Application of a new CBCT software with specific filters for blooming artifact reduction: case series

Mike R **BUENO**[1,2]
Carlos **ESTRELA**[3]
Bruno C **AZEVEDO**[4]
Anibal **DIOGENES**[5]

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ABSTRACT

Introduction: Root canal fillings and intraradicular posts often create white contrast artifacts and possible volumetric changes on CBCT scans known as blooming artifacts. These alterations could lead to the incorrect interpretations reducing the diagnostic of an acquired CBCT volume, particularly when evaluating potential root fractures and root perforations. **Methods and Results:** In six clinical cases, the positive and negative effects of beam hardening artifacts on the diagnosis of root fractures, root perforations and porcelain restoration cementation were evaluated. These artifacts, induced by the higher density of root canal filling materials, cements for crown placement and intracanal posts, may potentially lead to inaccurate or false interpretations. A novel software, e-Vol DX, which has specific filters for blooming artifact reduction (BAR), was used to improve the diagnostic value of acquired CBCT volumes. **Conclusions:** The use of the e-Vol DX software package for the reconstruction of CBCT scans improved visualization of anatomical structures and reduced blooming artifacts. Improved data visualization may help reveal essential details that, in conjunction with clinical findings, are useful to achieve a correct diagnosis.

Keywords: Artifacts. Cone-beam computed tomography. Diagnosis. Root canal treatment. Software.

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[1] Professor of Radiology, Departamento de Radiologia, Faculdade de Odontologia São Leopoldo Mandic (Campinas/SP, Brazil).

[2] CROIF - Odontologia Diagnóstica (Cuiabá/MT, Brazil).

[3] Professor of Endodontics, Departamento de Estomatologia, Universidade Federal de Goiás (Goiânia/GO, Brazil).

[4] Assistant Professor of Oral Radiology, School of Dentistry, University of Louisville (Louisville/KY, USA).

[5] Professor of Endodontics, Department of Endodontics, University of Texas at San Antonio, (San Antonio/TX, USA).

»All authors participated in the development of the initial study involving this new software.

Patients displayed in this article previously approved the use of their facial and intraoral photographs.

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Contact address: Mike Reis Bueno
E-mail: mike@croif.com.br

Introduction

The dramatic advances of contemporary Endodontics have greatly facilitated the management of clinical procedures and improved the rates of survival of endodontically treated tooth. One of these developments was the incorporation of cone-beam computer tomography (CBCT) as an imaging diagnostic tool.[1-3]

Decision-making in Endodontics involves the correct interpretation and diagnosis of 2D and 3D imaging of maxillofacial structures. Complex clinical cases require specialized knowledge and accurate interpretation of 2D and 3D images. Correct acquisition, data correction and imaging navigation will lead to improved interpretation of the patient's anatomy, which are essential for the success of a root canal treatment.[3]

One of the critical problems in decision-making when evaluating a CBCT scans arises when higher density materials such as metal are present within the region of interest, and may induce imaging artifacts on the 3D scans. Imaging of structures with high degree of density variation could reduce of definition of the reconstructed image and present challenging artifacts and volumetric distortions, degrading the overall quality of CBCT scans, potentially leading to misdiagnosis.[4-7] The misinterpretation of an image, often due to changes on CBCT images, may be a serious problem resulting in operative errors.[8,9]

There are many different types of 3D imaging artifacts such as noise, beam hardening, double cortication, and the most frequent ones are associated with the intensity of the x-ray beam, patient motion, sensor calibration. High density objects may appear as cupping, streaks, dark bands, flare artifacts, or white contrast artifacts.[4-7] Barrett and Keat,[5] in a study about beam hardening, explained that an X-ray beam polychromatic and is composed of individual photons with a range of energies. As the beam passes through an object, low energy photons are absorbed and only high-energy photons are now passing though, therefore making the energy beam "harder".

The materials used in root canal treatments have different densities, which may result in volumetric changes of root canal fillings when visualized on CBCT scans. These changes may induce white contrast artifacts and, therefore, lead to possible misinterpretations of real dentin remnants, which pose a potential risk of misdiagnosis.[10-14] In addition to studies to understand and minimize the problems caused by artifacts,[15-25] a new software has been developed to reduce artifacts associated with endodontic and restorative materials[24] in acquired CBCT scans.

A recent CBCT software package (e-Vol DX)[23] has been developed to limit the occurrence of white contrast artifacts associated with root canal filling material, such as gutta-percha points, endodontic sealers, cements for crown cementation and intracanal posts, and, thus, to improve predictability of diagnosis and decision-making in operative accidents, such as root fractures and root perforations. This case series demonstrate potential of this novel CBCT viewing software package (e-Vol DX) as a tool to reduce white contrast artifacts resulting in greater diagnostic and decision-making value.

