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Enhancement cone beam computed tomography filters improve in vitro periimplant dehiscence detection

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Objective. To investigate whether cone beam computed tomography filters would improve periimplant dehiscence detection.
Study design. A hundred titanium implants were placed in bovine ribs in which defects simulating periimplant dehiscence had previously been created. After images acquisition, three oral radiologists assessed them with and without the following filters: Angio Sharpen high 5 × 5, Shadow, Sharpen 3 × 3, Sharpen Mild, and Smooth. The McNemar test verified the disagreement between all images versus the reference standard and original images versus images with filters; $P < .05$ was considered statistically significant.
Results. Dehiscence detection using the original images and the Shadow filter disagreed from the reference standard ($P < .05$), as well as when using the filters instead of the original images ($P < .05$).
Conclusion. All the filters tested, with the exception of the Shadow, improved periimplant dehiscence detection. The Sharpen 3 × 3 filter was considered best for this task. (Oral Surg Oral Med Oral Pathol Oral Radiol 2013;116:633-639)

Bony coverage of at least 1 mm around an implant is included in criteria to guarantee the success of dental implant treatment.[1] The distance from the alveolar bone level to the implant neck is another parameter used. The absence of bone initiating from the cervical portion of the implant characterizes a dehiscence defect. Insufficient bone thickness and inadequate implant placement may lead to periimplant dehiscence. In such cases, aesthetics and hygiene are compromised.[1] An early diagnosis of periimplant dehiscence is vitally important as it can lead to gingival recession, bone and implant loss.[2]

In general, periimplant dehiscence is not detected by bidimensional radiographs because it develops in the vestibular or lingual plates.[3] On the other hand, cone beam computed tomography (CBCT) provides tridimensional images of the cortical bone near a dental implant. However, artifacts caused by metals make the diagnosis difficult and time-consuming, since they reduce contrast and obscure structures, thereby impairing the visualization of regions of interest.[4] The literature has stated that the postoperative assessment of dental implants is compromised by artifacts induced by titanium, produced by the beam-hardening effect.[3,4] According to a previous study, CBCT was less accurate in the detection of simulated periimplant dehiscence than periimplant fenestration.[5]

Task-specific filters are tools of CBCT or digital radiography software designed to enhance images, by mathematically reducing or increasing specific characteristics.[6] There is some controversy as to whether the use of enhancement filters in digital radiography can improve the diagnosis of caries lesions.[6-14] It has been shown that the diagnostic accuracy of root fractures and periodontal assessment does not change with the application of filters,[15-19] while filters are statistically better for periimplant bone measurement.[20,21]

On the other hand, some studies have shown that CBCT filters exert little influence on the diagnosis of external root resorption,[22] while they are significant for the diagnosis of root fractures.[15] Against this background, the aim of this study was to investigate whether CBCT filters would improve the diagnosis of periimplant dehiscence. The variables in the study were the presence or absence of dehiscence and the factors enhancement filters.

MATERIALS AND METHODS

This study design was approved by the local Research Ethics Committee at the Piracicaba Dental

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Statement of Clinical Relevance

The use of enhancement CBCT filters provides a better assessment of periimplant dehiscence. This defect may compromise the aesthetics and hygiene of implants, leading to treatment failure, and CBCT can avoid reentry surgeries.

