JKMS

Original Article
Medical Imaging

Check for updates

OPEN ACCESS

Address for Correspondence:
Sun-Won Park, MD, PhD
Department of Radiology, Seoul National University College of Medicine, Seoul Metropolitan Government-Seoul National University Boramae Medical Center, 20 Boramae-ro 5-gil, Dongjak-gu, Seoul 07061, Korea.
E-mail: swpark8802@gmail.com

ORCID iDs
Leonard Sunwoo
https://orcid.org/0000-0003-0374-8658
Sun-Won Park
https://orcid.org/0000-0002-5063-2685
Jung Hyo Rhim
https://orcid.org/0000-0001-5822-9770
Yeonah Kang
https://orcid.org/0000-0002-5078-3213
Young Seob Chung
https://orcid.org/0000-0003-3965-8507
Young-Je Son
https://orcid.org/0000-0002-8702-9804
Soo Chin Kim
https://orcid.org/0000-0002-0511-1696

Metal Artifact Reduction for Orthopedic Implants: Brain CT Angiography in Patients with Intracranial Metallic Implants

Leonard Sunwoo [1], Sun-Won Park [2,3] Jung Hyo Rhim [3], Yeonah Kang [3], Young Seob Chung [4], Young-Je Son [4], and Soo Chin Kim [5]

[1]Department of Radiology, Seoul National University Bundang Hospital, Seongnam, Korea
[2]Department of Radiology, Seoul National University College of Medicine, Seoul, Korea
[3]Department of Radiology, Seoul Metropolitan Government-Seoul National University Boramae Medical Center, Seoul, Korea
[4]Department of Neurosurgery, Seoul Metropolitan Government-Seoul National University Boramae Medical Center, Seoul, Korea
[5]Department of Radiology, Seoul National University Hospital, Healthcare System Gangnam Center, Seoul, Korea

ABSTRACT

Background: The purpose of this study was to qualitatively and quantitatively evaluate the effects of a metal artifact reduction for orthopedic implants (O-MAR) for brain computed tomographic angiography (CTA) in patients with aneurysm clips and coils.

Methods: The study included 36 consecutive patients with 47 intracranial metallic implants (42 aneurysm clips, 5 coils) who underwent brain CTA. The computed tomographic images with and without the O-MAR were independently reviewed both quantitatively and qualitatively by two reviewers. For quantitative analysis, image noises near the metallic implants of non-O-MAR and O-MAR images were compared. For qualitative analysis, image quality improvement and the presence of new streak artifacts were assessed.

Results: Image noise was significantly reduced near metallic implants ($P < 0.01$). Improvement of implant-induced streak artifacts was observed in eight objects (17.0%). However, streak artifacts were aggravated in 11 objects (23.4%), and adjacent vessel depiction was worsened in eight objects (17.0%). In addition, new O-MAR-related streak artifacts were observed in 32 objects (68.1%). New streak artifacts were more prevalent in cases with overlapping metallic implants on the same axial plane than in those without ($P = 0.018$). Qualitative assessment revealed that the overall image quality was not significantly improved in O-MAR images.

Conclusion: In conclusion, the use of the O-MAR in patients with metallic implants significantly reduces image noise. However, the degree of the streak artifacts and surrounding vessel depiction were not significantly improved on O-MAR images.

Keywords: Aneurysm; Computed Tomography; Computed Tomographic Angiography; Metal Artifact Reduction for Orthopedic Implants; Image Noise

Author Contributions

Conceptualization: Sunwoo L, Park SW. Data curation: Sunwoo L, Park SW, Rhim JH, Kang Y, Chung YS, Son YJ, Kim SC. Formal analysis: Sunwoo L, Park SW, Rhim JH, Kang Y. Methodology: Sunwoo L, Park SW, Kim SC. Validation: Sunwoo L, Park SW. Visualization: Sunwoo L. Writing - original draft: Sunwoo L. Writing - review & editing: Park SW.

INTRODUCTION

Computed tomographic angiography (CTA) offers excellent visualization of small vascular details, enabling the detection of small aneurysms.[1,2] However, after treatment such as surgical clipping or endovascular coil embolization, the evaluation of intracranial vessels is hampered by beam-hardening and photon starvation artifacts caused by the metallic implants.[3-5] Beam-hardening is caused by the increase in mean energy transmitted when the beam passes through an object due to preferential absorption of lower-energy protons. Photon starvation refers to the decreased number of photons that reach the detector due to the attenuation of the X-ray beam after passing through high-atomic-number materials such as metal or bone.[4] The combination of these two artifacts produces streak artifacts, observed as alternating dark bands obscuring the surrounding area on computed tomography (CT) images.

To manage this issue, adjustments of CT scan parameters, such as increasing the tube voltage and current, reducing the collimation and field-of-view, and the application of a dedicated reconstruction kernel, may be helpful.[6,7] Surgical clips positioned perpendicular to the scan plane produce fewer artifacts.[7] In addition, several techniques have been proposed to reduce the metal artifact on CT, including the monoenergetic processing of dual-energy CT data; sinogram inpainting methods; and iterative, statistical, and filtering methods.[8,9] Several studies have found that metal artifact reduction (MAR) is useful for CTA or flat-panel detector CT in patients with intracranial metallic implants.[10-13]

The metal artifact reduction for orthopedic implants (O-MAR; Philips Healthcare, Best, the Netherlands) is a commercial iterative reconstruction method intended to reduce metal artifacts on conventional CT.[14] The O-MAR is based on an iterative algorithm that generates a metal-only image from the metal sinogram and subtracts it from the original input image. This process is repeated until no large clusters of metal pixels are present in the resulting image. To date, several studies have evaluated its ability to reduce the metallic artifacts in various target lesions.[15-19] However, to the best of our knowledge, no study has investigated the effectiveness of the O-MAR in patients with intracranial metallic implants. The purpose of this study was to qualitatively and quantitatively evaluate the effects of the O-MAR on brain CTA images in patients with aneurysm clips and coils.

