RESEARCH ARTICLE

CT of facial fracture fixation: an experimental study of artefact reducing methods

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Objectives: This study aimed to determine the optimal post-operative CT imaging method that enables best visualization of facial bony structures in the vicinity of osteosynthesis material.

Methods: Conducted at Töölö Hospital (Helsinki, Finland), this study relied on scanning a phantom with CBCT, 64-slice CT and high-definition multislice CT with dual-energy scan (providing monochromatic images of 70-, 100-, 120- and 140-keV energy levels) and iterative reconstruction (IR) methods. Two radiologists assessed the image quality, and the assessments were analyzed. In addition, a physicist performed a semi-quantitative analysis of the metal-induced artefacts.

Results: The three subjects most easily assessed were the loose screw and both the bone structure and the fracture further away from the screw and the plate. Soft tissues adjacent to the screw and the plate remained more difficult for assessment. Both image interpreters agreed that the artefacts disturbed their assessments under dual energy. Metal artefacts disturbed the least under multislice CT with IR [adaptive statistical iterative reconstruction (ASiR) and VEO]. Neither interpreter found metal suppression helpful in CBCT.

Conclusions: CBCT with or without a metal artefact reduction algorithm was not optimal for post-operative facial imaging compared with multislice CT with IR. Multislice CT with ASiR filtering offered good image quality performance with fast image volume reconstruction, representing the current sweet spot in post-operative maxillofacial imaging.

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Introduction

The surgical treatment of facial fractures involves restoring both the shape and function of the face. Only after the evolvement of the internal fixation of facial bones has it been possible to repair unstable or dislocated facial fractures reaching a stable bony base upon which to restore soft tissues.¹

Osteosynthesis plates of various materials, such as titanium, polymers or stainless steel, can be used in the

fixation of fractures to maintain the restored position; detecting metal plates in X-rays can be useful.² However, the high attenuation of X-rays in the metal material causes artefacts. These artefacts may conceal clinically important anatomical structures.² The type and thickness of metal pieces impacts the artefact seen in CT images.^{3,4} Titanium creates markedly fewer artefacts than stainless steel.³ The larger the object, the bigger the artefact. Thus, X-rays should be directed so that they pass through the metal implant at its smallest projected surface area. In addition, the imaging

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parameters applied affect the properties and severity of the artefacts. An increasing voltage improves the penetration of the X-ray resulting in fewer artefacts, as does lower pitch settings.⁴ A slower CT gantry rotation may also enhance the image quality if the scan time is not an issue due to patient movement.⁵ After the actual imaging, the artefacts can be reduced by specific metal correction algorithms during image reconstruction. Further optimization can be performed during post-processing and visualization.⁴

Fundamentally, multislice CT and CBCT artefacts are induced by discrepancies between the assumptions made in image reconstruction (mathematical algorithm) and the actual physical imaging process involving a highly complex combination of individual patient features, technical scanner performance and image acquisition system. Artefacts can interfere with diagnostics and therefore, it is important that users are able to recognize various artefacts when they appear in the image data. The polychromatic nature of the diagnostic X-ray spectrum used in the CT and CBCT scanners is modified by the attenuating structures of the patient and other materials, leading to a harder spectrum, *i.e.* higher energy X-rays detected by the scanner. In image reconstruction, without specific corrections, this leads to beam-hardening artefacts with underestimated attenuation values on the related patient regions. Also, scatter signal interferes with image calculation and causes deviations in the observed images. Typically, these effects appear as darker shadows and lighter bands. Metal structures may attenuate relatively all incident X-rays and thus cause more severe artefacts. Overall, image artefacts are typically induced by various sources with combined appearance in the image data. Various technical and computational solutions aim at suppressing these effects to improve diagnostic image quality.^{6,7}

In this article, the main artefacts evaluated from the clinical CBCT and CT data are streaks (distinct dark and light lines originating from a metal object, which can extend relatively far from the original disturbing region) and blooming (more gradual intensity change along the distance from the metal surface towards the background tissue, a more local spilling).