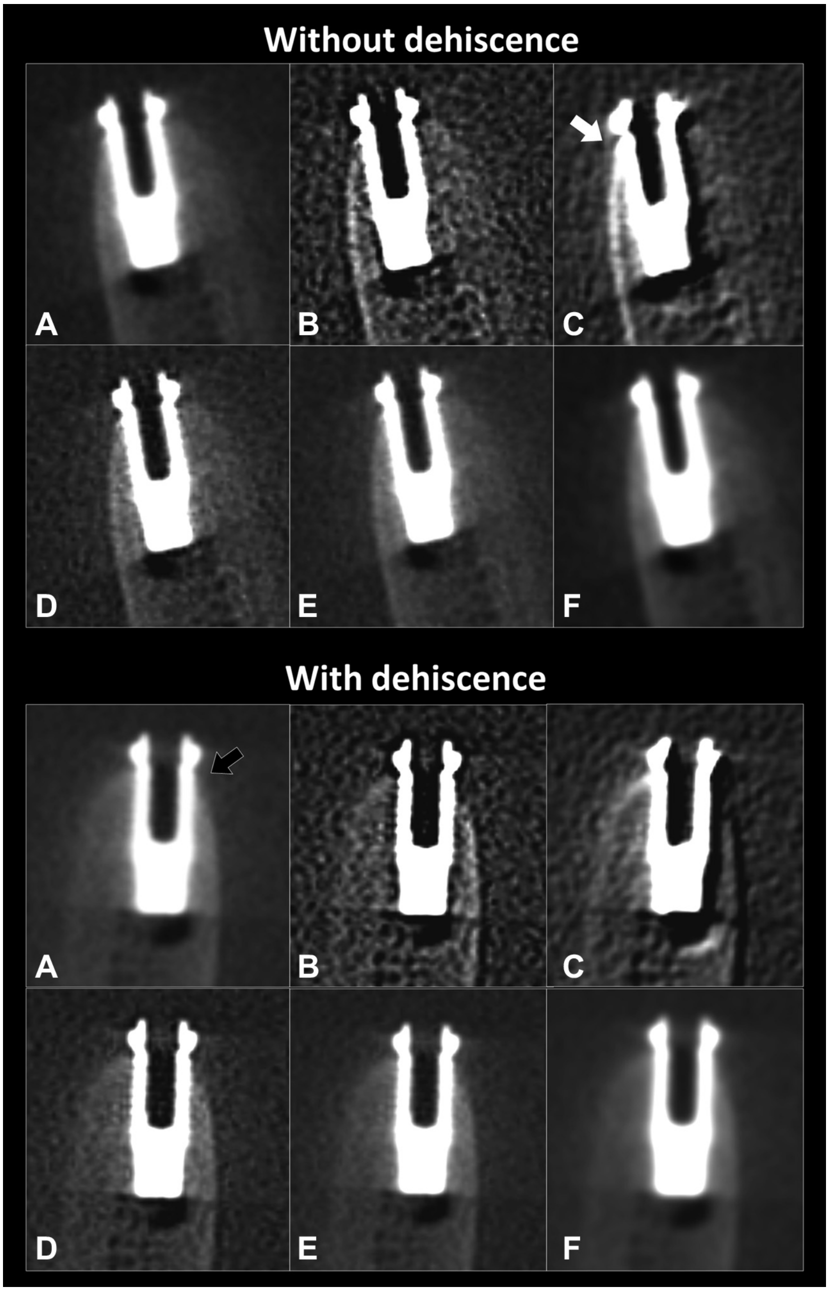

Fig. 1. Sagittal CBCT slices showing two implants with (black arrows) and without the simulated periimplant dehiscence: (**A**) no filter, (**B**) Angio Sharpen High 5 × 5, (**C**) Shadow, (**D**) Sharpen 3 × 3, (**E**) Sharpen Mild, (**F**) Smooth. The white arrow points a metal artifact enhanced by the Shadow filter, which makes it difficult to visualize the bone.

School – University of Campinas. An operator introduced defects to simulate dehiscence in sixteen fragments of fresh bovine ribs, using a standard preparation machine[23] and a spherical burr. These defects were 2.5 mm in diameter, with a half-elliptical form and were randomly distributed in the implant sites. Bovine ribs were used to simulate the alveolar bone tomographic aspect, as they had already been used in a previous study.[24]

The dehiscence defects were created on the edge of the bovine rib, which would correspond to the cervical portion of the implant to be placed. When all the defects had been introduced, an oral surgeon with experience in implant dentistry placed a hundred 3.75 × 11 mm titanium implants (Titamax, Neodent, Curitiba, PR, Brazil) in the bovine ribs. Most of the ribs received six implants separated from each other in 10 mm, but four ribs had seven implants with the same spacing. There was only one defect per implant. A reference standard was obtained through the macroscopic analysis of the ribs.

The ribs with the implants were then placed in a container with water to simulate soft tissue attenuation. Image acquisition was performed using a CBCT unit (Next Generation i-Cat, Imaging Sciences International Inc., Hatfield, PA, USA) operating at 120 kVp, 5 mA, scanning time of 26.9 s, field of view of 8 × 8 cm, voxel size 0.2 mm, full-scan (360°). The final sample comprised 100 sites for the evaluation of dehiscence (50 with defects and 50 without, randomly distributed).

