARCH ARTICLE

Influence of VistaScan image enhancement filters on diagnosis of simulated periapical lesions on intraoral radiographs

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Objective: To evaluate whether image enhancement filters of VistaScan system improve the diagnostic accuracy of simulated periapical lesions.

Methods: 10 sockets were prepared on bovine ribs to fit a bovine tooth. Bone defects were created and successively enlarged providing four groups ($n = 10$): Group 0, absence of lesions; Group 1, periapical lesions with 1.6 mm in diameter; Group 2, with 1.8 mm in diameter; and Group 3, with 2.1 mm in diameter. Periapical radiographs were taken using a photostimulable storage phosphor plate and DBSWIN software. VistaScan filters were applied and the images were allocated into seven groups: Nonfiltered, Fine, Caries 1, Caries 2, Endodontic, Periapical and Noise Reduction. All the 280 images were assessed about the presence or absence of periapical lesions. Pixel intensities standard deviation were compared between nonfiltered and filtered images. Two-Way Analysis of Variance and the *post hoc* Tukey's test were used to compare area under the ROC curve, sensitivity and specificity.

Results: VistaScan filters showed no significant difference for area under receiver operating characteristic curve ($p = 0.124$), sensitivity ($p = 0.835$) and specificity ($p = 0.832$). Area under receiver operating characteristic curve ($p = 0.000$) and sensitivity ($p = 0.000$) in 2.1 mm lesions size were significantly higher than in 1.6 mm and 1.8 mm lesions size. Pixel intensities standard deviation was significantly changed in the filtered images compared to nonfiltered ones ($p < 0.01$), except for Fine in the bone region ($p > 0.05$).

Conclusion: VistaScan enhancement filters do not influence the diagnostic accuracy of simulated periapical lesions. On the other hand, larger lesions were more frequently detected. The filters change the pixel intensities reducing or intensifying the differences between similar regions.

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Introduction

Periapical diagnosis depends on accurate radiographic examination to make possible the assessment of conditions which clinical examination alone cannot provide, such as the evaluation of the location and extent of apical periodontitis that can influence treatment planning and outcomes.¹ However, lesions restricted to cancellous bone cannot be consistently detected in

periapical radiographs, which is an obstacle to establishing the diagnosis.² Thus, clinicians must be aware of how accurate each radiographic method is, and which image can provide the most reliable information regarding periapical bone lesions.

Clinical studies were carried out to assess the effect of image enhancement filters on the diagnostic accuracy of periapical lesions on digital radiographs, however, those are often based on small samples^{3,4} and repeated acquisitions were not allowed in patients due to irradiation

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exposure. *In vitro* analysis, such as by using chemical^{5,6} or burs^{7,8} to create lesions, although does not reliably represent the edges of a pathologic lesion, it is a feasible way to perform studies with a higher sample size and multiple images acquisitions.

Using digital systems, images presentation can be altered by adjusting the characteristic curve and additional filtering of the digital data before displaying the data on the screen.⁹ Besides, it is possible to alter the display options for image interpretation after exposure using enhancement procedures available in imaging software.¹⁰ It may improve the visibility of anatomical structures or alterations close to each other, which appear with similar contrasts in the original image.¹¹ The effect of contrast-adjustment-based enhancement filters has no increase the overall diagnostic accuracy of periapical lesions.^{3,5,8,12} On the other hand, image enhancement filters act on processing of electronic signals contained in detector pixels. Thus, from a defined signal frequency, the pixels below or above the same are modified, removing partially or totally the undesirable signal characteristics,¹³ which may provide different results.

DBSWIN software, which belongs to the VistaScan storage phosphor plate system (Dürr Dental, Bietigheim-Bissingen, Germany), allows to capture images with 20 line pairs per millimeter of spatial resolution and 16 bits of contrast resolution. Also, it provides several types of filters for tasks in Dentistry, which represent a selection of different settings for the frequency range to be intensified and for the amplification multiplier.¹¹ Despite of its manufacturer's indications for specific tasks, it is possible to apply specific task filter for different diagnostics, which allows to investigate if a different setting of frequency range generated for a task can influence the diagnostic accuracy of other task, as endodontics in this case.

