Are Optimised CBCT Protocols Suitable to Detect Simulated Vertical Root Fracture in the Presence of Metal Outside and/or Inside the Fov?

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Abstract

Dose optimisation has been revisited in the literature due to the high frequency of cone-beam CT (CBCT) scans and, the reduction of the field-of-view (FOV) size has shown to be an effective strategy. However, small FOV scans have negative influences of the truncation effect from the exomass.

The aim of this study was to evaluate the diagnostic accuracy of an optimised CBCT protocol for the detection of simulated vertical root fracture (VRF) in the presence of metallic artefacts from the exomass and/or endomass.

Twenty teeth were endodontically instrumented and VRF was induced in half of them. All teeth were individually placed in a human mandible, metallic materials were placed in the exomass and/or endomass, and CBCT scans were obtained at two dose protocols: standard and optimised. Three radiologists evaluated the images and indicated the presence of VRF using a 5-point scale. Sensitivity, specificity and area under the ROC curve (AUC) were obtained and compared using ANOVA ($\alpha=0.05$).

Overall, sensitivity, specificity and AUC did not differ significantly ($p>0.05$) between the dose protocols.

In conclusion, optimised protocols should be considered in the detection of simulated VRF irrespective of the occurrence of artefacts from metallic materials in the exomass and/or endomass.

Introduction

Optimisation is the process of making use of a resource as effectively as possible. When it comes to Radiology, radiation dose optimisation is a protection principle which assures that the X-ray dose delivered to the patient is as low as diagnostically acceptable being indication-oriented and patient specific (ALADAIP).[1–4] Recently, this concept has been revisited in the scientific community due to the increased application of computed tomography, which presents relatively higher X-ray dose than bidimensional techniques.[5]

Numerous factors affecting the radiation dose of a CBCT scan can also influence the final image quality such as the field-of-view (FOV) size, C-arm rotation degree, number of collected basis images, exposure time, tube current (milliamperage, mA) and tube voltage (kilovoltage, kV).[6–8] Technically, the reduction of these parameters decreases the X-radiation dose; however, the definition of an ideal optimised protocol is challenging because it must also balance the diagnostic task, individual risks of the patient, and inherent aspects of the CBCT unit.[4,5]

The reduction of the FOV size has shown to be an efficient strategy for radiation dose optimisation due to the reduction of the effective dose without compromising the image quality and diagnostic accuracy.[9–11] However, when small FOVs are used, all the surrounding structures outside of the FOV but still between the source of X-rays and the image receptor (so-called exomass) have shown to generate image artefacts,[12,13] which can be exacerbated in the presence of highly attenuating materials.[13,14] This is a frequent clinical condition in dentistry because of the wide use of high-density materials in oral rehabilitation, such as titanium implant, ceramic components, gutta-percha, and fiberglass and metallic posts. Interestingly, a recent previous study showed that the present of metallic materials in the exomass and/or endomass do not affect the diagnostic accuracy of vertical root fracture.[15]

CBCT artefacts have shown to decrease the diagnostic accuracy of vertical root fracture (VRF), which is an undesirable and frequent clinical situation defined as a longitudinally oriented interruption of the dental root from the apex to the coronal portion.[16] The recommended CBCT protocol when VRF is suspected includes a small FOV and, given the microscopic characteristics of this diagnostic task, the highest possible spatial resolution;[17–19] however, the latter is often correlated with higher X-ray dose[20] due to the need for higher energetic parameters, mainly to increase the contrast-to-noise ratio.

Positive and promising results of optimised CBCT protocols for endodontic purposes are being obtained by using half-scan mode[21–23] and relatively larger voxel sizes (0.30 mm) at decreased spatial resolution.[24] However, to the best of the authors' knowledge, there is no information in literature focusing on reducing energetic parameters (mA and kV) in the presence of metallic materials in the CBCT exomass for the diagnosis of VRF. Therefore, the aim of this study was to evaluate the diagnostic accuracy of an optimised CBCT protocol for the detection of simulated VRF in the presence of metallic artefacts from the exomass and/or endomass.