Case 1

A 52-year-old woman was referred to a private oral and maxillo-facial radiology clinic (CROIF, Cuiabá, Brazil) for imaging studies because of discomfort in the region of the right maxillary central incisor. The clinical examination revealed no edema, sinus tract, or any other tissue abnormalities. Her medical history was negative for any comorbidities.

A CBCT study was indicated, and the volumes were acquired using a PreXion 3D scanner (Prexion 3d Inc., San Mateo, CA) using a standard protocol: thickness - 0.100 mm; dimensions - 1.170 mm x 1.570 mm x 1.925 mm; FOV - 56.00 mm; voxel - 0.108 mm; exposure time - 37s (16 bits); tube voltage: 90 kVp; and tube current: 4 mA. Scans were examined using proprietary software native to the scanner and using the novel software (e-Vol DX, CDT Software; Bauru, Brazil) operated on a PC workstation equipped with Intel i7-7700K processor, 4.20 Ghz (Intel Corp., Santa Clara, CA), NVIDIA GeForce GTX 1070 video card (NVIDIA Corporation, Santa Clara, CA), Dell P2719H monitor at a resolution of 1920X1080 pixels (Dell Technologies Inc., Texas, USA) and Windows 10 Pro (Microsoft Corp., Redmond, WA).

The original CBCT scans visualized with the proprietary software package of the scanner showed a large volume in the region of the root canal filling in tooth #11, induced by a white contrast artifact associated with a low-density area, as well as perforation of the buccal periapical cortical bone (Fig 1 A, C, E).

The volume was than exported as a multifile DICOM format and reconstructed using the novel CBCT software program (e-Vol DX, CDT Software; São José dos Campos, Brazil). The blooming artifact reduction (BAR) filter was applied, and significant improvement of the image quality was observed. The spaces between the gutta-percha points and the root canal walls were clearly showed, suggesting treatment failure as the leading potential case for this periapical finding. The masking of low-density areas within the endodontic filling material was a result of the white contrast artifact (Fig 1 B, D, F).

The diagnosis was apical periodontitis of tooth #11. Nonsurgical root canal retreatment, as well as subsequent follow-up, was suggested to control the endodontic infection and symptoms. The use of the