The aim of this study was to find out the optimal post-operative CT imaging method that enables best visualization of facial bony structures in the vicinity of osteosynthesis material.

Methods and materials

This study was conducted at Töölö Hospital (Helsinki, Finland) by scanning a phantom with CBCT, 64-slice CT and high-definition (HD) multislice CT with dual-energy scan (providing monochromatic images of 70-, 100-, 120- and 140-keV energy levels) and iterative reconstruction (IR) methods (Table 1). In adaptive statistical iterative reconstruction (ASiR) technique, both 10 and 30% levels of blending were used with the 64-

slice scanner. In addition, the ASiR with 50% blending at the HD mode, 40% blending at the dual-energy (gemstone spectral imaging) mode and the model-based iterative reconstruction technique (VEO) was applied as an alternative reconstruction method with HD multislice CT (Table 1). The used ASiR blending levels correspond to typical clinical settings selected for optimal image quality for radiologists.

The CBCT scanner used in this study was Planmed Verity® (Planmed Oy, Helsinki, Finland). The CBCT scanner has an X-ray tube with a tungsten target, anode voltage set to 96 kV and anode current 9–10 mA (depending on the protocol). The scanner has a 20 × 25-cm flat-panel amorphous silicon detector enabling a field of view of 13 × 16 cm with a scan time of 18 s.⁸ The multislice CT scanners used in this study were the GE Lightspeed VCT 64-slice model and GE Discovery CT750 HD scanner (GE Healthcare, Milwaukee, WI). The use of dual-energy scans and VEO is included only in the GE Discovery CT750 HD multislice CT scanner.

The phantom consisted of an unfrozen head of a deceased pig, selected because the bone structure reasonably resembles that of a human face despite being somewhat larger. An oral and maxillofacial surgeon (JL) performed two sagittal osteotomies on the mandible to resemble two fracture lines. Subsequently, two plates—a 2.0 titanium miniplate (W Lorenz, Jacksonville, FL) and a 2.3 titanium miniplate (KLS Martin, Tuttlingen, Germany)—were attached to the mandible using two different-sized screws (1.5–2.0 mm). One screw was intentionally left poorly attached. In addition, one of the screw holes was drilled too large to resemble osteolysis. Similar to an authentic human mandibular surgery, the soft tissues were closed. After preparing the phantom, all scans were completed within 2 h. A radiologist with 11 years' subspecialty experience in musculoskeletal and trauma imaging (MPK) using a three-dimensional (3D) workstation (GE Advantage Workstation v. 4.6) reconstructed the reformats in three standard orthogonal planes. The standard clinical slice thickness of 1 mm was used, and special care was taken to ensure that the slice orientation and positioning were identical across all scans.

Two radiologists—(VH) (Interpreter *a*) and (AS) (Interpreter *b*)—with 10 and 16 years' subspecialty experience in musculoskeletal and trauma radiology (VH) and oral radiology (AS), respectively, assessed the image quality (Agfa Impax v. 6.5, Mortsel, Belgium). The assessments were performed separately and without knowing which device or protocol (Table 1 and Figure 1) yielded which image. For each scan, interpreters assessed 10 different items (Table 2), which the interpreters knew prior to completing the assessment. Prior to the assessment, the interpreters discussed the items to ensure uniformity in assessment criteria. Likert scale was used as an aid in the assessment. A third researcher (EP) analyzed the assessments.