Materials And Methods

Ethical Aspects

All the following methods were carried out in accordance with the Declaration of Helsinki and this study was approved by the Research Ethics Committee of the Piracicaba Dental School of the University of Campinas, Brazil (CAAE: 98690918.9.0000.5418).

Custom-made exomass phantom

A partially edentulous dry human mandible, obtained from the dentomaxillofacial radiology department of Paris University, was covered with Mix-D, a validated soft tissue simulator of the absorption and scattering of the X-rays.[4] Twenty single-rooted human teeth were extracted for clinical reasons unrelated to the present study and collected after obtaining a written informed consent from all patients, which is in agreement with the Research Ethics Committee of the Piracicaba Dental School of the University of Campinas, Brazil. All teeth had the crown sectioned at the cement-enamel junction by a metallographic cutter (Isomet 1000; Buehler Ltd, Lake Bluff, IL) to avoid bias of memorization of the tooth during the evaluation. The resulting roots were endodontically instrumented (Wave-One primary file system, tip size 25, .07 taper, 25 mm, Dentsply Maillefer) using the reciprocating motion (X-Smart Plus, Dentsply Maillefer). VRF was induced in ten teeth, half of the sample, using the international testing machine Instron 4411 (Instron Corporation, Carton, MA) adjusted at 500 N and 1 mm per minute cross-speed.

Additionally, to assure the presence of root fracture, all teeth were scanned with the micro-CT unit Quantum FX (PerkinElmer, Waltham, US), adjusted to 160 mA, 90 kV, 2 minutes of scanning, a FOV size of 20 x 20 mm and a voxel size of 0.04 mm.

In order to simulate a frequent clinical condition without deterioration of the CBCT image arising from the intracanal material of the tooth of interest,[25] a fiberglass post (diameter, 1 mm; height, 10 mm; WhitePost DC, FGM, Joinville, Brazil) composed of fiberglass, epoxy resin, radiopaque compound, inorganic load, and polymerization promoters, was inserted into the root canals of all teeth, which were individually placed in the empty socket of the left second premolar of the human mandible. Finally, to simulate a wide range of dispositions of metallic materials in the oral cavity, titanium implants (diameter, 3.5 mm; height, 10 mm; KOPP, Curitiba, PR, Brazil) and cobalt-chromium intracanal posts (cobalt-chromium alloy, Talmax, Curitiba, PR, Brazil) were alternatively placed at four different locations in the exomass and inside of the FOV (endomass), as follows: I Exo – one metallic material in the exomass (in left third molar socket), II Exo – two metallic materials in the exomass (in the right canine and left third molar sockets), ExoEndo – one metallic material in the exomass (in the left third molar socket) and one metallic material in the endomass (in the left first premolar socket), and Endo – one metallic material in the endomass (in the left first premolar socket) (Fig. 1).

CBCT scans and X-ray dose protocols

For each of the twenty prepared teeth, the imaging phantom was scanned without any metallic material in the exomass (control) and with metallic materials, of different compositions, alternatively placed at the four dispositions previously described using the CBCT unit CS 9300 (Carestream, Rochester, NY, United States) adjusted to a FOV of 5 x 5 cm, voxel size of 0.09 mm, and two dose protocols: standard (100 mAs, 90 kVp, and a dose-area-product of 7.13 $mGycm^2$) and optimised (24 mAs, 70 kVp, and a dose-area-product of 0.86 $mGycm^2$) (Figs. 2 and 3). The standard protocol was based on the manufacturer's settings and the optimised protocol on the study of Oenning et al.[26] that showed considerable decrease of the effective dose with an acceptable image quality in the same CBCT unit used in this study. The resulting volumetric data were exported in DICOM format.