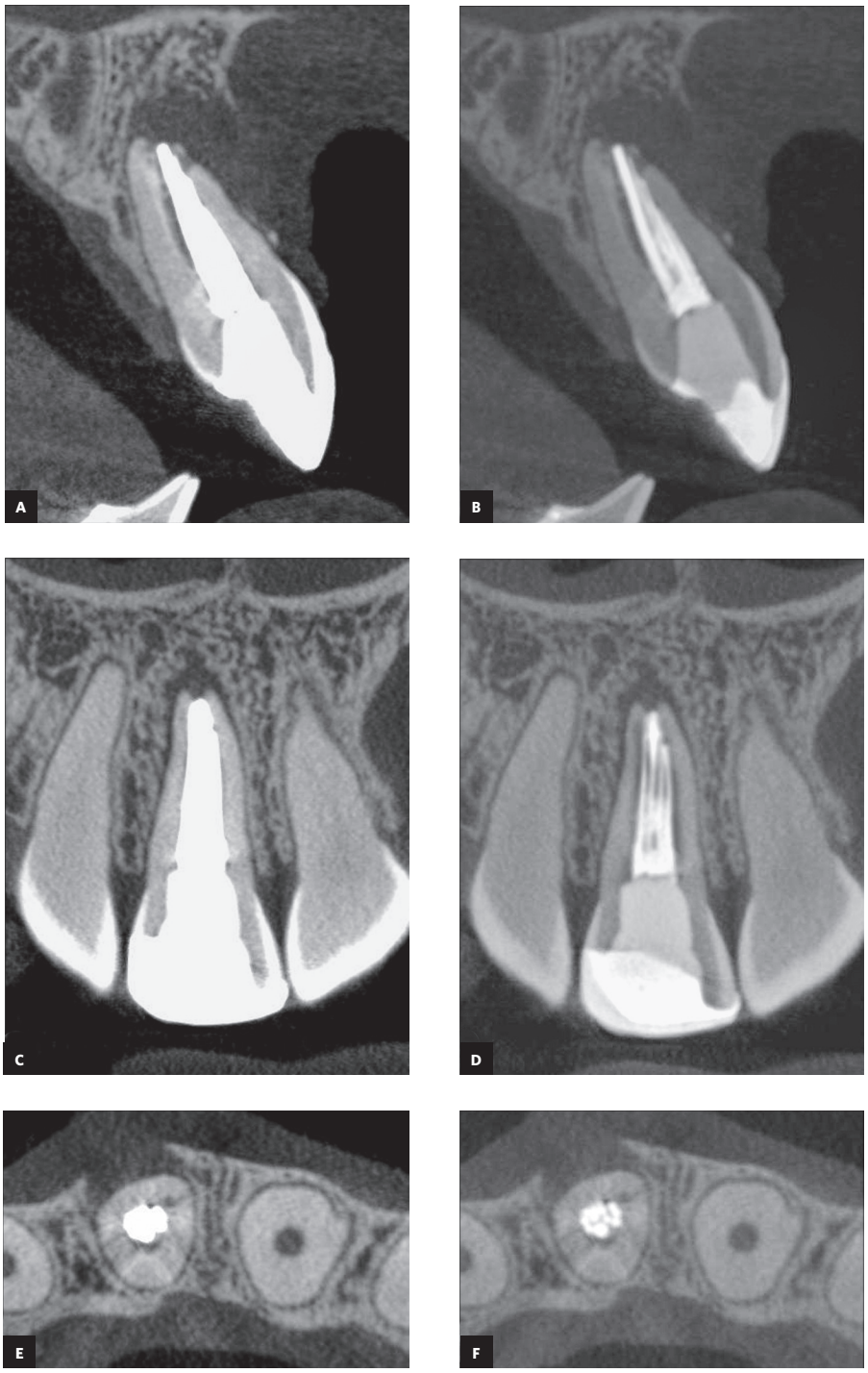

Figure 1. The original CBCT scans (**A, C, E**) shows white contrast artifact in tooth #11, which make it difficult to verified the failed root canal treatment; (**B, D, F**) After use the BAR filter a improvement of the image quality was observed. The spaces between the gutta-percha points and the root canal walls were clearly revealed.

e-Vol DX software and its advanced artifact reducing filters aided in assessing the quality of the previous endodontic treatment and in the decision making between retreatment and endodontic microsurgery. In this case, orthograde retreatment was elected since the quality of the previous endodontic treatment could be improved upon. Nonetheless, adequate follow up was scheduled and endodontic microsurgery will be elected if symptoms or radiolucency persists following adequate orthograde retreatment.

Case 2

A 46-year-old woman was referred to a private oral and maxillo-facial radiology clinic (CROIF, Cuiabá, Brazil) for imaging studies because of pain in the left maxillary central incisor during mastication. The clinical examination revealed no mobility or sinus tract around the tooth. Palpation of buccal and lingual structures in this site revealed mild edema and redness of the gingiva. Her medical history was negative for any comorbidities.

Because of the complexity of this clinical case, CBCT scans were acquired using a Prexion 3D scanner (Prexion 3d Inc., San Mateo, CA) using the standard protocol described in case 1.

The original CBCT scans, visualized using the scanner's proprietary software of the region of tooth #21 showed a large volume that corresponded to the intracanal post in the middle and coronal thirds of the tooth. CBCT images revealed a white contrast artifact, what appeared to be complete absence of dental structure and a hypodense buccal area (Fig. 2A, C, E).