A semi-quantitative analysis of the streak artefacts was performed by a physicist (TM) using an in-house

Table 1 Devices and protocols—Planmed Verity® (Planmed Oy, Helsinki, Finland), GE Discovery CT750 HD and GE Lightspeed VCT (GE Healthcare, Milwaukee, WI)

<i>Protocol</i>	<i>Protocol values</i>
A Planmed Verity® (CBCT)	
A1 High resolution	96 kV, 10 mA normal dose
A2 High resolution + metal suppression	96 kV, 9 mA low dose
A3 Standard	
A4 Standard + metal suppression	
A5 Low dose	
A6 Low dose + metal suppression	
B GE Discovery CT750 HD	
B1 “Facial bone”	<p>Axial series: Helical full 0.4 s</p> <p>Detector coverage: 40</p> <p>Slice thickness: 0.625 mm, interval: 0.312 mm</p> <p>Pitch/speed 0.516 : 1/20.62</p> <p>Manual mA 120–40 mA</p> <p>SFOV: head, DFOV: >23</p> <p>Calculation algorithm: DETL, ReconOption: PLUS, W/L 2600/600, ASiR 30%</p> <p>Recon2: 0.625/0.312 mm; SOFT, ReconOption: FULL, W/L 400/40, ASiR 30%</p> <p>Recon3: 1.25/1.25 mm, Detail, ReconOption: FULL, W/L 2600/600, ASiR 30%</p> <p>Image matrix size 512 × 512</p> <p>Axial series: Helical full 0.4 s, HiRes mode ON</p> <p>Detector coverage: 20</p> <p>Slice thickness: 0.625 mm, interval: 0.312 mm</p> <p>Pitch/speed 0.531 : 1/10.62</p> <p>Manual mA 120 kV–40 mA</p> <p>SFOV: Head, DFOV: >23</p> <p>Calculation algorithm: HD DETL, ReconOption: PLUS, W/L 2600/600, volume ASiR 50%</p> <p>Recon2: 1.25 mm/1.25 mm, HD Detail, ReconOption: FULL, W/L 2600/600</p> <p>ASiR 50%</p> <p>Image matrix size 512 × 512</p> <p>Axial series: helical full 0.4 s</p> <p>Detector coverage: 20</p> <p>Slice thickness: 0.625 mm, interval: 0.312 mm</p> <p>Pitch/speed 0.531 : 1/10.62</p> <p>Manual mA 120 kV–40 mA</p> <p>SFOV: head, DFOV: 25</p> <p>Calculation algorithm: detail, ReconOption: PLUS-E, W/L 2600/600, ASiR 30%</p> <p>Recon2: 0.625/0.625 mm, STND, VEO IR</p> <p>Image matrix size 512 × 512</p> <p>Slice thickness 0.625 mm</p> <p>0984 : 1 39, 37</p> <p>Rotation time 0.5 s, detector coverage 40 mm, estimated dose 10.18 mGy</p> <p>Image matrix size 512 × 512</p> <p>GSI-51 preset</p> <p>GSI ASiR 40%</p> <p>Phase 75–75%</p> <p>MARS used; GSI filter not in use</p>
B2 “Facial bone” HD	
B3 “Facial bone” VEO	
B4 GSI monochromatic 70 keV	
B5 GSI monochromatic 100 keV	
B6 GSI monochromatic 120 keV	
B7 GSI monochromatic 140 keV	
C GE Lightspeed VCT	
C1 “Facial bone” ASiR 30%	Slice thickness 0.625 mm, pitch and speed (mm/rotation) 0.516 : 1 20.62
C2 “Facial bone” ASiR 10%	Rotation time 0.4 s, 120 kV, 40 mA
C3 “Facial bone” ASiR 30% + bone	Image matrix size 512 × 512
C4 “Facial bone” ASiR 10% + bone	

ASiR, adaptive statistical iterative reconstruction; DFOV, display field of view; GSI, gemstone spectral imaging; IR, iterative reconstruction; mA, milliamperes; SFOV, scan field of view; VCT, volume CT; VEO, model-based iterative reconstruction technique.