VRF analysis

All the CBCT volumes were assessed by three oral and maxillofacial radiologists with over 10 year of experience, blinded and previously calibrated, for the detection of VRF. The evaluators were calibrated and trained before the beginning of the assessment. They classified the presence of VRF using a scale of 5 points: 1, absolutely absent; 2, presumably absent; 3, uncertain; 4, presumably present; and 5, absolutely present. The assessment was done in a quiet and darkened room and, to avoid visual fatigue, a limit of 25 volumes per day and an interval of 24 h between sessions were respected. The evaluators were allowed to control brightness, contrast and zoom settings.

A revaluation of 25% of the CBCT volumes of each experimental group (with and without fracture, standard and optimised dose protocols and, with and without metallic materials at different dispositions and compositions) were performed after 30 days to analyse intra-observer confidence.

Statistical analysis

The SPSS software, version 25 (SPSS, Chicago, IL, USA) and GraphPad Prism 8.0 (GraphPad Software, LA Jolla, CA, USA) were used to perform all the analyses with a significance level of 5% ($\alpha = 0.05$). The area under the receiver operating characteristic curve (AUC), sensitivity, and specificity were calculated. ANOVA two-way with post-hoc Tukey test was used to compare the AUC, sensitivity, and specificity values between the dose protocols and the different dispositions and compositions of the metallic materials in the exomass and/or endomass. Weighted Kappa test was used to measure the intra- and interobserver agreements and the results were interpreted according to Landis & Koch[27] (0.00–0.20, poor; 0.21–0.40, reasonable; 0.41–0.60, moderate; 0.61–0.80, good; 0.81–1.00, excellent).

Results

In most of the dispositions of the metallic materials, the AUC (standard, 0.91–0.97; optimised, 0.81–0.94), sensitivity (standard, 0.87–0.97 optimised, 0.63–0.93), and specificity (standard, 0.77–0.97; optimised, 0.60–0.91) values did not differ significantly ($p > 0.05$) between the dose protocols, except when a titanium implant was in the endomass, in which the sensitivity was significantly higher ($p < 0.05$) for the standard dose protocol. When comparing the composition of the metallic materials, no significant difference was found for AUC ($p > 0.05$), sensitivity ($p > 0.05$) and specificity ($p > 0.05$) between titanium and cobalt-chromium. (Table 1).

Table 1
Mean values (standard deviation) of the area under the receiver operating characteristics curve (AUC), sensitivity, and specificity for different dose protocols, material dispositions and compositions. An asterisk indicates significantly lower sensitivity than the standard protocol for the same material and disposition.

	Dose protocol	Control	Material	Dispositions			
				I Exo	II Exo	ExoEndo	Endo
AUC	Standard	0.94 (0.04)	Ti	0.95 (0.03)	0.94 (0.04)	0.89 (0.12)	0.92 (0.07)
			CoCr	0.90 (0.08)	0.94 (0.01)	0.92 (0.07)	0.93 (0.04)
	Optimised	0.94(0.01)	Ti	0.94 (0.04)	0.93(0.03)	0.82(0.03)	0.83 (0.03)
			CoCr	0.84 (0.03)	0.81(0.03)	0.85 (0.09)	0.82 (0.07)
Sensitivity	Standard	0.88 (0.08)	Ti	0.91 (0.10)	0.88 (0.08)	0.91 (0.10)	0.95 (0.04)
			CoCr	0.85 (0.13)	0.88 (0.08)	0.88 (0.08)	0.88 (0.08)
	Optimised	0.87 (0.90)	Ti	0.93 (0.12)	0.83 (0.12)	0.77 (0.15)	0.63 (0.06)*
			CoCr	0.87 (0.15)	0.77(0.15)	0.73 (0.15)	0.70 (0.10)
Specificity	Standard	0.89 (0.08)	Ti	0.95 (0.04)	0.91 (0.04)	0.75 (0.30)	0.78 (0.18)
			CoCr	0.88 (0.08)	0.91 (0.04)	0.88 (0.08)	0.88 (0.08)
	Optimised	0.90 (0.10)	Ti	0.80 (0.26)	0.83(0.15)	0.60(0.36)	0.90 (0.10)
			CoCr	0.77 (0.15)	0.73 (0.21)	0.87(0.15)	0.83 (0.12)

Both the intraobserver (0.42–0.71) and interobserver (0.53–0.75) agreements ranged from moderate to good.