Studies on the effect of image enhancement filters on the diagnostic accuracy of periapical lesions on digital radiographs were quite a lot in the late 1990s and early 2000s.^{5-8,12,14} However, the results are inconclusive. To

the best of our knowledge, there is no study assessing the diagnostic accuracy of using image enhancement filters of VistaScan on diagnosis of simulated periapical lesions, nor its effect on the pixel intensities. Considering the increasing use of digital systems and available tools in the software, as well as the challenge in the early diagnosis of periapical lesions, our aim was to evaluate whether image enhancement filters of VistaScan improve the diagnostic accuracy of simulated periapical lesions with different sizes and their influence on pixel intensities.

Methods and materials

One bovine tooth with a fully formed single and straight root, and bovine ribs with uniform trabecular bone architecture in the radiographic image and thicker than the diameter of the bovine tooth were used in this study. 10 sockets were prepared on the bovine ribs using a round carbide bur (KG Sorensen, Cotia, SP, Brazil) and a conical diamond bur (KG Sorensen, Cotia, SP, Brazil). The adjustment of the apical third of the root was previously assessed by periapical radiography.

Bone defects were created at the base of the sockets ($n = 10$) with a round carbide bur (KG Sorensen, Cotia, SP, Brazil) to simulate periapical lesions. Each socket underwent three successive rounds of bone defect enlargement with the following round carbide bur sizes (diameters): #5 (1.6 mm); #6 (1.8 mm); #8 (2.1 mm). Thereby, periapical conditions were classified into four groups ($n = 10$): Group 0, absence of simulated periapical lesions; Group 1, simulated periapical lesions with 1.6 mm in diameter; Group 2, simulated periapical lesions with 1.8 mm in diameter; and Group 3, simulated periapical lesions with 2.1 mm in diameter (Figure 1).

Periapical radiographs were taken with the FOCUS dental X-ray unit (Instrumentarium Dental, Tuusula, Finland) operating at 70 kVp, 7 mA and 40 cm

Figure 1 Four groups of periapical conditions. (A) Group 0, absence of simulated periapical lesions; (B) Group 1, simulated periapical lesions with 1.6 mm in diameter; (C) Group 2, with 1.8 mm in diameter; (D) Group 3, with 2.1 mm in diameter.

Figure 2 Post-processed images using VistaScan filters and nonfiltered image. (A) Non-filtered; (B) Fine; (C) Caries 1; (D) Caries 2; (E) Endodontics; (F) Periodontal; (G) Noise reduction. Images of Group 3.

source-to-object distance. A photostimulable storage phosphor plate size 2 of the VistaScan system was used with exposure time of 0.08 s and scanned in the proper scanner using the DBSWIN software (Dürr Dental AG, Beitigheim-Bissingen, Germany). Each socket was radiographed with the bovine tooth inside before and after each round of bone defect enlargement. An acrylic resin device was used to allow standardized reproducible periapical radiographs and, to simulate soft tissue attenuation, a 2.5-cm-thick acrylic resin block was placed between the X-ray tube and the bovine rib.^{15,16}

DBSWIN software provides six filters for specific tasks: Fine, Caries 1, Caries 2, Endodontic, Periodontal and Noise Reduction. After the VistaScan plates reading, those six filters were applied to the 40 acquired images. In total, 280 images were obtained, which were divided into seven groups ($n = 40$): Nonfiltered, Fine, Caries 1, Caries 2, Endodontic, Periodontal and Noise Reduction (Figure 2), and exported as 8-bit TIFF files. All the images were presented separately in PowerPoint software (Microsoft Corp, Seattle, WA, USA), with image compression disabled, and viewed on a 24.1-inch LCD monitor (MDRC-2124, Barco N.V., Courtray,

Belgium) with a screen resolution of 1920×1200 pixels. The observers could use zoom tool if necessary, but brightness and contrast adjustments were not allowed.