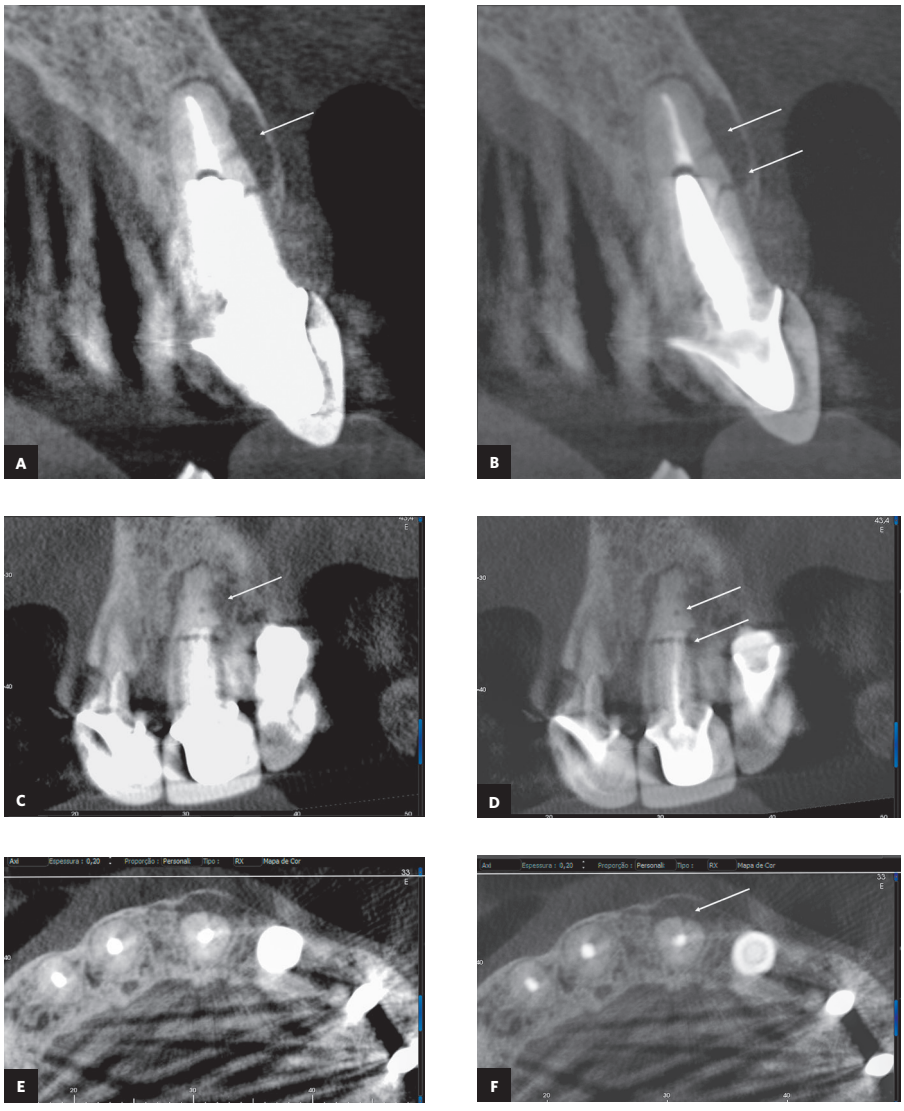

Figure 2. The original CBCT scans (**A, C, E**) shows white contrast artifact in tooth #21 with a large dimensional volume of intracanal post occupying the middle and coronal thirds and complete absence of dental structure; (**B, D, F**) The BAR filter was applied to reduce white contrast artifact making it possible to clearly see a fracture line associated with the intraradicular post. Additional navigation on CBCT scans revealed a low-density line suggestive of a lateral canal associated with the buccal low-density lesion superior to the fracture line.

The original volume was exported as a multifile DICOM format and reconstructed with the CBCT e-Vol DX software. The BAR filter was applied to reduce white contrast artifact caused by the high-density material within the canal making it possible to clearly see a fracture line associated with the intraradicular post. There were sharp limits between the post and the remaining dental structure (the line projected in Figures 2C and 2D could be of artifact that commonly occurs near the post apex, as in Figure 2A). Further navigation of the CBCT scans revealed a low-density line suggestive of a lateral canal associated with the buccal low-density lesion superior to the fracture line (Fig 2 B, D, F).

The diagnosis was buccal root fracture associated with intraradicular post in the middle third, as well as active apical periodontitis of tooth #21. The recommended treatment was tooth extraction and placement of a dental implant to restore the aesthetic and masticatory functions.

Case 3

A 63-year-old woman was referred to a private oral and maxillo-facial radiology clinic (CROIF, Cuiabá, Brazil) for imaging studies of tooth #21 due to the suspected root fracture. CBCT scans were acquired using a Prexion 3D scanner (Prexion 3d Inc., San Mateo, CA) (Fig 3A) and the standard protocol described above, which is routinely used in the clinical radiology center where this study was conducted. The tooth was endodontically treated and had a large intraradicular post slightly displaced palatally. White contrast artifact made it difficult to rule out presence or absence of a root fracture accurately. Clinical examination revealed no mobility, edema or sinus tract around the tooth. Palpation of buccal and lingual structures in this site revealed no abnormalities. Patient's medical history was negative for comorbidities.

The original DICOM file of the volume was opened and artifact filters applied using the e-Vol DX software (Fig 3B) to remove the metal artifact around the intraradicular post in the palatal and buccal regions. The sharp demarcations between the post and the remaining dental structure became clear, and PDL spaces were within normal limits. Although the root canal was not completely filled, no imaging findings associated with a root fracture were observed. As result, endodontic retreatment was elected and the scheduled extraction of the tooth was cancelled. This proper artifact reduction by the e-Vol DX software was crucial in altering the treatment decision in this case.

