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CLINICAL INVESTIGATION — IMAGING

Metal Artifact Reduction for Orthopedic Prosthesis in Lower Extremity CT Venography: Evaluation of Image Quality and Vessel Conspicuity

Hyunsik Woo[1] · Jee Won Chai[1] · Young Ho Choi[1] · Kwang Nam Jin[1]

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Abstract

Purpose This study evaluates the image quality of lower extremity CT venography reconstructed with orthopedic metal artifact reduction (O-MAR) in patients with unilateral or bilateral metallic prostheses in the hip or knee.

Methods This retrospective study was approved by our institutional review board, and informed consent was waived. Twenty-nine patients of lower extremity CT with 51 metallic hip or knee prostheses were reconstructed to both standard CT images and O-MAR images. The subjective image quality and vessel conspicuity for both images were evaluated by two readers using five-point scales (0–4). Vessel conspicuity scores of 3 or 4 were considered diagnostically acceptable. Image noise was measured in the air and subcutaneous fat.

Results O-MAR images showed significantly higher scores of subjective image quality ($p < .001$) and vessel conspicuity ($p = .002$) than standard CT images. Diagnostic acceptance of vessel conspicuity was not significantly different between O-MAR images and standard CT images ($p = 1.000$). O-MAR images showed significantly less image noise than conventional CT images ($p < .001$ for both air and subcutaneous fat).

Conclusion O-MAR may be an effective solution for the metal artifacts in lower extremity CT venography; however, the distance between prostheses and vessels affects the diagnostic acceptance in patients with metallic hip or knee prostheses.

Level of Evidence Level 4, Case Series.

Keywords Computed tomography · Orthopedic prosthesis · Metal artifact · Lower extremity · Venography

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✉ Kwang Nam Jin
wlsrhkdska@gmail.com

[1] Department of Radiology, Seoul Metropolitan Government-Seoul National University Boramae Medical Center, 20, Boramae-ro 5-gil, Dongjak-gu, Seoul 07061, Korea

Introduction

Total hip or knee replacement arthroplasty is one of the most commonly performed operations worldwide [1]; however, symptomatic venous thromboembolism develops in 2–5% of patients with knee or hip replacement arthroplasty [2]. Computed tomography (CT) is an essential tool in evaluating patients with orthopedic prostheses because it provides a direct visualization of the calcified bone and bone matrix as well as the hardware [3]. However, metallic prostheses produce severe artifacts in CT due to beam-hardening effects, photon starvation, and edge effects [4–6]. These metal artifacts reduce the image quality and diagnostic accuracy of periprosthetic tissues and adjacent vascular structures in CT [3, 7–9]. Ultrasound does not cause metallic artifacts and is the first choice for the diagnosis of deep vein thrombosis (DVT) [10]; however, it cannot penetrate the superficial hardware margin, does not show the entire venous anatomy of the lower extremities, and is dependent on the skill of the operator.

Since the invention of CT, various methods such as image processing algorithm and iterative deblurring have been proposed to suppress metal artifacts [11, 12]. Commercially available metal artifact reduction methods have been recently proven to improve image quality in abdominopelvic CT, head-and-neck CT, and cerebral CT angiography [13–17]. However, only one study has investigated the image quality of metal artifact reduction for orthopedic implants in lower extremity CT venography [18]. Metal artifact reduction for orthopedic implants (O-MAR; Philips Healthcare, Best, the Netherlands) is one projection-based metal artifact reduction algorithm that can substrate the corrupted data with estimates for the corrected values after detecting and segmenting the corrupted projection data produced by metallic implants [19]. This study evaluates and compares the image quality of orthopedic metal artifact reduction (O-MAR) images and standard CT images of lower extremity CT venography in patients with metallic hip or knee prostheses.