Prior to images assessment, three oral radiologist observers were calibrated. A simulated periapical lesion was characterized by a radiolucency associated with the radiographic root apex with at least twice the width of the supposed periodontal ligament space.^{17,18} The evaluators were instructed to disregard the presence or absence of the lamina dura and focus their attention strictly on the presence or absence of a periapical radiolucency. Periapical radiographs with each enhancement filter were presented in a randomized order and individually assessed by the observers, who should note down the presence or absence of periapical lesions using the following 5-point confidence scale: 1, definitely absent; 2, probably absent; 3, unsure; 4, probably present; and 5, definitely present; After 1 month, 30% of the periapical radiographs from each group were reassessed following the same conditions to determine intraobserver agreement.

To evaluate the influence on pixel intensities and technically estimate the noise introduced by using VistaScan

Figure 3 Regions of interest in air and bone used to calculate mean grey value and its standard deviation.

enhancement filters, mean grey value and its standard deviation (SD) were measured individually in two regions of interest (ROI) within air and bone (Figure 3) on nonfiltered images and on each post-processed image by Fine, Caries 1, Caries 2, Endodontic, Periodontal and Noise Reduction filters. Those ROI were reproduced exactly for all other periapical radiography using ImageJ ROI Manager tool (ImageJ software, National Institutes of Health, Bethesda, MD).

The changes in pixel intensities from applying each enhancement filter was calculated by arithmetic operations by ImageJ software Image Calculator tool with Difference as mathematical operation using the following formula: $[Final\ Image = |Nonfiltered\ Image - Filtered\ image|]$. The final images generated from the difference between the nonfiltered image and each filter show which pixels were modified by the enhancement filter application and its intensity.

Quadratic-weighted k statistics was used to determine inter- and intraobserver agreement. Sensitivity, specificity and receiver operating characteristic (ROC) curve analysis were used to calculate the diagnostic accuracy values (area under the ROC curve) of each observer concerning to each simulated periapical lesion group

and each VistaScan enhancement filter for detecting the presence or absence of the simulated periapical lesion. Two-way (filters x size of lesions) analysis of variance (ANOVA) and the *post hoc* Tukey's test compared the area under the ROC curve, the sensitivity and the specificity, and one-way ANOVA compared the pixel intensities SD between non-filtered and filtered images.

Additionally, we performed an analysis of the answers of the evaluators for each filter without considering the size of the lesions, simulating a single large group for each filter ($n = 30$), which was compared by one-way ANOVA.

IBM SPSS Statistics 22.0 (IBM Corp, Armonk, NY) was used to carry out the statistical analyzes. The level of significance was set at 5%.

Results

Means of intra- and inter observer agreement were substantial, according to Landis & Koch (1977),¹⁹ ranging from 0.69 to 0.80 and 0.61 to 0.67, respectively.

Table 1 shows the mean and standard deviation of the diagnostic accuracy values (area under the ROC curve, sensitivity and specificity) from the observers concerning to simulated periapical lesion groups and VistaScan filters.

There were no statistically significant differences between VistaScan filters considering or not the size of the lesions for area under ROC curve ($p = 0.124$ and 0.776 , respectively), sensitivity ($p = 0.835$ and 0.997 , respectively) and specificity ($p = 0.832$ and 0.991 , respectively). When comparing the lesion size groups, the area under ROC curve ($p < 0.001$) (Figure 4) and sensitivity ($p < 0.001$) for the VistaScan filters were significantly higher in Group 3 ($p < 0.001$) than in Groups 1 and 2, which did not statistically differ between each other (Figure 4 and Table 1).

Application of enhancement filters showed statistically significant changes of pixel intensities SD in the filtered images when compared to nonfiltered ones ($p < 0.01$) in air and bone (Figure 5) regions, except for Fine filter in bone region ($p > 0.05$).

For the air region, the filters had different results in images. While the Fine and the Noise reduction filters effectively reduced the noise in these regions, the others did the opposite, by increasing the contrast between similar pixel intensities. In the bone region, this last pattern was observed for all the filters, except for the Fine.

Figure 6 shows the pixels that had intensity changes by applying the different enhancement filters. The Noise reduction filter modified the entire contrast scale of the image and, therefore, had the most pixels changed.