MATLAB® (Mathworks, Natick, MA) program and 3D Slicer software (The National Alliance for Medical Imaging Computing). Contrast investigations of a relatively homogeneous soft-tissue region near the metal implant were performed after matching the data sets with rigid co-registrations. Owing to differences in the

imaging techniques, we normalized the image intensity values to 0 for fatty tissue and 1 for muscle tissue. [Figure 2](#) shows the location investigated and the region of interest placements. Radially drawn line profiles were chosen as the comparison metric, since the artefacts may manifest themselves at arbitrary angles. All data

Figure 1 An axial image from each protocol: Series B and C images were flipped for readability (originally appeared as mirror images due to the different position of the phantom).

sets were identically analyzed and 5% and 95% quantile values were recorded at various distances from the metal. This procedure aimed to provide both hypo-intense and hyperintense signal artefacts relative to the discernibility between the two fixed tissue types. The resulting graphs were qualitatively examined for the magnitude and extent of the artefact.

Results

Overall, both interpreters agreed that the loose screw and both the bone structure and fracture further away from the screw and the plate represented the easiest

items to assess (Table 3). The most difficult item to assess was the soft tissue adjacent to the screw and the plate.

Both interpreters agreed that the blooming artefacts disturbed their assessments under dual energy (B4, B5, B6 and B7). However, Interpreter *b* found that the blooming artefacts disturbed the assessments in some cone-beam scans (A2, A3, A4 and A5), while Interpreter *a* did not.

Interpreter *a* found that streak artefacts highly disturbed the assessments under dual-energy scans (B4, B5, B6 and B7), whereas Interpreter *b* found these to be only mildly disturbed. Both interpreters agreed that streak artefacts least disturbed their

Table 2 The items assessed by each radiologist

Very difficult to interpret (1), quite difficult to interpret (2), neither difficult nor easy to interpret (3), relatively easy to interpret (4) or very easy to interpret (5)
Loose screw (third screw on the left side)
Osteolysis (fifth screw on the right side)
Fracture line in the direct vicinity (<5 mm) of the screw and the plate
Fracture line further (≥5 mm) from the screw and the plate
Bony structure in the direct vicinity (<5 mm) of the screw and the plate
Bony structure further (≥5 mm) from the screw and the plate
Soft tissue in the direct vicinity (<5 mm) of the screw and the plate
Soft tissue further (≥5 mm) from the screw and the plate
Disturbed very much (1), disturbed quite much (2), disturbed neither much nor slightly (3), disturbed only slightly (4), did not disturb (5)
Streak artefacts
Blooming artefacts

Figure 2 (a) The final artefact curve (dashed line) calculated from the difference between the 95% and 5% quantile values (solid lines) for the normalized data (grey dots) at various distances: if no artefact is present, the curve should remain constant across the distance. (b) Prior to analysis, all data sets were normalized to 0 at the white region of interest (ROI) and 1 at the black ROI mean. (c) The black arrow shows the direction of the distance measured from the nearest metal. This procedure was repeated for all voxels in the neighbouring homogeneous region.

assessments under multislice CT with ASiR filtering (C1, C3 and C4).

When rating the artefacts overall, Interpreter *b* rated conventional CTs with various levels of filtering (B1, B2, C1, C2, C3 and C4) and IR (B3) as highest, but rated standard- and low-dose CBCT (A3 and A5) as lowest. Interpreter *a* rated conventional CT with ASiR filtering (C1, C3 and C4) as highest and dual-energy scans (B4, B5, B6 and B7) as lowest.

Using CBCT, neither interpreter perceived metal suppression as helpful. For the various objects, interpretation remained either the same or more difficult using metal suppression with one minor exception (Table 3).

Figure 3a–c show the quantitative analysis plots for each scanner. Planned Verity® graphs indicated a clear artefact reduction in the soft tissue when metal suppression was enabled. Only a small effect from the choice of protocol can be seen. Multidetector CT (MDCT) scanners (data groups B1–3 and C1–4) showed a quite concise magnitude and extent behaviours between each other apart from the notably poorer gemstone spectral images. We found that a 70-keV monochromatic reconstruction (B4) yielded the smallest artefact in the gemstone spectral images, while others (B5–B7) indicated curves quite similar to one another.

