RESEARCH ARTICLE

Metal artefact reduction for patients with metallic dental fillings in helical neck computed tomography: comparison of adaptive iterative dose reduction 3D (AIDR 3D), forward-projected model-based iterative reconstruction solution (FIRST) and AIDR 3D with single-energy metal artefact reduction (SEMAR)

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Objectives: To compare the differences in metal artefact degree and the depiction of structures in helical neck CT, in patients with metallic dental fillings, among adaptive iterative dose reduction three dimensional (AIDR 3D), forward-projected model-based iterative reconstruction solution (FIRST) and AIDR 3D with single-energy metal artefact reduction (SEMAR-A).

Methods: In this retrospective clinical study, 22 patients (males, 13; females, 9; mean age, 64.6 ± 12.6 years) with metallic dental fillings who underwent contrast-enhanced helical CT involving the oropharyngeal region were included. Neck axial images were reconstructed with AIDR 3D, FIRST and SEMAR-A. Metal artefact degree and depiction of structures (the apex and root of the tongue, parapharyngeal space, superior portion of the internal jugular chain and parotid gland) were evaluated on a four-point scale by two radiologists. Placing regions of interest, standard deviations of the oral cavity and nuchal muscle (at the slice where no metal exists) were measured and metal artefact indices were calculated (the square root of the difference of the squares of them).

Results: In SEMAR-A, metal artefact was significantly reduced and depictions of all structures were significantly improved compared with those in FIRST and AIDR 3D ($p \leq 0.001$, sign test). Metal artefact index for the oral cavity in AIDR 3D/FIRST/SEMAR-A was 572.0/477.7/88.4, and significant differences were seen between each reconstruction algorithm ($p < 0.0001$, Wilcoxon signed-rank test).

Conclusions: SEMAR-A could provide images with lesser metal artefact and better depiction of structures than AIDR 3D and FIRST.

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Introduction

Various types of diseases, such as infection, carcinoma and malignant lymphoma, arise in the structures present

in the oral cavity and the oropharyngeal region. CT plays an important role in the evaluation of these diseases; for example, evaluation of the extent of infection,¹ evaluation of primary tumour extension²⁻⁴ and detection of lymph node metastasis which is common in

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oropharyngeal carcinoma.⁵ However, a considerable number of patients have metallic dental fillings, and the metal artefacts, resulting from the presence of these fillings, cause an impairment in the image quality and diagnostic performance.^{6,7} Therefore, metal artefact reduction in neck CT is a challenge to overcome.

Several techniques are available for the reduction of metal artefacts. Increased tube current, high tube voltage and thin collimation can reduce metal artefacts; however, the effect is limited, with increased radiation exposure being a problem.⁸ Additional scanning with a gantry tilt is helpful in depicting structures, the visualization of which is impaired by metal artefact in helical scan.⁷ However, this technique would also result in an increased radiation dose. Virtual monochromatic image with a high keV, which is derived from dual-energy CT, is reported to be helpful in reducing metal artefacts; however, dual-energy CT requires a specific CT scanner and scanning protocol.^{9,10} At the reconstruction step,¹¹ metal-implanting methods^{12–16} or iterative reconstruction algorithms^{17,18} are available to reduce metal artefacts. Single-energy metal artefact reduction (SEMAR) for helical scan data is a metal-implanting method and the forward-projected model-based iterative reconstruction solution (FIRST) is a full iterative reconstruction algorithm, and both have become available recently. To our knowledge, the effect of both techniques on reducing the degree of metal artefact and on improving the depiction of structures in the oral cavity and the oropharyngeal region from dental fillings in helical neck CT has not been investigated.

The aim of this study was to investigate and compare the degree of metal artefact reduction and the depiction of structures in the oral cavity and the oropharyngeal region in helical neck CT for patients with metallic dental fillings using SEMAR and FIRST.

Methods and materials

This retrospective clinical study was approved by our institutional review board, and the need for written informed consent was waived.