Table 1 Mean and standard deviation of the values of area under the ROC curve, sensitivity and specificity concerning to simulated periapical lesion groups and VistaScan filters

		VistaScan filters					
		Simulated periapical lesions			Caries 2		
		Non-filtered	Fine	Caries 1	Caries 2	Endodontic	Noise reduction
Area under the ROC curve	Group 1	0,67 ± 0,04Aa	0,68 ± 0,10Aa	0,67 ± 0,04Aa	0,67 ± 0,06Aa	0,7 ± 0,08Aa	0,67 ± 0,05Aa
	Group 2	0,7 ± 0,11Aa	0,67 ± 0,12Aa	0,73 ± 0,05Aa	0,76 ± 0,06Aa	0,73 ± 0,03Aa	0,73 ± 0,05Aa
	Group 3	0,85 ± 0,07Ba	0,77 ± 0,16Ba	0,79 ± 0,07Ba	0,86 ± 0,03Ba	0,82 ± 0,10Ba	0,81 ± 0,20Ba
Sensitivity	Group 1	0,47 ± 0,25Aa	0,50 ± 0,14Aa	0,45 ± 0,23Aa	0,42 ± 0,30Aa	0,40 ± 0,29Aa	0,55 ± 0,13Aa
	Group 2	0,55 ± 0,24Aa	0,47 ± 0,26Aa	0,55 ± 0,13Aa	0,55 ± 0,23Aa	0,45 ± 0,24Aa	0,55 ± 0,30Aa
	Group 3	0,77 ± 0,12Ba	0,67 ± 0,26Ba	0,65 ± 0,17Ba	0,67 ± 0,19Ba	0,77 ± 0,17Ba	0,70 ± 0,16Ba
Specificity	Group 1	0,75 ± 0,20Aa	0,85 ± 0,23Aa	0,82 ± 0,15Aa	0,87 ± 0,15Aa	0,85 ± 0,19Aa	0,82 ± 0,24Aa
	Group 2	0,75 ± 0,20Aa	0,80 ± 0,22Aa	0,82 ± 0,15Aa	0,87 ± 0,15Aa	0,85 ± 0,19Aa	0,82 ± 0,24Aa
	Group 3	0,75 ± 0,20Aa	0,80 ± 0,22Aa	0,82 ± 0,15Aa	0,87 ± 0,15Aa	0,85 ± 0,19Aa	0,82 ± 0,24Aa

ROC, receiver operating characteristic;

Means followed by different letters (uppercase in the vertical and lowercase in the horizontal) are significantly different ($p < 0.05$) according to two-way ANOVA and Tukey test.

Discussion

The objective of evaluating the effect of different VistaScan enhancement filters on simulated periapical lesions was based on the knowledge that, as periapical lesions are usually asymptomatic, they are frequently detected during routine radiographic examination.² But, some authors have found that periapical lesions confined to the cancellous bone are not easily visualized in intra-oral radiography.²⁰ Studies have shown that the use of enhancement filters in digital radiography improves the diagnosis of several tasks in Dentistry,^{6,8,13,21} so we assessed the diagnostic accuracy of using VistaScan enhancement filters on diagnosis of simulated periapical lesions restricted to the cancellous bone.

Since periapical bone lesions are difficult to simulate, bone defects were created by using a round carbide bur because it allows to create lesions with more precise and standardized sizes than using chemical solutions. Although this method does not accurately recreate the anatomical shapes of inflammatory periapical lesions, it allows the experimenter to create and observe lesions of progressively increasing dimensions. Moreover, exactly how much bone must be lost before a lesion is detectable is still debatable.^{2,22} Barbat & Messer⁷ found that disruption of the lamina dura alone is, in most cases, radiographically detectable. However, in our study it was not possible to simulate the lamina dura. They also demonstrated that the expanded lesion in cancellous bone is readily visualized. As our main objective was to evaluate the influences of enhancement filters, we opted to use a model that can show lesions of increasing sizes, involving only cancellous bone, but without extra variables as removal of lamina dura or cortical plates. Regarding the root and sockets adjustments, the root apex was used as a model during the preparation of the sockets being its adaptation tested at each stage of sockets preparation to obtain an optimal adaptation.