Under dim lighting conditions, images were individually assessed by three previously calibrated oral radiologists on a 17″ LCD monitor (resolution 1280 × 1024, 32-bit). The oral radiologists had to have at least 3 years' experience in CBCT in order to participate in the study. The evaluations were performed using sagittal slices with thickness determined by the voxel size, i.e., 0.2 mm. All images were first analyzed without filter application (original images). Then, images were assessed using the following filters of the XoranCat software version 3.0.34 (Xoran Technologies, Ann Arbor, MI, USA), one at a time: Angio Sharpen High 5 × 5, Shadow, Sharpen 3 × 3, Sharpen Mild, and Smooth (Figure 1). It was decided to use these particular filters as they were considered the most representative among the ones available in the software. The oral radiologists could also use the zoom tool and adjust brightness and contrast of the images, if necessary.

The presence or otherwise of periimplant dehiscence was used as response variables. Twenty percent of the images were re-evaluated after 30 days. Inter and intraobserver agreements were calculated using the κ test (poor, 0.40; moderate, 0.40-0.59; good, 0.60-0.74; excellent agreement 0.75-1.00).

Sensitivity (correctly identifying the presence of dehiscence), specificity (correctly identifying the absence of dehiscence), accuracy (proportion of correctness), positive predictive value (probability of true-positive result occurring) and negative predictive value (probability of true-negative result occurring) were calculated for each filter. The McNemar test was used to examine the disagreement between all images versus the reference standard and the original images versus images with filters. The null hypothesis considered there was no disagreement; $P < .05$ was considered statistically significant.

RESULTS

The mean of intra and interobserver agreements ranged from moderate to good. κ values per filter are specified in Table I.

Sensitivity, specificity, accuracy, positive and negative predictive values are all shown in Table II. The highest sensitivity (0.80) was obtained for the Shadow filter. Specificity (0.84) and PPV (0.76) were highest for the original images. Accuracy (0.74) and NPV (0.73) were highest for the Sharpen 3 × 3 filter.

Table I. Means of intra and interobserver κ values per filter

Filter	*Intraobserver (SD)*	*Interobserver (SD)*
Original images	0.42 (0.06)	0.64 (0.08)
Angio Sharpen high 5 × 5	0.58 (0.09)	0.54 (0.02)
Shadow	0.44 (0.01)	0.43 (0.01)
Sharpen 3 × 3	0.70 (0.09)	0.72 (0.02)
Sharpen Mild	0.70 (0.04)	0.63 (0.01)
Smooth	0.62 (0.09)	0.42 (0.01)

SD, standard deviation.

The results of the McNemar test are presented in Table II. The null hypothesis of no disagreement was rejected on comparing the original images and the Shadow filter versus the reference standard ($P < .05$). It was also rejected on comparing all the filters used versus the original images ($P < .05$).

DISCUSSION

Periimplant dehiscence can result in esthetic impairment and/or treatment failure.[2] This mainly occurs when dental implants are placed in the anterior region, where the facial bone is thin.[25] When periimplant dehiscence is detected during surgery, guided bone regeneration (GBR) procedures to apply synthetic membranes have been used in order to generate bone over the exposed implant surface.[26] However, some authors have reported the regeneration of bone in acute-type dehiscence defects without the use of GBR techniques.[27,28] CBCT can be useful in determining whether dehiscence is present or otherwise. It can then be adequately treated or monitored, where necessary.

Periapical radiographs are normally used in postoperative evaluations of dental implants because they are more accurate when determining if osseointegration has occurred and whether or not there are periimplant radioluscences.[29] However, when periimplant dehiscence is suspected, CBCT is the preferred imaging method since it allows for a complete evaluation of the cortical plates around the implant. Therefore reentry procedures − which are more invasive − can be avoided.[30] It has already been shown that CBCT can precisely determine cortical bone thickness near dental implants, especially when a higher voxel resolution is used.[24] Furthermore, other studies have demonstrated that CBCT can also determine cortical thickness in a dentate alveolar bone, although the presence of fenestration or dehiscence defects could be overestimated.[31-33] Mengel et al.[2,34] have shown that CBCT provided high accuracy for measurements of periodontal and periimplant defects, with image quality superior to that of either computed tomography (CT),