Materials and Methods

Study Subjects

This retrospective study was approved by our institutional review board, and informed consent was waived. From January 2013 to September 2014, a search of our institutional radiology information system revealed 450 subjects who underwent lower extremity CT venography for suspected DVT. Reconstructed O-MAR images and standard CT images showed 36 subjects with orthopedic prosthesis in the hip or knee. Internal fixation for femur neck fracture were classified as hip prosthesis. We excluded four subjects without O-MAR images and three subjects with only small fixation screws in the knee. There were six subjects of unilateral knee prosthesis and 14 subjects of bilateral knee prostheses; in addition, there were six subjects of unilateral hip prosthesis, one subject of bilateral hip prostheses, one subject of unilateral knee and hip prostheses, one subject of bilateral knee prostheses and unilateral hip prosthesis, and one subject of bilateral knee and hip prostheses. Subjects with multiple prostheses were counted as separate cases of prostheses. Finally, 51 cases of metallic hip or knee prostheses with O-MAR and standard CT images were included in the analysis. Table 1 summarizes the demographic data.

Table 1 Characteristics of study participants

Characteristics	Value
No. of subjects	29
Women	26
Men	3
Age (year)[a]	74 ± 6 (62–88)
Body mass index (kg/m^2)[a]	26 ± 3 (17–31)
No. of metallic prosthesis	51
Knee	39
Unilateral total knee replacement arthroplasty	7
Bilateral total knee replacement arthroplasty	16
Hip	12
Unilateral total hip replacement arthroplasty	6
Bipolar hip hemiarthroplasty	2
Internal fixation for femur neck fracture	4

[a]Mean ± SD (range)

Image Acquisition and Reconstruction

Lower extremity CT venography was performed with a 128-channel CT scanner (Ingenuity, Philips Healthcare, Cleveland, Ohio) in the craniocaudal direction from the iliac crest to the ankles. Scanning was performed approximately 3 minutes after the intravenous injection of iodine contrast. We injected 2 mL/kg of iodine contrast (Optiray 320; Mallinckrodt, St. Louis, MO) with a power injector at a rate of 2.5 mL/s via an 18- or 20-gauge catheter placed at the antecubital vein. The scanning parameters were a tube voltage of 120 kVp, reference tube current time of 90 mAs, a detector collimation of 64 mm × 0.625 mm, gantry rotation time of 400 ms, and pitch of 1.49. The reconstruction parameters of standard CT images were a slice thickness of 5 mm, increment of 5 mm, standard filter (B), and an iterative reconstruction technique (iDose4, Philips Healthcare). O-MAR images were reconstructed in addition to standard CT images for patients with metallic hip or knee prostheses. The reconstruction parameters for O-MAR images were the same as standard CT images except for the application of O-MAR. Volume CT dose index ($CTDI_{vol}$) and dose-length product (DLP) were recorded from the dose report image of each CT scan.

Qualitative Image Analysis

Two board-certified radiologists (J.W.C and K.N.J) blinded to the reconstruction parameters retrospectively evaluated the subjective image quality of O-MAR images and standard CT images using a picture archiving and communication system viewer (Maroview, Infinitt, Seoul, Korea) while displayed side by side. The readers independently selected an axial CT image that depicted the longest diameter of the prosthesis and the most prominent metal artifact [15]. Adjustment of window width and level was

Table 2 Comparison of subjective image quality and vessel conspicuity of metal artifact reduction for orthopedic prosthesis (O-MAR) images and standard CT images

Characteristics	Prosthesis	Reader	Scores (mean ± SD)		p
			O-MAR	Standard CT	
Subjective image quality	Knee	1	1.8 ± 0.6	0.5 ± 0.6	< .001
		2	1.4 ± 0.7	0.1 ± 0.3	< .001
	Hip	1	3.4 ± 0.7	1.4 ± 0.5	.002
		2	2.8 ± 0.7	1.3 ± 0.5	.002
	Overall	1	2.2 ± 0.9	0.7 ± 0.7	< .001
		2	1.7 ± 0.9	0.4 ± 0.6	< .001
Vessel conspicuity	Knee	1	0.4 ± 0.6	0.1 ± 0.4	.013
		2	0.2 ± 0.4	0.1 ± 0.3	.102
	Hip	1	3.7 ± 0.7	3.2 ± 0.6	.058
		2	3.6 ± 0.7	3.0 ± 0.6	.008
	Overall	1	1.1 ± 1.5	0.8 ± 1.4	.002
		2	1.0 ± 1.5	0.8 ± 1.3	.002

[a]SD = Standard deviation.