Case 4

A 45-year-old woman was referred to a private oral and maxillo-facial radiology clinic (CROIF, Cuiabá, Brazil) for follow-up of the root canal treatment of tooth #46, performed more than 10 years before with suspected perforation of the distal canal during post space preparation and cementation. The clinical examination revealed no mobility, edema, or sinus tract. Results of palpation of the buccal and lingual structures in this site were normal. Her medical history was negative for comorbidities.

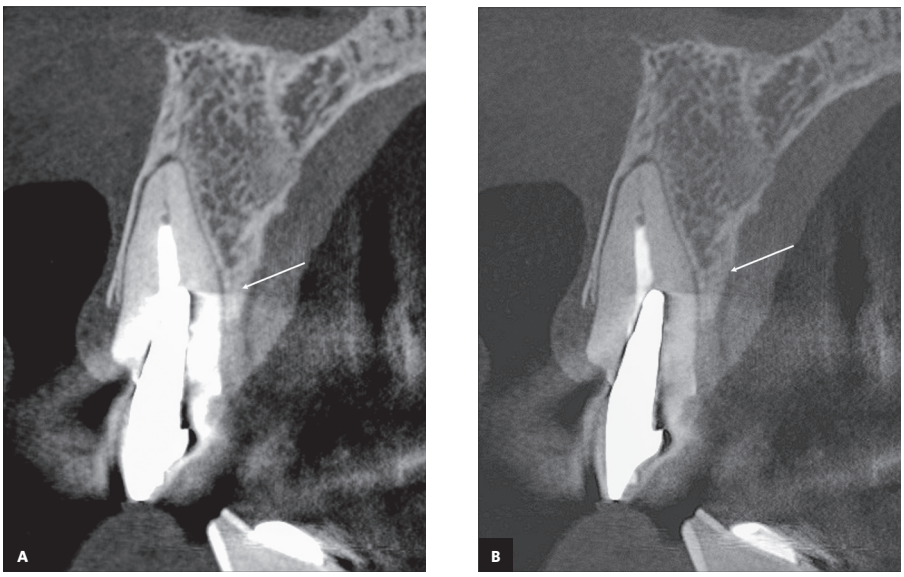

Figure 3. The CBCT scans (**A**) exhibit the tooth #21 with root canal treatment, and an extensive intraradicular post somewhat displaced to the palatal area, whose white contrast artifact made it difficult to rule out presence or absence of a root fracture accurately; (**B**) In the artifact filters applied using the e-Vol DX software, and it may be verified that although the root canal was not completely filled, no imaging findings associated with a root fracture were observed.

A CBCT study was indicated, and images were acquired using a Prexion 3D scanner (Prexion 3d Inc., San Mateo, CA) and the same protocol described in case 1. The original CBCT scans revealed that tooth #46 had a treated root canal and a metal restoration extending to the coronal aspect of the canal (Fig 4 A-E). A white contrast artifact made it impossible to determine the occurrence of root perforation associated with the intraradicular post (Fig 4B, D).

The original DICOM file of the image and the CBCT e-Vol DX software images were used to reduce the metal artifacts that were making image interpretation difficult, and root perforation at the furcation level was confirmed (Fig 4 C, E). After careful consideration and discussion with the patient, tooth extraction was elected followed by the placement of a dental implant for an implant-supported prosthesis. In this case, endodontic retreatment was not performed to clinically confirm the presence of the perforation. Both the endodontist and restorative dentist determined that the prognosis of an implant would be more favorable than endodontic retreatment with perforation repair. Thus, the use of the e-Vol DX software in the decision-making process was crucial in determining the course of treatment while facilitating the communication of the findings between the oral maxillofacial radiologist, endodontist and restorative dentist.