Subjects

A radiologist (KY, with 6 years' imaging experience) searched the picture archiving and communication system for patients with metallic dental fillings and/or metal implants who underwent contrast-enhanced helical CT with 320-detector CT (Aquilion™ ONE Vision Edition; Toshiba Medical Systems Corporation, Tochigi, Japan) involving the oral cavity and oropharyngeal region. Patients who raised their arms during scanning or those for whom data were acquired in the arterial phase were excluded. Between June 2015 and September 2015, 24 patients meeting these criteria were identified. Image sets of 2 patients were randomly selected (as a result, a 63-year-old male and a 51-year-old male) and were used for training purposes as described later. These images

were excluded from the final analyses and as a result, 22 patients (13 males and 9 females; mean age, 64.6 ± 12.6 years) were included for the final analyses. The location of metallic dental fillings was as follows: both sides ($n = 20$), right side ($n = 1$) and left side ($n = 1$). The indications for CT scan were as follows: carcinoma of the oral cavity ($n = 9$), infection of the neck ($n = 4$), oropharyngeal carcinoma ($n = 2$), tumour of the mandible ($n = 2$), hypopharynx carcinoma ($n = 1$), laryngeal carcinoma ($n = 1$), thyroid carcinoma ($n = 1$), paranasal sinus tumour ($n = 1$) and muscle atrophy ($n = 1$).

CT image acquisition

The following scanning parameters were used: scan mode, helical; helical pitch, 51.0; gantry rotation time, 0.5 s; detector configuration, 0.5×80 mm; tube voltage, 120 kVp. For tube current, automatic exposure control with a fixed noise index was used, and the mean CT dose index volume and dose-length product (with scan range) were as follows: 22.8 ± 12.7 mGy and 690.8 ± 286.7 mGy cm (neck only, 18 patients) and 12.4 ± 5.2 mGy and 655.8 ± 320.1 mGy cm (neck to chest, 4 patients). Contrast materials with a concentration of 300 mg I ml^{-1} were used. The total volume of the contrast material was determined by multiplying the body weight by two with an upper limit of 100 ml (for example, 90 ml for patients weighing 45 kg and 100 ml for patients weighing 60 kg). For patients with renal function impairment, the dose of the contrast material was reduced appropriately. The contrast material was injected within 60 s, and the scan was performed for 60 s (for a scanning range of the neck only) or 90 s (for a scanning range of neck to chest) after initiating the injection of contrast materials.

CT image reconstruction

From helical scan data, axial images of the neck were reconstructed using the following algorithms: adaptive iterative dose reduction three dimensional (AIDR 3D), FIRST with body standard algorithm and AIDR 3D with SEMAR (SEMAR-A). For reconstruction of AIDR 3D and SEMAR-A images we used enhanced standard algorithm with FC04 kernel (*i.e.* soft-tissue kernel). AIDR 3D is a hybrid iterative reconstruction algorithm which has become available in advance to FIRST. AIDR 3D performs better than filtered back-projection (FBP) with regard to noise and low-contrast detectability.¹⁹ Therefore, 72 image sets (24 patients) were obtained by reconstruction. 6 image sets (2 patients) were used for training purposes, and 66 image sets (22 patients) were used for the final analyses. The following parameters were identical across the reconstruction algorithms: z-axis range, from the frontal sinus to the hyoid bone; slice thickness, 3.0 mm; slice interval, 3.0 mm; and the field of view, 20–25 cm (adjusted to body size).

Qualitative image analyses

2 radiologists (KK and RI with 7 and 3 years' imaging experience, respectively) were included in the qualitative

image analyses. Images were evaluated using a commercial viewer (Vue PACS; Carestream, Tokyo, Japan) with a preset window level of 40 HU and a window width of 400 HU. All the image sets were randomized. And one type of image of each patient was evaluated at a time, not in a side-by-side way. Aforementioned radiologists blinded to patient data and image reconstruction algorithms independently evaluated the image sets. They evaluated the gross degree of metal artefact on a four-point scale (4 = no or minimal artefact, 3 = moderate metal artefact, 2 = severe metal artefact in a small area and 1 = severe metal artefact in a large area) and the depiction of the following structures on a four-point scale [4 = good depiction, 3 = slightly decreased depiction, 2 = poor depiction in a small area (*e.g.* dark band in a small area) and 1 = poor depiction in a large area (*e.g.* dark band in a large area)]: the apex and root of the tongue, the parapharyngeal space, the superior portion of the internal jugular chain and the parotid gland. The two radiologists (KK and RI) were also asked to find nodular or mass lesions located at the structures evaluated.