Discussion

CT scanning of the maxillofacial region with thin slices reveals the skeletal anatomy and yields accurate 3D reconstructions.⁹ Technological advances in intra-operative CT, better plating systems and new surgical instruments and operative techniques have improved our ability to adequately reduce and fix facial fractures and osteotomies.¹⁰ With decreasing radiation doses, CT is likely to become the primary post-operative imaging modality among such patients.

MDCT enables fast imaging with a wide anatomical coverage using thin slices and a high resolution, enabling high-quality reformats and isotropic imaging.^{11–13} New scanner models have yielded reduced rotation times and improved tube efficiency, together with an increased number of detector rows and wider detector widths. In addition, image reconstruction techniques and data processing capacity have improved.¹⁴ MDCT revolutionized imaging and improved the diagnostics of facial fractures.¹⁵

The rapid development of imaging techniques resulted in new X-ray modalities. CBCT is relatively new compared with conventional CT imaging methods. However, CBCT already enjoys wide use particularly in oral radiology. Along with hard-tissue imaging, the evolved

Table 3 Rating of the items assessed using each device and protocol (A1–C4 in Table 1)

Device and protocol (A1–C4) by each interpreter (a, b)	Very difficult to interpret (1), quite difficult to interpret (2), neither difficult nor easy to interpret (3), relatively easy to interpret (4) or very easy to interpret (5)	Loose screw on the left side	Osteolysis on the right side	Fracture line in the direct vicinity (<5 mm) of the screw and the plate		Fracture line further (≥5 mm) from the screw and the plate		Bony structure in the direct vicinity (<5 mm) of the screw and the plate		Bony structure further (≥5 mm) from the screw and the plate		Soft tissue in the direct vicinity (<5 mm) of the screw and the plate		Soft tissue further (≥5 mm) from the screw and the plate		Disturbed very much (1), disturbed quite much (2), disturbed neither much nor slightly (3), disturbed only slightly (4) or did not disturb (5)	Streak artefacts	Blooming artefacts
A1a	5	5	5	5	5	5	5	5	5	5	5	2	2	2	2	2	5	5
A1b	5	5	2	2	2	4	4	2	5	5	5	1	2	2	2	2	5	5
A2a	5	5	4	4	2	4	4	4	4	5	5	2	2	2	3	3	5	5
A2b	5	5	3	3	2	4	4	2	5	5	5	1	2	2	3	3	1	1
A3a	5	5	5	5	4	5	5	4	5	5	5	3	3	3	2	2	5	5
A3b	5	5	3	3	2	4	4	2	5	5	5	1	2	2	1	1	2	2
A4a	4	4	4	3	3	4	4	3	4	4	4	1	1	1	3	3	5	5
A4b	5	5	2	2	2	3	3	2	5	5	5	1	2	2	2	2	1	1
A5a	5	5	5	5	5	5	5	4	4	5	5	1	1	1	1	1	5	5
A5b	5	5	3	3	2	4	4	2	5	5	5	1	1	1	2	2	1	1
A6a	5	5	3	3	3	4	4	2	5	5	5	1	1	1	1	1	4	4
A6b	5	5	2	2	2	3	3	2	4	4	4	1	1	1	3	3	4	4
B1a	5	5	5	5	5	5	5	4	4	5	5	5	5	5	3	3	5	5
B1b	5	5	4	4	5	5	5	5	5	5	5	1	1	1	5	5	5	5
B2a	5	5	5	5	5	5	5	5	5	5	5	4	4	4	5	5	5	5
B2b	5	5	3	3	5	5	5	5	5	5	5	1	1	1	5	5	5	5
B3a	5	5	5	5	5	5	5	4	5	5	5	5	5	5	3	3	5	5
B3b	5	5	4	4	5	5	5	5	5	5	5	1	1	1	5	5	5	5
B4a	1	1	1	1	1	1	1	1	2	2	2	2	2	2	4	4	1	1
B4b	4	4	2	2	3	3	3	2	3	3	3	1	1	1	3	3	1	1
B5a	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	1	1
B5b	4	4	1	1	3	3	3	1	3	3	3	1	1	1	4	4	1	1
B6a	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	1	1
B6b	4	4	1	1	2	2	2	2	3	3	3	5	5	5	4	4	1	1
B7a	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	1	1
B7b	4	4	1	1	2	2	2	1	3	3	3	1	1	1	4	4	1	1
C1a	4	4	4	4	4	4	4	5	5	5	5	4	4	4	5	5	5	5
C1b	5	5	4	4	5	5	5	4	4	5	5	2	2	2	5	5	5	5
C2a	4	4	4	4	4	4	4	4	4	5	5	4	4	4	5	5	5	5
C2b	5	5	4	4	5	5	5	5	5	5	5	2	2	2	5	5	5	5
C3a	5	5	5	5	5	5	5	5	5	5	5	3	3	3	4	4	5	5
C3b	5	5	4	4	5	5	5	4	4	5	5	2	2	2	5	5	5	5
C4a	5	5	5	5	5	5	5	5	5	5	5	2	2	2	3	3	4	4
C4b	5	5	4	4	5	5	5	5	5	5	5	2	2	2	5	5	5	5