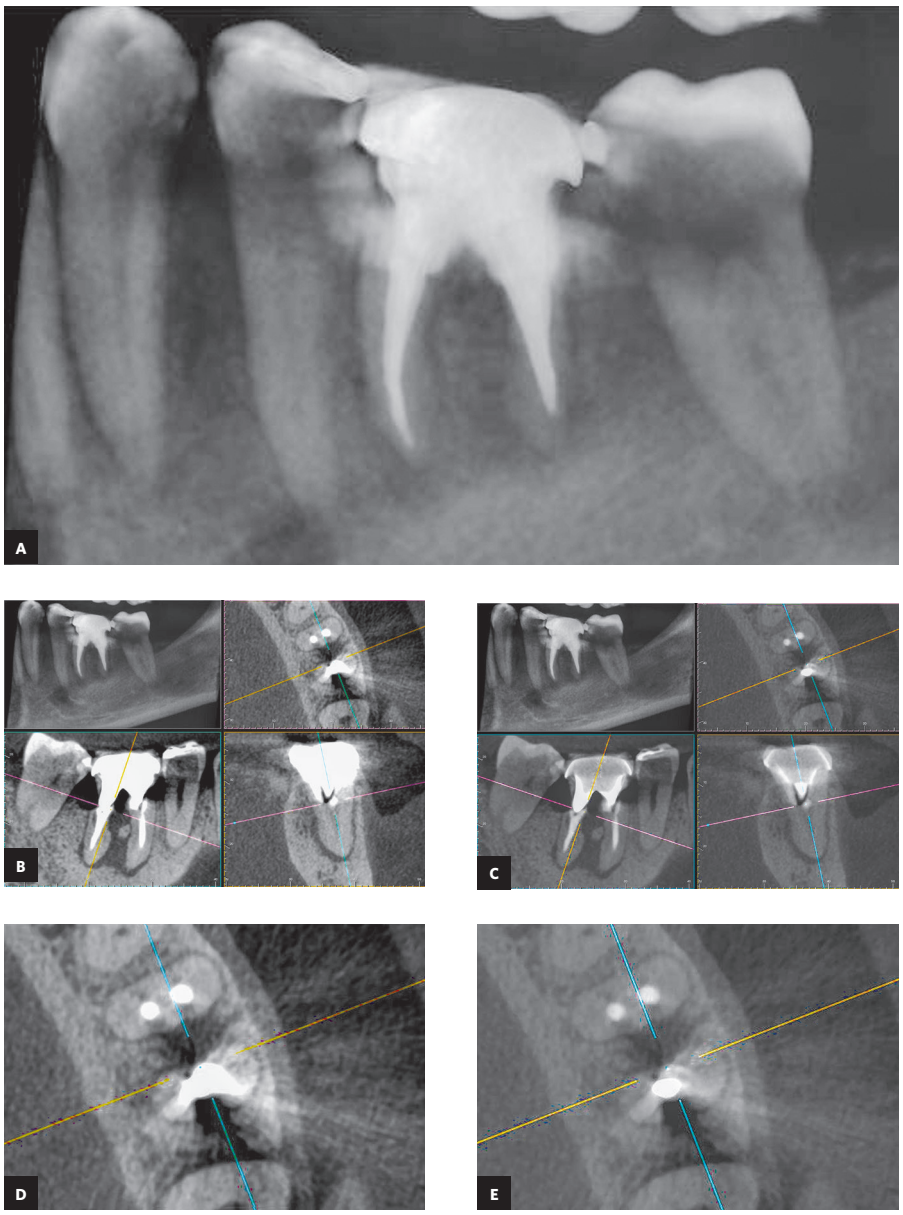

Figure 4. The original CBCT scans (**A**) revealed that tooth #46 had a treated root canal and a metal restoration extending to the coronal aspect of the canal. A white contrast artifact made it impossible to determine the occurrence of root perforation associated with the intraradicular post (**B, D**); the BAR filter was used to reduce the metal artifacts making it possible to confirm root perforation at the furcation level (**C, E**).

Cases 5, 6

Two clinical cases involving maxillary central incisors (Figs 5A-C, 6A-C) demonstrate the effect of removal of the white contrast artifact found in the region of the intraradicular post (Fig 5A, B) and the porcelain restoration (Fig 6B) on the analysis of the quality of the restoration. The use of the CBCT e-Vol DX software was determinant to confirm the cementation line between the dentin walls of the root canal and the post in case 5 (Fig 5 C) and the porcelain laminate veneers in case 6 (Fig 6C). In this case, the use of e-Vol DX allowed to verify the quality of both crown cementation or adaptation and post placement.