Quantitative image analyses

Quantitative image analyses were performed by a radiologist (KY) with the Vue PACS (Carestream). Circular or ovoid regions of interest (ROIs) were placed in the oral cavity (about 400 mm²) and nuchal muscle (with about 100 mm²) at the level of the hyoid bone where no metal exists. For placing ROIs, the copy and paste function of the ROI was used to ensure that the size and location of ROIs were same between different reconstruction algorithms within a patient. ROIs were placed without referencing the measured values and after placing ROIs, CT attenuation and standard deviation (SD) were recorded. ROIs were placed twice, and the measured data were averaged. SD of the ROI is widely used as an indicator of image noise; however, it is affected by both image noise and metal artefact at the slice where the metal exists. To calculate the degree of metal artefact from SD, reducing the degree of image noise as far as possible, the metal artefact index was calculated from the following formula:

$$\left[(\text{SD}_{\text{ORAL}})^2 - (\text{SD}_{\text{MUSCLE}})^2 \right]^{1/2}$$

SD_{ORAL} and SD_{MUSCLE} denote SD of the oral cavity and SD of the nuchal muscle, respectively. A similar artefact index was also used in a previous study evaluating the degree of metal artefacts.²⁰

Statistics

For statistical analyses, the software JMP v. 11.0.0 (SAS Institute, Cary, NC) was used. Sign tests were performed to compare data from qualitative image analyses between AIDR 3D, FIRST and SEMAR-A. For quantitative image analyses, median values were

shown unless otherwise indicated, and Wilcoxon signed-rank tests were performed to compare data between AIDR 3D, FIRST and SEMAR-A. For comparison of multiple groups, the Bonferroni correction was applied, and a *p*-value of <0.0167 (= 0.05/3) was considered to indicate a significant difference. To analyze interobserver agreement regarding the qualitative image analyses, Cohen's weighted kappa analyses were performed. The following kappa values were used to indicate agreement: 0.00–0.20 (poor agreement), 0.21–0.40 (fair agreement), 0.41–0.60 (moderate agreement), 0.61–0.80 (good agreement) and 0.81–1.00 (excellent agreement).

Results

Qualitative image analyses

The detailed results of the qualitative image analyses are shown in Table 1. SEMAR-A significantly reduced metal artefacts (*p* ≤ 0.0001) and improved the depiction of all evaluated structures (*p* ≤ 0.001) compared with AIDR 3D and FIRST (Figure 1). With SEMAR-A, depictions of structures other than the apex of the tongue were rated as good or only slightly decreased for most patients. There was no significant difference between AIDR 3D and FIRST in the degree of metal artefact impact (*p* = 0.1250–0.5000) and depiction of structures (*p* = 0.2891–1.0000). Interobserver agreements were excellent for both the degree of metal artefact: AIDR 3D (0.92), FIRST (0.97) and SEMAR-A (0.91) and the depiction of each structure: AIDR 3D (0.84–0.97), FIRST (0.89–0.99) and SEMAR-A (0.92–0.98).

5 patients had pathologically proved carcinoma; 2 tongue carcinomas, 2 oropharyngeal carcinomas and 1 laryngeal carcinoma. And 7 lesions were found in these patients; 6 lymph node metastases (Figure 2) and 1 primary lesion of oropharyngeal carcinoma. One radiologist found seven lesions each in AIDR 3D, FIRST and SEMAR-A, respectively. The other radiologist found five lesions, six lesions and six lesions in AIDR 3D, FIRST and SEMAR-A, respectively.

Quantitative image analyses

The detailed results of the quantitative image analyses are shown in Table 2. The median CT attenuations of the oral cavity were 436.6 HU and 425.5 HU for AIDR 3D and FIRST, respectively. These values were extraordinarily high owing to the artefact. The CT attenuation of the oral cavity in SEMAR-A (97.8 HU) was significantly lower than that in AIDR 3D and FIRST (*p* < 0.0001).

The SDs of ROI for the oral cavity in SEMAR-A were significantly lower than those in AIDR 3D and FIRST (*p* < 0.0001). On the other hand, there was no significant difference in the SD of the nuchal muscle between SEMAR-A (5.1) and AIDR 3D (5.1) (*p* = 0.1841), while it was significantly lower than that in FIRST (7.4) (*p* < 0.0001).