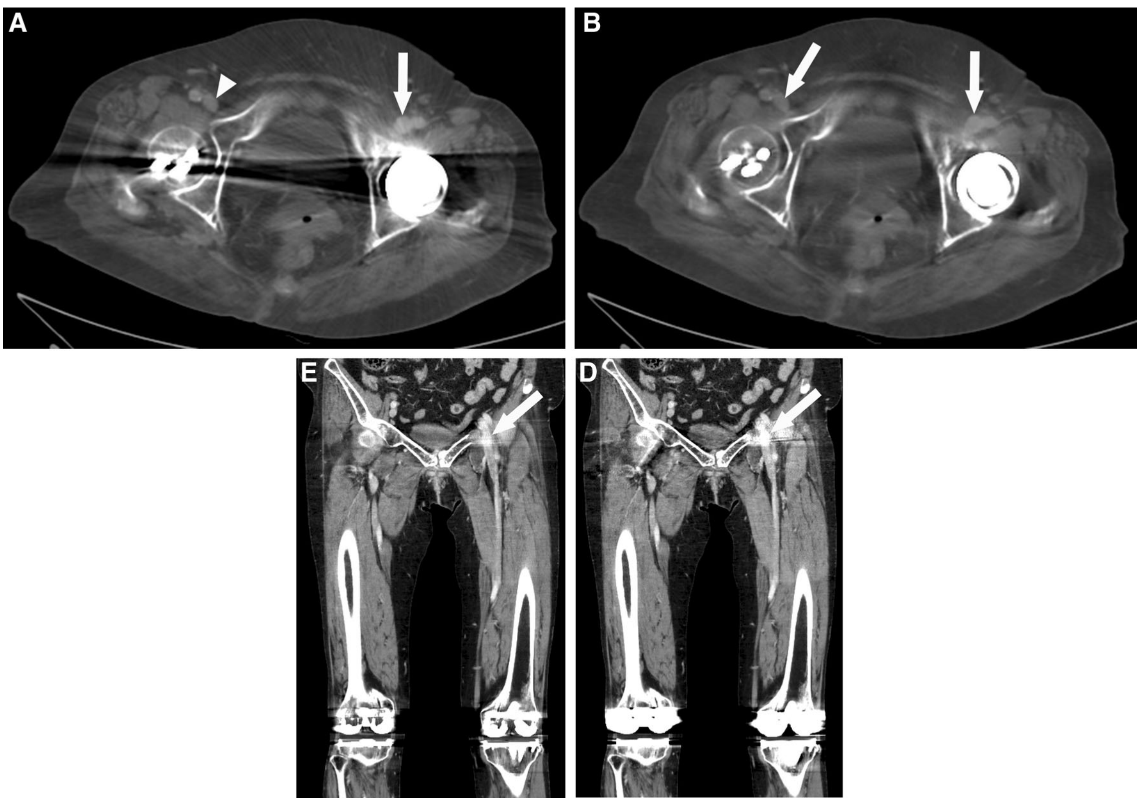

Fig. 1 Lower extremity CT venography in an 84-year-old woman with bilateral hip prostheses and bilateral total knee prostheses. Standard axial CT image, **A,** shows a faintly recognizable left femoral vein (arrow) with moderate confidence with partial contamination of metal artifacts. The right femoral vein is fully recognizable (arrow head). O-MAR axial image, **B**, shows decreased metal artifacts with both femoral veins fully recognizable (arrows). On the coronal section showing the left femoral venous segment (arrow), vessel conspicuity is better in O-MAR coronal image (**D**) than standard coronal image (**C**). O-MAR images were considered diagnostically acceptable for both femoral veins in terms of vessel conspicuity.

allowed. Subjective image quality evaluation focused on periprosthetic metal artifacts using the following five-point scale: 0 = severe artifact with nondiagnostic image quality, 1 = major artifacts with considerably impaired image quality, 2 = moderate artifacts with partly impaired image quality, 3 = minor artifacts with acceptable image quality, and 4 = minimal or no artifacts with good image quality [15, 20].