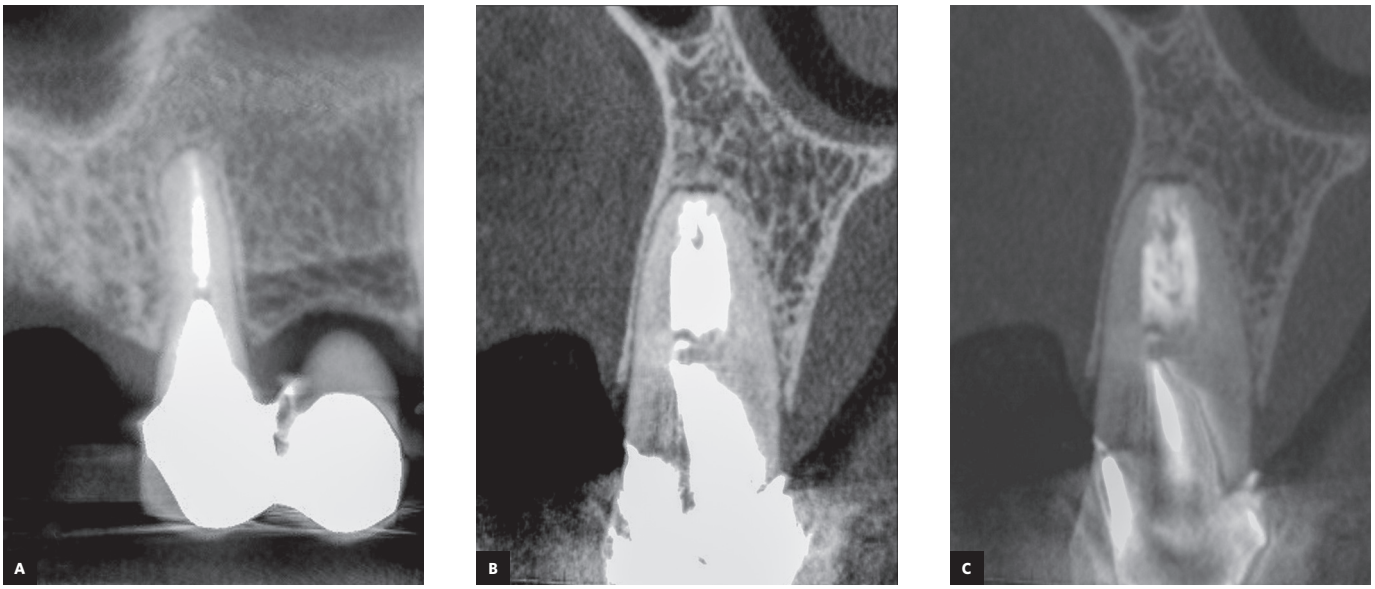

Figure 5. (**A, B**) CBCT scans show white contrast artifact in the intraradicular post in tooth #11, and its remotion after the use of the CBCT e-Vol DX software, characterizing the space between the post and the walls of the root canal (**C**).

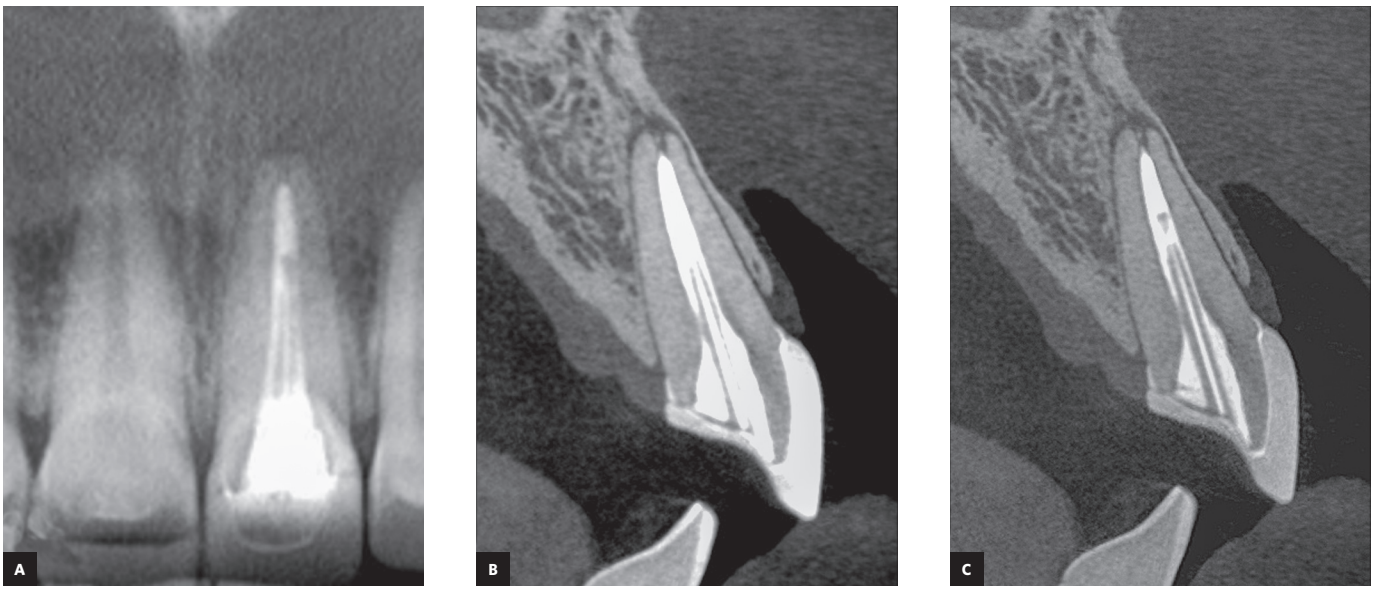

Figure 6. (**A, B**) In another maxillary central incisor, the use of BAR filter was determinant to verify the cementation line in porcelain laminate veneers (**C**).