Discussion

Radiation dose reduction in diagnostic imaging is an appropriate precaution as long as the resulting image presents sufficient quality to be diagnostically acceptable; this is the concept from which the principle of optimisation in radiology is based upon.[5,26] In this respect, the present study proposed as a strategy for radiation optimisation for VRF evaluation, the reduction of mAs and kV. The results indicate that a substantial decrease of the dose-area-product in CBCT (8 fold less) is possible while maintaining the diagnostic accuracy in the presence of metal artefacts from the exomass and/or endomass.

The optimised scanning protocol used in this study was based on the study of Oenning et al. (2018)[26] that evaluated 6 different scanning protocols at a fixed FOV (8 x 8 cm) but varying kVp, mAs, number of basis images, and voxel size to the visualisation of anatomical features of peadiatric skulls. They selected this protocol, as the optimal one, based in the observers scores and exposure factors. To propose a higher reduction of radiation dose and increase the exomass, this study used a smaller FOV size (5 x 5 cm). It is important to highlight that the present study was based on the suggested optimal protocol only as we used the same CBCT unit. The use of literature-based optimised protocols should consider that the effective dose and the image quality can change between CBCT units.[6]

Some exposure settings, such as the mAs and kV, are normally pre-adjusted by the manufacturer that is supposed to have considered the diagnostic task, patient size and age when aiming for better image quality.[9] The mAs has a directly proportional linear relationship with the number of X-ray photons since it affects the number of electrons available in the cathode of the tube when X-rays are produced. Additionally, the kV is responsible for the voltage at which the electrons are subjected and, consequently, for the energy of the resulting X-ray photons, which affects the balance between photoelectric and Compton effects when interacting with the matter. Although higher mAs and kV values are positive for increasing the signal-to-noise ratio, the radiation dose is inevitably increased as well.[3,11,28] Pauwels et al.[28] studied the isolated and combined effect of mAs and kV on the radiation dose and contrast-to-noise ratio, and suggested that optimisation in CBCT should be based only on mAs reduction because the highest kV value used demonstrated less image degradation even at lower dose levels. Conversely, other studies on dose optimisation showed that both the mAs (from 105 to 52.5 and 157.5 to 87.5) and kV (from 90 to 80) can be reduced without significant impact in the accuracy of diagnostic tasks such as assessment of impacted maxillary canine and periodontal structures.[2,29]

In the present study, the radiation dose of the protocols was assessed by the dose-area-product, in $Gy.cm^2$, which is the absorbed dose multiplied by the irradiated area provided in the CBCT unit once the exposure settings are selected. It stablishes achievable X-ray dose and relates reasonably well with effective dose.[30,31] Previous studies also reduced the dose-area-product without a negative influence on the diagnostic accuracy of impacted maxillary canine (52%)[2], periodontal structures (55%),[29] and peri-implant bone lesions (93%).[32]

Optimised CBCT protocols should consider several key-points such as patient age, size and gender, exam indication and, mostly, the balance between risks and benefits of the exam.[26] The European Society of Endodontology[19] and the American Association of Endodontists guidelines[17,18] advise the use of limited FOV CBCT for endodontic purposes; furthermore, the scientific literature has shown positive results of optimised CBCT protocols by using half-scan to detect root fracture[22,23] and lower mAs and half-scan to detect external root resorption.[21,24] Importantly, unlike from the present study, none of these studies considered the presence of metallic materials in the scanned area, which can cause artefacts on CBCT images and negatively influence the diagnostic accuracy.[33] Bechara et al.[22] made use of endodontically treated teeth with gutta-percha and showed a significant increase of false-positive diagnosis of root fracture when the number of basis images was halved, due to an increase of beam hardening artefact in the image by gutta-percha. However, the accuracy and sensitivity did not vary significantly.