a, Interpreter a; b, Interpreter b.

Figure 3 Results from the metal artefact analysis: the plotted quantile differences show a typical decreasing streak artefact strength (variation in intensity), as the distance from the metal increases. Enabling metal suppression in Planned Verity® (grey points in a) decreased the apparent artefact effect. GE scanner protocols (b, c) without the gemstone spectral imaging (GSI) data resulted in a similar behaviour in both the magnitude and extent of the artefact; a has a different scale compared with b and c. ASiR, adaptive statistical iterative reconstruction; VEO, model-based iterative reconstruction technique.

technological design allows its application in certain soft-tissue imaging as well. Its potentially lower radiation dose, lower price and smaller size associated with CBCT scanners serve as advantages compared with conventional CT installations.¹⁶ While hard tissues can be seen explicitly, artefacts may emerge owing to scatter, beam hardening, patient movement and beam geometry.^{6,7}

Dual-energy CT stands as a new method useful in the analysis of materials and, furthermore, in suppressing artefacts caused by metal. In clinical routines, these devices rely on either two tubes using different tube voltages (*e.g.* 80 and 140 kV) and filters or one tube using a changing tube voltage. Virtual monochromatic images with different effective photon energy levels (40–140 keV) can be calculated from the dual-energy data obtained. A monochromatic CT image can be useful in improving the visualization of a contrast agent and, as in this study, reducing metal-induced artefacts.¹⁷

Filtered back projection (FBP) represents the current standard image reconstruction method, given its relative sensitivity to noise. Owing to Poisson statistics in X-ray imaging, lowering the dose by reducing the tube current may result in an unacceptable increase in image noise. Recently, evolved image reconstruction methods such as IR were introduced to CT.¹⁸ In comparison with FBP

reconstruction using an image from projections of an object in a single step, IR algorithms estimate the image through multiple passes over the projection data.¹⁹ IR techniques address the challenges for low-dose scans, high-resolution reconstructions and artefact reduction even when data are incomplete or limited. However, depending on the level of physics, object, optics and statistical modelling, IR methods require a longer reconstruction time than conventional FBP reconstruction methods.²⁰ Compared with FBP, the IR technique may allow as much as a 60% dose reduction in the facial CT scan without compromising the diagnostic image quality.²¹