Table 3 Diagnostic acceptance of metal artifact reduction for orthopedic prosthesis (O-MAR) images and standard CT images

Prosthesis	Diagnostic Acceptance	Reader 1		Reader 2	
		O-MAR	Standard CT	O-MAR	Standard CT
Knee	Acceptable	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	Unacceptable	39 (100.0%)	39 (100.0%)	39 (100.0%)	39 (100. 0%)
Hip	Acceptable	11 (91.7%)	11 (91.7%)	11 (91.7%)	10 (83.3%)
	Unacceptable	1 (8.3%)	1 (8.3%)	1 (8.3%)	2 (16.7%)
Overall*	Acceptable	11 (21.6%)	11 (21.6%)	11 (21.6%)	10 (19.6%)
	Unacceptable	40 (78.4%)	40 (78.4%)	40 (78.4%)	41 (80.4%)

*p values were 1.000 for both readers in the comparison between O-MAR and standard CT images

Table 4 Comparison of image noise of metal artifact reduction for orthopedic prosthesis (O-MAR) images and standard CT images

Image noise	Prosthesis	Noise (HU; mean ± SD)		p
		O-MAR	Standard CT	
Air	Knee	18.6 ± 9.3	32.1 ± 47.1	< .001
	Hip	10.0 ± 5.9	10.1 ± 5.6	.209
	Overall	16.6 ± 9.3	26.9 ± 18.4	< .001
Subcutaneous fat	Knee	16.2 ± 11.1	64.5 ± 47.1	< .001
	Hip	9.2 ± 3.3	12.3 ± 3.2	.006
	Overall	14.5 ± 10.2	52.3 ± 46.8	< .001

HU Hounsfield unit; *SD* standard deviation.

The readers also evaluated the vessel conspicuity of the femoral or popliteal veins using the following five-point scale: 0 = totally obscured, 1 = questionably recognizable, 2 = faintly recognizable with low confidence, 3 = fairly recognizable with moderate confidence, and 4 = fully recognizable with high confidence. Vessel conspicuity scores from 0 to 2 were considered unacceptable and scores of 3 or 4 were considered acceptable for the diagnosis of DVT. Average subjective image quality and vessel conspicuity scores were compared between O-MAR images and standard CT images.

Quantitative Image Analysis

Quantitative image analysis was performed by one reader (J.K.N). The standard deviation (SD) of CT attenuation was measured as image noise by placing circular regions of interest (ROIs) on the axial CT image that depicted the longest diameter of the prosthesis. The ROIs were located in the air ventral to the prosthesis and the subcutaneous fat dorsal to the prosthesis [21, 22]. Large circular ROIs were drawn in the air ventral to the prosthesis and in the subcutaneous fat dorsal to the prosthesis to minimize measurement bias. The sizes of the ROIs were 1000–2000 mm^2 and 10–400 mm^2, respectively.

Statistical Analysis

Subjective image quality, vessel conspicuity, and image noise were expressed as mean ± SD, and the Wilcoxon signed-rank test compared O-MAR images and standard CT images. The diagnostic acceptance of vessel conspicuity was expressed as frequencies and percentages, and McNemar's test was used for comparison. Interobserver agreement between the two readers was evaluated using Cohen's weighted kappa statistics with linear weights. Statistical analysis was performed using commercially available software (SPSS Statistics version 20, IBM, Chicago, Ill; MedCalc Software, MedCalc, Mariakerke, Belgium). A p value of less than .05 was considered significant.

Results

O-MAR images showed significantly higher scores of subjective image quality ($p < .001$) and vessel conspicuity ($p = .002$) than standard CT images (Table 2) (Fig. 1). There was no diagnostically acceptable case of both O-MAR images and standard CT images for knee prostheses (Table 3). However, more than 80% of O-MAR images and standard CT images showed diagnostically acceptable vessel conspicuity for hip prosthesis. O-MAR images showed significantly less image noise than conventional CT images in the air and subcutaneous fat ($p < .0001$ for both) (Table 4).

Inter-reader agreements for subjective image quality were .454 in O-MAR images and .445 in standard CT images. For the vessel conspicuity, inter-reader agreements were .760 in O-MAR images and .837 in standard CT images. Average $CTDI_{vol}$ and DLP were 4.8 ± 1.0 mGy and 615.6 ± 132.5 mGy × cm, respectively.