Table 1 Detailed results of qualitative image analyses

Readers	Number of patients for each score			Comparison (p-value)		
	AIDR 3D	FIRST	SEMAR-A	SEMAR-A vs AIDR 3D	SEMAR-A vs FIRST	FIRST vs AIDR 3D
Degree of metal artefact (1/2/3/4)						
Reader 1	18/1/3/0	19/3/0/0	1/14/7/0	0.0001 ^a	<0.0001 ^a	0.1250
Reader 2	20/2/0/0	20/0/2/0	0/8/14/0	<0.0001 ^a	<0.0001 ^a	0.5000
Depiction of the apex of the tongue (1/2/3/4)						
Reader 1	18/3/0/1	18/3/0/1	1/15/4/2	<0.0001 ^a	<0.0001 ^a	1.0000
Reader 2	19/3/0/0	19/2/1/0	9/11/2/0	0.0005 ^a	0.0010 ^a	1.0000
Depiction of the root of the tongue (1/2/3/4)						
Reader 1	1/16/2/3	1/15/3/3	0/0/15/7	<0.0001 ^a	<0.0001 ^a	1.0000
Reader 2	12/7/3/0	12/7/2/1	0/4/15/3	<0.0001 ^a	<0.0001 ^a	1.0000
Depiction of the parapharyngeal space (1/2/3/4)						
Reader 1	2/9/8/3	1/11/3/7	0/0/5/17	<0.0001 ^a	<0.0001 ^a	0.2891
Reader 2	4/13/3/2	4/10/6/2	0/0/15/7	<0.0001 ^a	<0.0001 ^a	0.5078
Depiction of the superior portion of the internal jugular chain (1/2/3/4)						
Reader 1	0/1/15/6	0/0/13/9	0/0/0/22	<0.0001 ^a	0.0002 ^a	0.2891
Reader 2	0/8/10/4	0/7/8/7	0/0/4/18	<0.0001 ^a	0.0001 ^a	0.2891
Depiction of the parotid gland (1/2/3/4)						
Reader 1	0/0/15/7	0/2/13/7	0/0/2/20	0.0010 ^a	0.0002 ^a	0.6875
Reader 2	0/15/6/1	1/11/8/2	0/0/17/5	<0.0001 ^a	0.0001 ^a	0.5078

AIDR 3D, adaptive iterative dose reduction three dimensional; FIRST, forward-projected model-based iterative reconstruction solution; SEMAR-A, AIDR 3D with single-energy metal artefact reduction.

Scores for the degree of metal artefact (1 = severe artefact in a large area and 4 = no or minimal artefact).

Scores for the depiction of structures (1 = poor depiction in a large area and 4 = good depiction).

^aSignificant difference.

For the metal artefact index of the oral cavity, the following relationships were identified: AIDR 3D (572.0) > FIRST (477.7) > SEMAR-A (88.4). And significant differences were seen between each algorithm ($p < 0.0001$).

Discussion

The impaired image quality of neck CT due to metal artefact in patients with metallic dental fillings is

a problem. Our study indicates that SEMAR enables a significant reduction in metal artefacts on helical neck CT and a significant improvement in the depiction of the oral cavity and oropharyngeal region, while the effects of FIRST are limited. The depictions of structures in the oral cavity and oropharyngeal region other than the apex of the tongue were good or only slightly decreased with SEMAR-A. Therefore, SEMAR might be useful for evaluations of lesions in these structures (other than the apex of the tongue) with helical CT. Because a considerable number of patients have metallic

Figure 1 Axial CT images of a 58-year-old male reconstructed with adaptive iterative dose reduction three dimensional (AIDR 3D) (a), forward-projected model-based iterative reconstruction solution (FIRST) (b) and AIDR 3D with single-energy metal artefact reduction (SEMAR-A) (c). The degree of metal artefact (AIDR 3D/FIRST/SEMAR-A) was rated as 1 (severe in a large area)/1/2 (severe in a small area) and 1/1/3 (moderate) by Readers 1 and 2, respectively.

Figure 2 Axial CT images of a 47-year-old female with pathologically proven laryngeal carcinoma reconstructed with adaptive iterative dose reduction three dimensional (AIDR 3D) (a), forward-projected model-based iterative reconstruction solution (FIRST) (b) and AIDR 3D with single-energy metal artefact reduction (SEMAR-A) (c). The depiction of the internal jugular chain (AIDR 3D/FIRST/SEMAR-A) was rated as 3 (slightly decreased)/3/4 (good) and 2 (poor in a small region)/3/4 by Readers 1 and 2, respectively. Although both readers found these swollen lymph nodes with necrotic change (arrows), they are more clearly depicted with SEMAR-A (c) than with AIDR 3D (a) and FIRST (b).

dental fillings and SEMAR can be available for helical scan data, we believe that our study results may be applicable to considerable numbers of patients.

FIRST is categorized as a full iterative reconstruction algorithm. For reconstruction of images using FIRST, several models are considered during the iteration process, such as the anatomical-based regularization model, system model, statistical noise model, system optics model and cone-beam model, enabling a higher spatial resolution and a reduction in image noise and streak artefact. SEMAR is a metal-implanting method.¹¹ With this algorithm, the metal is first segmented from the original image. These data are then forward-projected in order to identify the metal trace on the sinogram and to correct it. Followed by back projections, tissue classification and forward projections, the final images are reconstructed.¹¹

Metal artefact was reported to be reduced in neck CT with SEMAR.^{15,16} However, these reports on SEMAR evaluated images reconstructed from volume scan data.^{15,16} Because a 16-cm range of z-axis can be covered with a single volume scan using 320-detector row CT, clinical applicability of a volume scan has been limited. In this study, we showed successful reduction of metal artefact with SEMAR for helical scan data. We also showed that depiction of each structure in the oral cavity and oropharyngeal region was significantly improved and that SEMAR was superior to FIRST for reducing metal artefact in neck CT.