Discussion

The advances of endodontic practice and research protocols due to the increase use of CBCT in recent years are undeniable and this technology has become an integral part of modern endodontics. New CT scanners (i.e. hardware) and software have also brought substantial improvements to imaging diagnosis and minimized the limitations of the first and second -generation devices.[15-25] Ideally, endodontic information about the scanned areas should be displayed in high resolution and free form artifacts to improve imaging diagnosis. The distortions induced by beam hardening, cupping artifacts, hypodense halos, streaks and volume overestimation may occur during the reconstruction of images of original objects.[7] Operative errors resulting of misinterpretations of CBCT scans may have negative impacts on planning, diagnosis and root canal treatment. Therefore, the acquisition, processing and display of 3D images should follow important phases to produce good quality images and prevent metal artifacts.[23]

The structures composed of higher-density materials in the maxillofacial complex pose major challenges for diagnosing and decision-making in Endodontics[8,11,12,23]. The recognition of a CBCT imaging artifact, and ideally its removal or reduction may prevent misdiagnosis in both simple and highly complex clinical cases. A diagnostic error may have a drastic impact on treatment results if an inadequate clinical protocol is selected.[3,8,23]

Several factors may affect image quality, such as: sensor size and type, voxel size, field of view, noise, dynamic image range, kilovoltage, milliamperage, acquisition time, scanner calibration, density of complex craniofacial structures, reconstruction algorithm, data correction tools such as sharpening, noise reduction filter, metal artifact reduction filter and DICOM format.[23]

Artifact reduction on CBCT volumes has been a major focus of previous studies, several of which developed techniques to avoid artifacts. Some of these tools are use different types of reconstruction algorithms.[15,16,18-21,25] Bechara et al.[15], in a study to determine whether a metal artifact reduction algorithm was effective and enhanced contrast-to-noise ratio, found that position changes significantly affected the contrast-to-noise ratio and the mean grey level of the control area. Barbosa et al.[19] reported that the application of an artifact reduction algorithm did not influence the diagnosis of root fractures, and its effects did not depend on root conditions, whereas gold posts reduced overall CBCT diagnostic ability, regardless of use of the artifact reduction algorithm. Queiroz et al.[20] found that the efficacy of a metal artifact reduction algorithm was similar for CBCT scans of dental materials obtained using different FOV and voxel sizes. Fox et al.[21] described a novel technique to characterize beam hardening (BH) artifacts on CBCT scans and found that filling materials with lower K-edge values reduced BH artifacts along the entire length of the root canal and limited the contribution of the dark artifact. Koç et al.[25] evaluated whether artifact reduction algorithms of different CBCT scanners affected the detection of endodontic complications, such as instrument fracture, strip perforation and under- or overfilled canals. They found no differences in complication detection between observers when using any of three with or without artifact reduction algorithms. Therefore, there is an unmet need to effectively reduce artifact to increase the diagnostic value of CBCT scans of teeth with radiopaque endodontic or restorative materials.

This need to reduce artifacts on CBCT volumes led to the development of a novel software program, named e-Vol DX, which has specific filters for blooming artifact reduction[23]. According to Bueno et al.[23], e-Vol DX has filters adjusted to the principles of the RAW format, which preserves the quality of the acquired image and potentially recovers underexposed or overexposed areas. These filters avoid loss of image quality and improve the saturation and brightness of specific areas, because the light areas of the image occupy a substantial amount of file space. These filters also prevent loss of image quality by using either white burst (streaks) or gray color, which is usually transformed into white color. Lastly, e-Vol DX has sophisticated image annotation capabilities that facilitate the description and emphasis of findings, facilitating the communication between oral maxillofacial radiologists, endodontists, restorative dentists and patients. Therefore, all stakeholders in the final treatment decision are able to obtain greater detail and diagnostic value in CBCT scans of complex cases that would be of little to no use otherwise.[23]

Conclusion

This case series demonstrate that the use of the e-Vol DX software for the reconstruction of CBCT volumes improved visualization of anatomical structures and reduced white contrast artifacts improving the decision making process. Better image navigation may reveal essential details that, in conjunction with clinical findings, are useful for a final diagnosis.

Acknowledgments

The authors participated in the development of the initial study involving this new software.

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