Improperly use of “enhancements”, such as brightness and contrast adjustments, may decrease diagnostic performance.²³ Therefore, to evaluate only the influence of the filters applied and to avoid adverse effects of individual preferences of observers, no adjustment of brightness and contrast was allowed in this study. Fixed settings gave an equal chance to compare the observers’ performance dealing with digital images, so these settings were kept constant to avoid a subjective manipulation. Furthermore, evaluating the images separately instead of pair-wise, the viewing time is shorter, and the risk of observer fatigue reduced, thus saving the observer resources for a larger number of evaluations. The waiver of a simultaneous image comparison and forced decision may result in a reduced sensitivity to small differences.¹¹

VistaScan system provides six types of image enhancement filters, which were already tested for caries²⁴ and simulated peri-implant bone level¹³ diagnosis. Enhancement filters adjust on images parameters

Figure 4 ROC curves of the means of the observers' assessment for simulated periapical lesion groups and VistaScan filters. ROC, receiver operating characteristic.

removing partial or totally undesirable information by post-processing electronic signs. High-pass filters accentuate transitions in density levels after the operation of mathematical algorithms in pixels' grey level, making edges more distinct, even though they may introduce more noise.²⁵ Fine, Caries1, Caries2, Endo and Perio filters are examples of high-pass filters. On the other hand, low-pass filters, like the Noise Reduction, approach by correcting scatter and resulting in images with a more uniform pixel intensities scale.²⁶

The enhancement filters of VistaScan system work manipulating not only image contrast, but also sharpness and noise. However, we did not find influences of these filters in the diagnostic accuracy of simulated periapical lesions, which may imply that diagnostic accuracy of periapical lesions is influenced by many factors, such

as scanned object, human jaw specimens⁵⁻⁸ or patients;^{3,4} methods of inducing artificial periapical lesions, chemically^{5,6} or by burs,^{7,8} besides inflammatory origin;^{3,4,14} in addition to lesion location and sample size. In our model, the simulated periapical bone defect was relatively large and easy to be detected, the observers are oral radiologists who are more experienced than other observers such as endodontists and general dentists; also a larger sample than the one used in the present study could demonstrate some differences that were not found here. On the other hand, when we tested all lesion sizes as only one test group, we also found that the filters of VistaScan did not interfere the diagnostic task evaluated here, which proved the sample size had little influence on the results.

Figure 5 Comparison of mean SD grey level between non-filtered and each enhancement filter. (a). Air region. (b) Bone region. (*) means $p < 0.05$ and (**) means ($p < 0.01$) according to one-way ANOVA and Tukey's test. ANOVA, analysis of variance; SD, standard deviation.

Figure 6 Post-processed images using VistaScan filters and nonfiltered image of Group 3. Nonfiltered (A) Fine (B); Caries 1 (C) Caries 2 (D) Endodontics (E). Periodontal (F) Noise Reduction (G) Result of differences produced in individual pixel intensities between non-filtered and filtered images for each filter: [Non-filtered—Fine] (h) [Non-filtered—Caries 1] (I) [Non-filtered—Caries 2] (j) [Non-filtered—Endodontic] (k) [Non-filtered—Periodontal] (l) and [Non-filtered—Noise reduction] (m).

Concerning lesions size, we found that with the increase in the lesions diameter, the mean values of the area under the ROC curve increased too, so it was easier to diagnose larger periapical lesions than smaller ones, which is in agreement with the findings of other authors.²⁷ Nevertheless, Stavropoulos²⁸ evaluating lesions of 1 and 2 mm found no statistical difference between sizes, also other authors found a great accuracy only when cortical plate is involved⁷ or periapical lesions are confined to cortical plate.⁸ We believe most of these discrepancies in results among studies are related to differences in the models used to create periapical bone defects, digital periapical radiography systems used and observer's experience.