Different IR algorithms have been developed. One such complex algorithm is the model-based iterative reconstruction (MBIR) algorithm VEO (GE Healthcare, Milwaukee, WI). The MBIR algorithm models the CT system more accurately than earlier and more approximative methods. Owing to the further modelling, MBIR may offer higher spatial resolution, further noise reduction and artefact correction; however, it is also computationally demanding and thus requires significantly longer time to reconstruct the image data volume. ASiR (GE Healthcare, Milwaukee, WI) is a statistical noise-reducing IR algorithm that can be applied at different levels of blending combined with the

typically used FBP algorithm. Typically, blending levels used clinically are up to 60%. ASiR algorithm does not involve such a high level of scanner and optical modelling as compared with VEO algorithm. Thus, the ASiR algorithm is computationally less demanding and enables faster reconstruction times, adhering to traditional FBP reconstruction times. Furthermore, the variable ASiR blending levels with the FBP data result in the familiar appearance of FBP images while reducing noise in the images.^{22–24}

CT image artefacts caused by metal objects remain a challenge for image reconstruction and post-processing of image data. In CTs with conventional FBP, metal artefacts may obscure vital information or, at worst, render distinguishing abnormal tissue impossible.²⁵

Because the soft-tissue contrast is typically lower in CBCT images, the impact of metal artefacts in the soft-tissue region is enhanced in CBCT.²⁶ Zhang *et al*²⁶ found that the algorithm to estimate pixel values inside the metal shadow region derived from the boundary pixel values using a diffusion process may not always be valid. If a streak artefact occurs, it is safer for it to remain recognizable than to fill the image with faux data to make it appear smoother. Under certain circumstances with large or irregularly shaped metal objects, imperfect corrections or new artefacts may appear.²⁶ Similarly, in our material, the use of metal suppression using CBCT did not yield an additional benefit. On the contrary, this technique rendered clinical image evaluation more difficult as it produced grey areas, which were difficult to identify as artefact. Our findings had the immediate implication of disabling the metal reduction option from our clinical CBCT protocols.

However, algorithms for metal reduction continue to evolve. The effective reduction of CT metal artefacts can be achieved by combining algorithms designed for specific types of implant materials.²⁵ Multi-energy imaging approaches functional imaging by identifying materials with an increased accuracy.²⁷ Dual energy can be used to lessen metal artefacts by reconstructing images with optimal energy levels. However, in our study, we found only slight benefit of using dual energy in its current state. Certain artefacts such as blooming seemed to get even worse around the metal targets.

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The approach we selected for the (semi-)quantitative analysis aimed to provide comparable values for the streak artefact magnitude and extent. The method provides a compromise between various detrimental effects from which images may suffer, such as the random orientation and the intensity variability of the streaks. The various choices seek to reduce the effects of outliers, random noise and tissue inhomogeneity. Normalization to two soft-tissue intensities seeks to ensure the comparability between CBCT and MDCT. While only limited conclusions may be drawn from an interdevice comparison, our results are in line with and support the interpreter findings on streak artefacts.

Our study suffers from several methodological limitations. Using an animal-derived phantom inadvertently results in a different anatomy and scanning slice orientation than that found in humans. With regard to blinding our data sets, the radiologists interpreting the scans were experienced and probably had no difficulty recognizing which scans resulted from CBCT or IR in multislice CT. Secondly, they had prior knowledge regarding where the loose screw and the screw with simulated osteolysis were placed. We chose this approach in order to ensure a similar pre-readout setup for each type of scan. In addition, using preset monochromatic images represents another limitation to our study. In everyday clinical work, the radiologist may typically set the energy level and slice thickness to capture the best image quality.

Overall, we found that the significance of metal artefacts is to some extent subjective. Interpreter *b*, as an oral radiologist, easily recognized CBCT examinations and was probably more critical than Interpreter *a* when evaluating blooming artefacts. Interpreter *b* found the “high-resolution CBCT protocol” superior to other CBCT protocols concerning alleviation of the blooming artefacts.

However, the worst and best stand out. Based on our findings, we do not recommend a non-iterative CBCT with or without a metal reduction algorithm for post-operative facial imaging. IR methods (ASiR and VEO) in multislice CT, however, performed well. Multislice CT with ASiR filtering offered good image quality performance with fast image volume reconstruction, representing the current sweet spot in post-operative maxillofacial imaging.

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