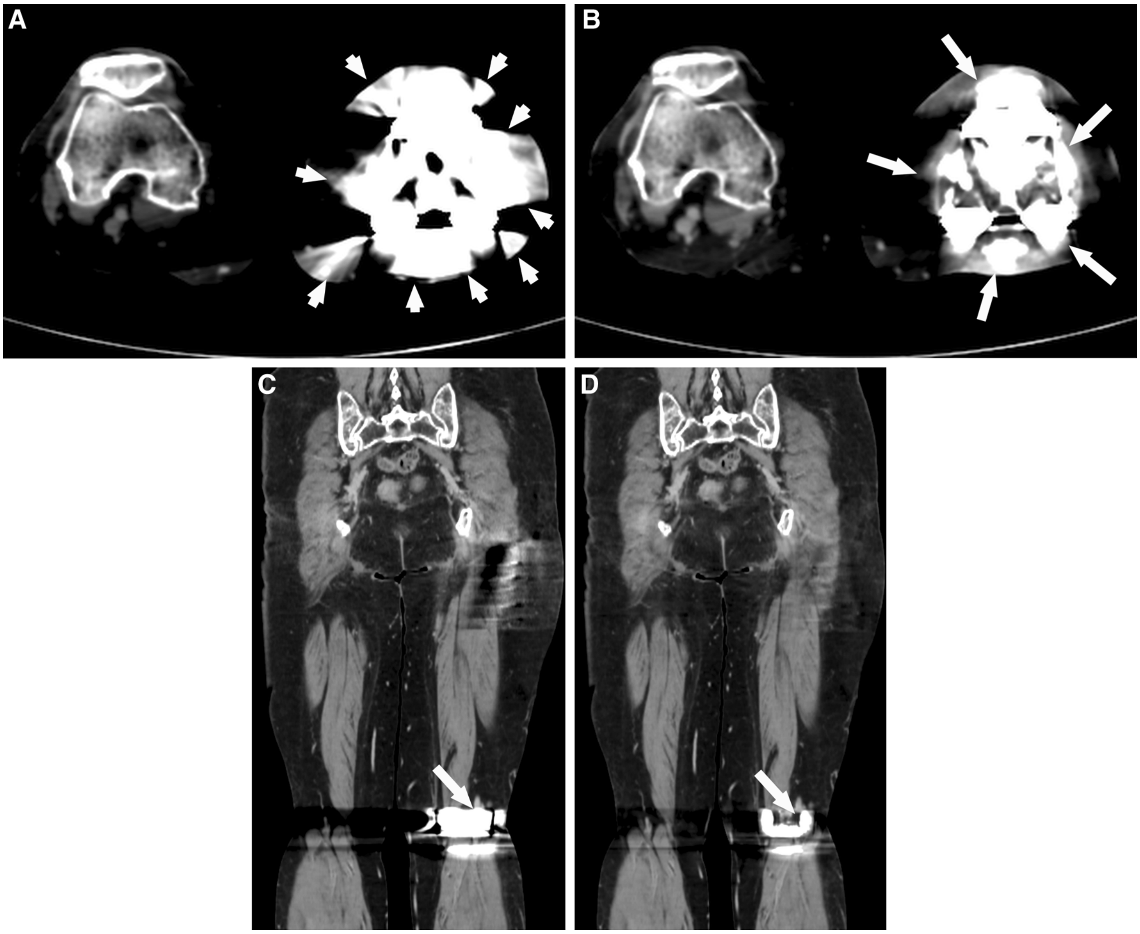

Fig. 2 Lower extremity CT venography in a 78-year-old woman with the left knee prosthesis and left hip prosthesis. Standard CT axial image, **A**, shows severe metal artifacts (short arrows) produced by the left knee prosthesis. O-MAR image, **B**, shows decreased metal artifacts (arrows). However, the left popliteal vein is obscured in both images. Standard coronal image, **C**, shows total obscuring of the left popliteal vein (arrow) adjacent to the metal artifact. O-MAR coronal image, **D**, also demonstrates the total obscuring of the left popliteal vein (arrow), although the length of obscuring segment was decreased. Both standard and O-MAR images are considered diagnostically unacceptable for vessel conspicuity in the left popliteal vein.