Our results showed that none of the six VistaScan system filters improved the diagnostic accuracy of simulated periapical lesions. Kullendorff & Nilsson¹² also showed that more complicated post-processing tools had low effectivity on the detection of periapical lesions. De Azevedo Vaz *et al.*¹³ assessed the measurement accuracy of simulated peri-implant bone level in

regions including bone and implant in air background, while Haiter-Neto *et al.*²⁴ assessed diagnostic accuracy of detection of proximal caries lesions, considering enamel and dentin in a black background. Both studies found that some filters were better than others (in the first, fine and noise filters had better performance than caries 1, caries 2, endodontic and periodontal filters, whereas in the second study fine filter was better than caries 1 and caries 2 filters), although none of the filters were better than nonfiltered images. Unlike, the present study found similar accuracy values comparing nonfiltered and filtered images, assessing periapical region involving only trabecular bone and dentin, which have quite similar densities. Therefore, we can infer that the diagnostic accuracy using some filters is higher when structures of different physical densities are investigated. Other reason might be the lower contrast between edges of bone lesion and healthy bone around than that present between structures and the darker background inherent to the evaluation of caries and peri-implant bone defect. In contrast to results of these studies,^{13,24}

Yalcinkaya *et al*¹¹ investigating image quality for specific anatomic structures, reported that observers scored nonfiltered and noise filter images lowest than caries 1, caries 2, endodontic and periodontal filters images, preferring then images with a slightly reduced level of brightness and increased contrast. This reinforces the idea that the effect of image treatment seems to be task dependent and the importance of studies that test different diagnostic tasks.

Moreover, we assume that the research model used in this study is the main reason to explain why our results are a little higher than those found in previous concerning the diagnostic accuracy values and inter- and intraobserver agreement.^{1,7,8,28} Also, the smaller spaces in cancellous bone of bovine ribs might explain why subtle changes in periapical defect sizes were more easily observed. In addition, the specificity was significantly higher than the sensitivity, as in other studies.^{17,29–31} If this result can be transferred to the clinical situation, the consequence seems to be a lower risk for a false-positive outcome. Then, when present, the lesion might be diagnosed in future periapical exams.

Besides the clinical aspects of these findings, it is also important to technically evaluate the changes that occur in the images by using these enhancements filters. Standard deviation of pixel intensities is a method proposed to measure noise in images of similar densities,³² and was used to evaluate the noise changes in air and bone regions. The Noise reduction and Fine filters effectively removed the noise in air region by reducing abrupt changes where applicable,³³ while the other filters increased these differences to intensify the contrast. Contrarily, except Fine, all other filters increased noise, in bone region, even Noise reduction filter, which is inconsistent with the general knowledge that the Noise reduction filter works removing noise. We can see in Figure 6A,G,M the application of Noise reduction, that aim to make image more homogeneous, seems to add some blurring and increase the overall contrast, which raised its related diagnostic value, but technically raised the standard deviation of pixel intensities.

There are some limitations to an *in vitro* study in which only images are evaluated without considering clinical parameters such as pulp vitality, history of trauma and pain, which can help in the diagnosis of periapical lesions, besides the difficulty in the reliable

representation of the lamina dura due to using of a non-human teeth and bone, however the sockets were produced for excellent adaptation of the root. However, *in vitro* analysis was the only way to perform this kind of study as repeated radiograph acquisitions were required, which is not possible in patients due to irradiation exposure. Additionally, using this model may present some advantages because it was possible to avoid using thin bone regions, as anterior mandibular area, where periapical region has a close association with cortical bone, in what even a minimal periapical bone loss might involve the bony cortex which can influence the detection of periapical lesions; and also to avoid overlapping of the periapical region by anatomical structures as the oblique line or mental foramen. Moreover, anatomical features immediately adjacent to the area of interest may result in poor contrast and, therefore, increased difficulty in assessing the periapical tissues; as our main aim was to compare the diagnostic accuracy between nonfiltered and filtered images, this noise created by anatomical structures was avoided. Therefore, it was possible to evaluate the actual influence of applying filters. Finally, a great number of image-processing algorithms have been developed to correct the effect of the exponential attenuation.⁹ Image-processing algorithms that work with different mathematical models could result in findings different from those found in the present study. Then, further studies using other intra-oral digital systems are necessary.

Conclusion

Using VistaScan enhancement filters do not influence the diagnostic accuracy of simulated periapical lesions. Besides, an increase in the dimension of the lesions provides a higher diagnosis rate, since simulated periapical lesions of 2.1 mm were more frequently detected. The filters change the pixel intensities of the images, reducing or intensifying the differences between similar regions.

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