Because high-density materials are frequently used in oral rehabilitation, the indication of small FOV CBCT for endodontic purposes increases the possibility of having them in the exomass. It is therefore important to consider this condition for the study of optimised protocols as high-density materials in the exomass have shown to negatively impact the CBCT image quality,[13,14] however, on the other hand, have shown to not affect the diagnostic accuracy of vertical root fracture.[15] In the present study, the presence of titanium implants or cobalt-chromium intracanal posts in the exomass and/or endomass did not influence the diagnosis of VRF at both standard and optimised protocols.

In order to only analyse the effect of artefacts arising from metallic materials around the tooth of interest, in the exomass and/or endomass, the present methodological design made use of fiberglass endodontic posts in the teeth of interest; they are currently used to reduce the tension of the root in an aesthetic restoration of endodontically treated teeth.[34] Previous studies have shown higher diagnostic accuracy of root fracture and less occurrence of CBCT artefacts in the presence of fiberglass post, when compared with gutta-percha and metallic alloys posts.[25,35] This can be possibly attributed to the different composition of these materials, considering that higher atomic number can produce more CBCT artefacts. Thus, hypodense streaks of the artefacts can mimic fracture lines and increase false-positive diagnosis.[36,37]

Overall, the reduction of mAs and kV on an optimised CBCT protocol was applicable without significant impact in the diagnosis of VRF. Despite the wide number of CBCT units available in the market presenting different configurations for scanning,[38] it is important to highlight that the outcomes of the present study encourage the search for dose optimisation. Further assessment of other CBCT units is needed to establish machine-specific dose-optimised protocols with solid indications and limitations in the diagnosis of VRF.

Conclusion

Optimised CBCT protocols should be considered in the detection of VRF of dental roots filled with fiberglass posts irrespective of the occurrence of artefacts from metallic materials in the exomass and/or endomass.

Declarations

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AUTHORS' CONTRIBUTIONS

A.P.C., B.S. and M.L.O. contributed to conception. A.P.C., F.M., R.J., D.Q.F., F.H-N., B.S. and M.L.O. contributed to design. A.P.C., F.M., K.F.V, A.C.O, D.Q.F, B.S and M.L.O. contributed to analysis. A.P.C. and M.L.O drafted the manuscript. All authors revised the manuscript, gave final approval and agreed to be accountable for all aspects of the work.

COMPETING INTERESTS

The authors declare no competing interests.

DATA AVAILABILITY

All the data that support the findings of the current study are available from the corresponding author upon reasonable request.