Discussion

This study revealed that O-MAR significantly improved subjective image quality, vessel conspicuity, and image noise of lower extremity CT venography in patients with metallic hip or knee prostheses. However, there was no diagnostically acceptable case of O-MAR images and standard CT images in patients with knee prostheses. In contrast, more than 80% of O-MAR images with hip prostheses showed diagnostically acceptable vessel conspicuity of the femoral veins (91.7% for reader 1 and 83.3% for reader 2) (Table 3). In addition, the diagnostic acceptance of standard CT images was already high with no significant difference for the diagnostic acceptance existing between O-MAR images and standard CT images. This means that O-MAR can only be used for hip prostheses and to reduce metal artifacts in lower extremity CT venography.

The results differ from previous studies. Yasaka et al. reported that the metal artifact reduction algorithm decreased metal artifacts and increased diagnostic confidence for the assessment of pelvic organs in pelvic CT [13]. Discrepancies in previous results and our study may be explained by differences in the distance between the target organ and metallic prosthesis. Data points corrupted by metal artifacts in the sinogram are removed and replaced with interpolated values of simulated tissue during the iteration steps of O-MAR [23]; therefore, a closer the target organ to the metallic prosthesis results in more data points replaced with interpolated values in the sinogram that can contribute to the reconstruction of the target organ. Consequently, a small organ closer to a large metallic prosthesis can possibly suffer image blurring from excessive interpolated data points.

This may explain why there was no diagnostically acceptable O-MAR image of the popliteal vein in patients