Table II. Diagnostic and McNemar's tests according to different filters

Filter	*Sensitivity*	*Specificity*	*Accuracy*	*PPV*	*NPV*	*P value**	*P value†*
Original	0.52	0.84	0.68	0.76	0.63	.008	−
Angio Sharpen High 5 × 5	0.76	0.58	0.67	0.64	0.70	.164	<.001
Shadow	0.80	0.46	0.63	0.59	0.69	.009	<.001
Sharpen 3 × 3	0.72	0.76	0.74	0.75	0.73	.845	.018
Sharpen Mild	0.74	0.68	0.71	0.69	0.72	.71	.002
Smooth	0.70	0.70	0.70	0.70	0.70	.855	.008

PPV, positive predictive value; *NPV*, negative predictive value.
**P* value of images versus reference standard.
†*P* value of image filters versus original images.

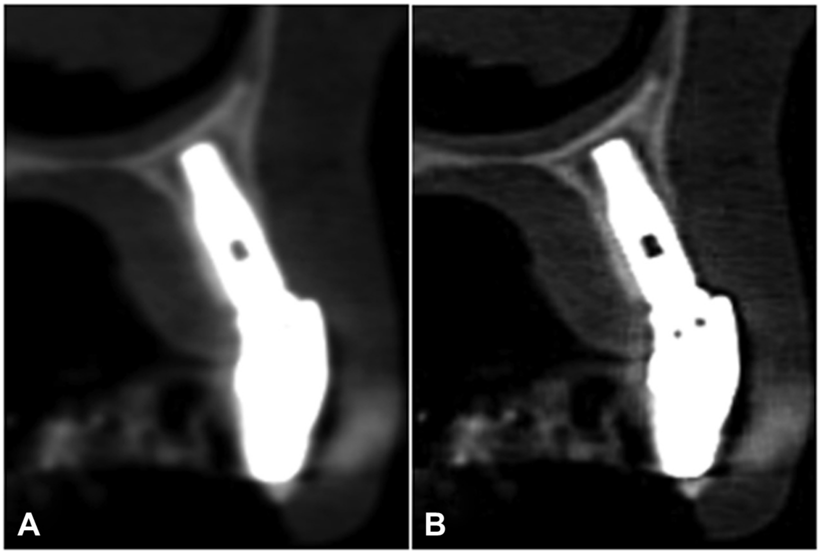

Fig. 2. Sagittal CBCT slice of images acquired from a patient demonstrating the usefulness of the sharpen 3 × 3 filter (**B**), which enhanced the visualization of the cortical bone, implant surface and a periimplant dehiscence defect. The same slice in its original form is also presented (**A**).

periapical or panoramic radiographs. Meanwhile, the literature has pointed that the postoperative evaluation of dental implants is compromised due to the artifacts produced by the beam-hardening effect.[3,4,35] Data in the literature regarding the postoperative tomographic evaluation of dental implants is limited up to now. Much needs to be studied since the parameters of treatment success were determined based on two-dimensional images.

Metal artifacts produced by the beam-hardening effect occur specially in the presence of high-density metals, but also with light metals, such as titanium.[36] The implant acts as a filter for the X-ray photons by attenuation of those with larger wavelengths, leading to reading error in the detector and production of hypodense regions not related to the object under examination.[35,36] A recent in vitro study[5] showed that CBCT is less accurate when detecting periimplant dehiscence than when detecting periimplant fenestration. The diagnostic values found for both defects were considered clinically acceptable in the light of Blitcher et al.,[37] since the values for the sum of sensitivity plus specificity were above 1.20. However, other criteria proposed by Leung et al.[33] and Hausen[38] consider that this value should be at least 1.60, a level not reached in the study. Therefore, enhancement filters in CBCT images were used in the present study in order to increase such values.