Although metal artefact index in FIRST was significantly improved compared with AIDR 3D, the difference between them were not as large as the difference in metal artefact index between SEMAR-A and AIDR 3D.

And the degree of metal artefact reduction was not significant with FIRST in a qualitative method. A similar full iterative reconstruction algorithm of model-based iterative reconstruction (MBIR) available from GE Healthcare was reported to decrease metal artefact in neck CT.¹⁸ The difference between the result of MBIR in that previous study and the result of FIRST in our study might have come from a scoring method in addition to the difference of algorithm itself. We compared the depiction of each structure; however, in the aforementioned previous study, the image criteria score was calculated as the sum of the rating score of eight structures.

For the image at the level where no metal exists, we evaluated the CT attenuation and SD of the nuchal muscle. In SEMAR-A, the CT attenuation and SD of the nuchal muscle at a slice where no metal artefact exists was almost equivalent to that in AIDR 3D. This result is reasonable because the SEMAR algorithm starts by segmenting metal in the images and might not affect images at slices where no metal exists. The image noise of the nuchal muscle (at the slice where no metal exists) in FIRST was significantly higher than that in AIDR 3D and SEMAR-A. The difference in algorithms of AIDR 3D and FIRST might explain for this difference in image noise; however, the precise reason remains unknown. Because our purpose was to compare the metal artefact reduction in different reconstruction algorithms, the image quality of FIRST at slices where no metal exists was not thoroughly investigated. Further studies on the relationship between increased image noise and depiction of structures or diagnostic performance with FIRST are needed.

Table 2 Detailed results of quantitative image analyses

Anatomical structures	Median scores (with interquartile ranges)			Comparison (p-value)		
	AIDR 3D	FIRST	SEMAR-A	SEMAR-A vs AIDR 3D	SEMAR-A vs FIRST	FIRST vs AIDR 3D
CT attenuation (HU)						
Oral cavity	436.6 (125.5, 604.5)	425.5 (159.8, 601.1)	97.8 (58.7, 148.9)	<0.0001 ^a	<0.0001 ^a	0.5392
Nuchal muscle	66.1 (63.3, 70.5)	65.6 (62.4, 71.7)	66.1 (63.3, 70.5)	0.2886	0.5081	0.4487
SD for the ROI						
Oral cavity	572.1 (272.3, 776.4)	477.8 (237.5, 594.9)	88.5 (58.0, 161.2)	<0.0001 ^a	<0.0001 ^a	<0.0001 ^a
Nuchal muscle	5.1 (4.4, 6.1)	7.4 (6.4, 7.8)	5.1 (4.4, 6.1)	0.1841	<0.0001 ^a	<0.0001 ^a
Metal artefact index						
Oral cavity	572.0 (272.3, 776.4)	477.7 (237.4, 594.8)	88.4 (57.8, 161.1)	<0.0001 ^a	<0.0001 ^a	<0.0001 ^a

AIDR 3D, adaptive iterative dose reduction three dimensional; FIRST, forward-projected model-based iterative reconstruction solution; ROI, region of interest; SD, standard deviation; SEMAR-A, AIDR 3D with single-energy metal artefact reduction.

^aSignificant difference.

Several limitations of our study should be acknowledged. First, our study included a small number of patients and did not investigate the diagnostic performance for specific diseases. The improvement in the depiction of structures was remarkable with SEMAR-A and a statistically significant difference was seen between SEMAR-A and AIDR. However, future studies on the diagnostic performance (sensitivity, specificity and accuracy) for specific diseases with a large population are needed. Second, our study cannot be applied to similar reconstruction algorithms available from other vendors. Finally, we did not assess the material of the metallic dental fillings.

Conclusion

In conclusion, SEMAR enabled a significant reduction of metal artefacts and significant improvement in the depiction of the oral cavity and oropharyngeal region in the neck CT of patients with metallic dental fillings, while the effect of FIRST was limited. And for structures other than the apex of the tongue, their depictions were good or only slightly decreased with SEMAR-A. Therefore, image reconstruction with SEMAR would be recommended for patients with metallic dental fillings in helical neck CT, especially for structures other than the apex of the tongue.

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