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Figures

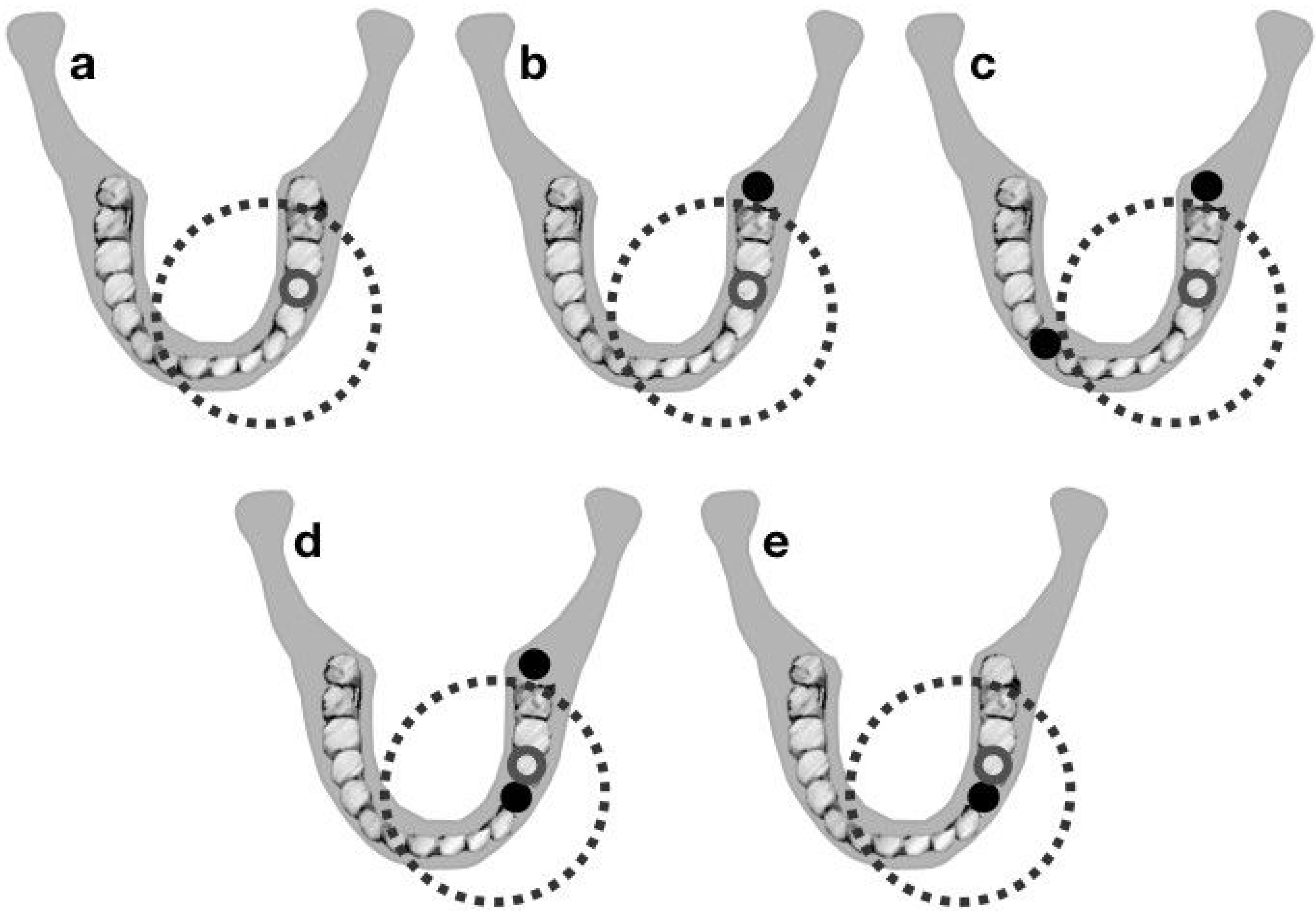

Figure 1

Scheme illustrating the dispositions of the metallic materials in the imaging phantom. The grey circle represents the region of interest (socket of the lower left second premolar), the black dotted circle highlights the limit of the field-of-view and the black solid circle indicates the location of the metallic materials. a) Control (absence of metallic material); b) I Exo - one metallic material in the exomass; c) II Exo - two metallic materials in the exomass; d) ExoEndo - one metallic material in the exomass and one metallic material in the endomass; e) Endo - one metallic material in the endomass.

Figure 2

Representative CBCT axial reconstructions of the standard and optimised protocols in different dispositions of titanium implants and cobalt-chromium intracanal posts in the mandible.