Enhancement filters are used to manipulate an image in order to visually enhance aspects not apparent in its original form, and thereby make vital diagnostic information visible to the human eye.[20] There are various enhancement filters available for digital radiography and computed tomography. It is important to understand the workings of these algorithms and their particular properties when deciding whether filters should be used and in what situations.[39] Despite the fact that radiographic image enhancement results in a better version of the original image, the clinician must take into consideration the fact that the image characteristics of density, contrast and noise are altered depending on the filter chosen.[13]

Few studies have evaluated the influence of enhancement filters on CBCT diagnosis. Research has shown that CBCT filters exert little influence on the diagnosis of external root resorption,[22] where the Sharpen 3 × 3 filter performs better (but not statistically significant) and the Shadow filter statistically worse than the original images. Likewise, the Angio Sharpen High 5 × 5 filter was statistically better than the original images for root fractures,[15] but the Sharpen 3 × 3 filter presented no statistically significant difference.

The results of our study were similar to those of the above-mentioned studies, since the Sharpen 3 × 3 and the Angio Sharpen High 5 × 5 filters were statistically better than the original images, while the Shadow filter was statistically different from both the original images and the reference standard. However, the highest sum of sensitivity plus specificity (1.48) found when using the Sharpen 3 × 3 filter was again lower than the cut-off value proposed by Leung et al.[33] and Hausen[38] (1.60). Periimplant dehiscence detection in filtered CBCT images still proved to be difficult, but a significant improvement was observed.

The Sharpen 3 × 3 and Angio Sharpen High 5 × 5 are high-pass filters, which accentuate the transition in density levels and the limits of pixels by subdividing them into matrixes of 3 × 3 and 5 × 5, respectively.[15] They, therefore, provided sharpened images of the implants and bone surface and enhanced visualization of the dehiscence defects. The Shadow filter presented highest sensitivity (0.80) but also low specificity (0.46) and PPV (0.59), which indicate a high false-positive rate. These results could be explained by the pronounced high-pass characteristics of this filter, which introduced considerable noise to the images and enhanced the metal artifacts, thereby giving the false assumption that these areas corresponded to dehiscence defects (white arrow in Figure 1).

Images with application of the Sharpen Mild filter were also statistically better than the original images, with the second highest value for the sum of sensitivity plus specificity (1.42). It is also a high-pass filter, but with milder characteristics. Therefore, the favorable results obtained with the Sharpen Mild filter may be attributed to enhancement of the implant and bone surface, but with less noise than the other high-pass filters used.

All the diagnostic values of the Smooth filter were equal to 0.70, which indicate homogeneous behavior. Its sensitivity, accuracy and NPV were higher than those of the original images, and the McNemar test indicated a statistically significant difference from the original images. The sum of sensitivity plus specificity for the Smooth filter was the third highest value (1.40). It is a low-pass filter, which reduces image noise by putting pixel values closer to each other and smoothing the limits.[11] The reduction of metal artifacts by homogenization of the pixels may have contributed to better results for this filter. In fact, CT images are usually smoothed in the reconstruction process in order to reduce image noise. We believe that the use of the Smooth filter was beneficial in this way.

Furthermore, manufactures and researchers have proposed algorithms based on mathematical operations to reduce metal and scatter artifacts during CBCT image reconstruction.[4,40] The use of an algorithm for metal artifact reduction has recently shown better image quality.[4] We recommend studies evaluating the application of these algorithms for the purposes studied herein.

As this was an in vitro study, the results presented here may be slightly different in clinical practice, especially when one considers the differences between the bovine ribs used and a patient's head, where there are more structures in the path of the X-ray beam. However, we believe this experimental model provides a valuable estimation of the differences between filtered/unfiltered images for the purpose presented. This is demonstrated in a clinical image (Figure 2), where the application of the Sharpen 3 × 3 filter enhanced the visualization of the cortical bone, implant surface and a periimplant dehiscence defect. The successive application of a series of filters (e.g.,: Sharpen, Smooth, and Sharpen Mild) where one filter corrects the adverse effects of the previous one can be considered for future research. Also, filters of imaging processing software which are independent of the CBCT system were not tested to see if different results would be found.

CONCLUSION

The results indicated that when assessing periimplant dehiscence it is preferable to use the enhancement filters studied herein, with the exception of the Shadow filter, than not to do so. They provided a better assessment of periimplant dehiscence than the original images. Of the filters used, the Sharpen 3 × 3 yielded highest diagnostic values. The Shadow filter, however, should be avoided because of the high false-positive rate presented, caused by the enhancement of metal artifacts and the amount of noise introduced. Quantitative studies are suggested in order to clarify the usefulness of enhancement filters in metal artifacts reduction.

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