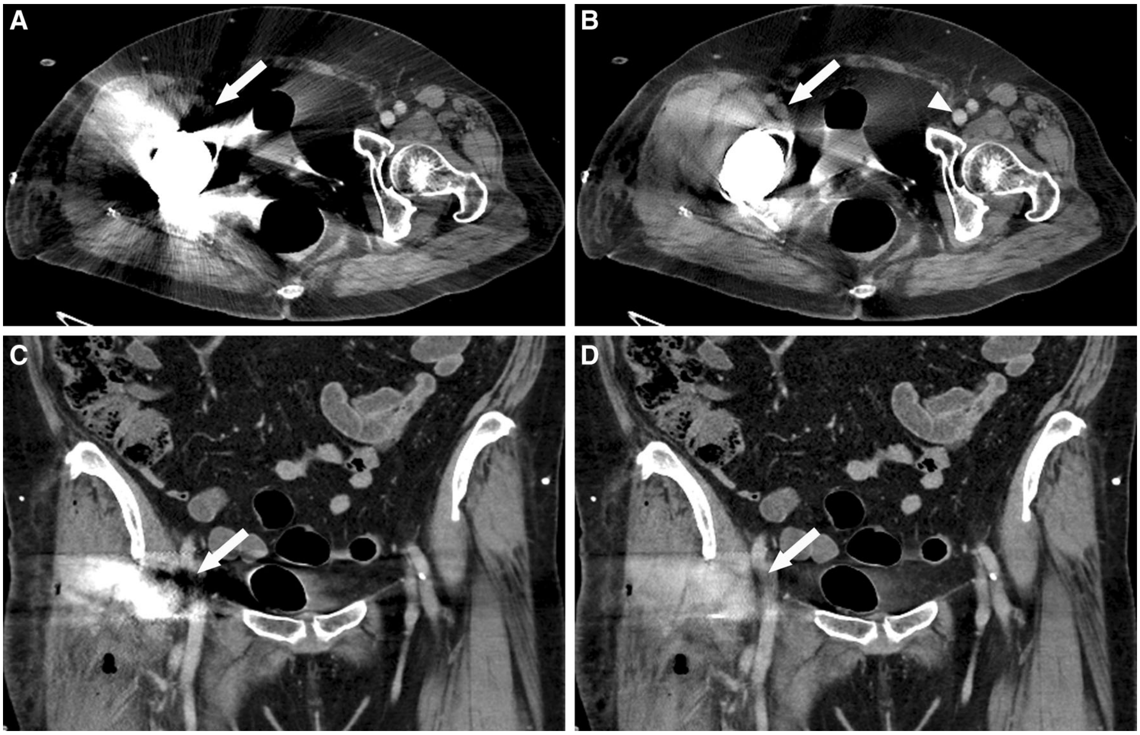

Fig. 3 Lower extremity CT venography in a 69-year-old woman. Standard CT image, **A**, shows severe metal artifact obscuring of the right femoral vein (arrow). O-MAR image, **B**, shows a faintly recognizable right femoral vein (arrow) despite of reduced metal artifacts. Although the vessel margin of the right femoral vein is demarcated, the intraluminal attenuation of the right femoral vein is distinctly lower than that of the left femoral vein (arrow head). Coronal standard (**C**) and O-MAR (**D**) images show the right femoral vein (arrow) obscured by metal artifact, although the degree of obscuring is less severe on coronal O-MAR image. Both images are considered diagnostically unacceptable for vessel conspicuity.

with metallic knee prostheses (Fig. 2). As the popliteal vein was too close to the knee prosthesis which was much larger than the popliteal vein, the conspicuity of the popliteal vein was obscured although the metal artifact and image noise was suppressed in O-MAR images. There were two cases where the reader rated the vessel conspicuity of the femoral vein as diagnostically unacceptable on O-MAR images. Two cases with hip prosthesis were evaluated as diagnostically unacceptable by reader 2 (Table 3). In these cases, the left femoral vein was close to the left metallic hip prosthesis due to paucity of the subcutaneous fat in the left femoral area. Similar to the situation of the popliteal vein, the conspicuity of the left femoral vein was obscured and blurred despite the slightly suppressed metal artifacts (Fig. 3). This also supports the possible influence of distance from metallic prosthesis on metal artifact reduction.

Non-depicted venous segment obscured by the metallic prosthesis may not be problematic when diagnosing DVT. The evaluation of the venous segments proximal and distal to the non-depicted venous segment would be sufficient to make a correct DVT diagnosis because most DVT initially occurs in the calf vein and then propagates to the femoropopliteal veins [24] with rare occurrences of an isolated DVT in the femoral or iliac vein [25, 26].

There are several different metal artifact reduction algorithms. Artifacts can also be reduced using high tube current or high tube voltage methods; however, a reduction achieved using this approach is limited and requires an increased radiation dose [27]. Recently developed virtual monochromatic imaging in dual-energy CT enables the effective reduction of beam hardening on high keV [28]. However, it requires specific CT scanners and scanning protocols. Another approach for artifact reduction and a better evaluation of soft tissue around metal implants is the use of an advanced iterative reconstruction algorithm instead of a standard filtered back projection [29]. The iterative reconstruction algorithm minimizes scatter and edge effects using correction algorithms [30].

There are several limitations to this study. First, only a small number of subjects were included retrospectively. The result of no significant difference in diagnostic acceptance of vessel conspicuity between O-MAR images and standard CT images might be due to the small sample size. However, despite this study not being designed as an equality test, the high p value of 1.000 implicates that the result of no difference was due to true non-difference and not due to the small sample size. Second, it was impossible to completely blind the readers to the reconstruction parameters. The comparison results may also have deviated in favor of O-MAR images because the readers could easily distinguish between O-MAR images and non-O-MAR images due to the metal artifacts in O-MAR images being dramatically suppressed. However, the diagnostic acceptance of vessel conspicuity between O-MAR images and standard CT images was not significantly different despite the potential bias. Third, the diagnostic performance of DVT between O-MAR images and standard CT images could not be evaluated because ultrasonography as a reference standard for DVT was not performed. Finally, this study only included CT venography images and did not evaluate the attenuation value in femoral or popliteal veins. Further studies will be required to prove the effect of O-MAR for CT angiography.

Conclusion

O-MAR improves subjective image quality, vessel conspicuity, and image noise for lower extremity CT venography in patients with metallic hip or knee prostheses; however, the distance between prostheses and vessels affects diagnostic acceptance.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and Animal Participants All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Ethical Approval This study has obtained IRB approval from SMG-SNU Boramae medical center and the need for informed consent was waived.

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