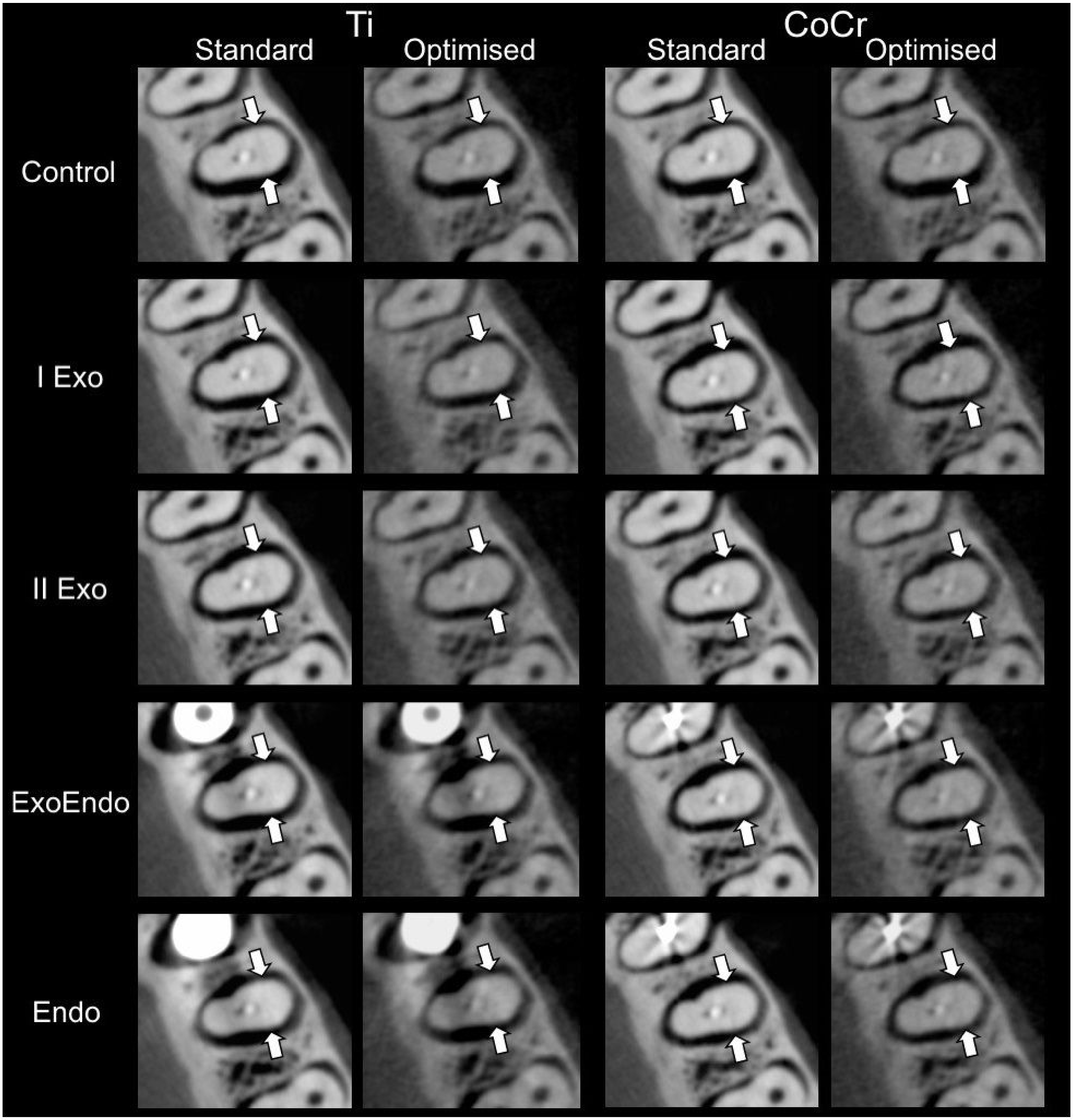

Figure 3

Cropped axial reconstructions of the standard and optimised CBCT protocols in different dispositions of titanium implant and cobalt-chromium intracanal posts in the mandible. The white arrows highlight the vertical root fracture in the second pre-molar.