METHODS

Subjects

Thirty-six consecutive patients (14 men and 22 women; mean age, 58.0 years; range, 38–80 years) who underwent brain CTA scanning after undergoing surgical clipping or endovascular coil embolization for intracranial aneurysm from December 2013 through January 2016 were enrolled in this study.

Image acquisition

All CTA images were obtained with a 128-channel multidetector CT scanner (Ingenuity; Philips Healthcare). The following CT parameters were used: tube voltage, 120 kVp; effective tube current-time product, 50–300 mAs; detector configuration, 0.625 mm; pitch, 1.172; rotation time, 0.4 s; matrix, 512 × 512; slice thickness, 0.9 mm; reconstruction interval, 0.45 mm. CT images were obtained in the unenhanced and arterial phases. All patients received 100 mL of Optiray 350 (Ioversol; Mallinckrodt, Hazelwood, MO, USA) followed by

a 30-mL saline flush injected at a rate of 4.5 mL/s using a power injector. All CT images were reconstructed with an iterative reconstruction algorithm at level 2 (iDose2). The iDose2 images were processed without the O-MAR (hereafter referred as non-O-MAR images) or with the O-MAR (hereafter referred to as O-MAR images).

Image analysis

Two qualified neuroradiologists (L.S. and S.W.P.) of 8 and 23 years of clinical experience, respectively, independently reviewed the images. The axial non-O-MAR images and O-MAR images were reviewed while displayed side-by-side.

Qualitative analysis

The images were evaluated for the degree of streak artifacts and the confidence in the depiction of the surrounding vessels for each metallic implant. In addition, the presence of new streak artifacts on O-MAR images was assessed. The degree of streak artifacts was graded using the following scale: 1) no streak artifact; 2) mild streak artifact that does not interfere with the depiction of adjacent structures; 3) moderate streak artifact that mildly impairs the depiction of adjacent structures; and 4) severe streak artifact that significantly impairs the depiction of adjacent structures. The confidence of the surrounding vessel depiction was evaluated on the following 3-point scale: 1) no loss of adjacent vessel density; 2) some loss of adjacent vessel density, but diagnostic; and 3) significant impairment of adjacent vessel interpretation.

The reviewers also evaluated the presence of new artifacts on the following scale: 1) no new streaks; 2) new streaks that do not interfere with the interpretation of adjacent structures; and 3) new streaks that impair interpretation. To assess the influence of two or more metallic objects on the same axial plane, the number of cases with overlapping objects and the presence of new artifacts in each case were recorded.

Quantitative analysis

Circular regions of interest (ROIs) approximately 25 mm² in size were manually placed in both non-O-MAR and O-MAR images at the following areas: immediate vicinity of the clip or coil mass, adjacent brain parenchyma, bilateral temporalis muscle, and air outside the cranium at the level of metallic implant (**Fig. 1**). ROI for immediate vicinity of the clip or coil mass was
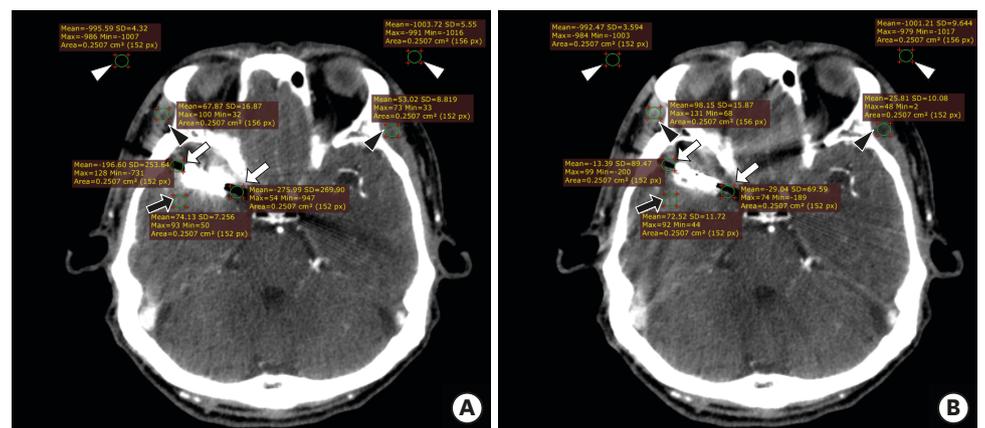

Fig. 1. Locations of the ROIs used for image analysis. Circular ROIs approximately 25 mm² in size were placed on (**A**) non-O-MAR images and on (**B**) O-MAR images at the following areas: immediate vicinity of the clip or coil mass (white arrows), adjacent brain parenchyma (black arrows), bilateral temporalis muscle (black arrowheads), and the air outside the cranium at the level of the metallic implant (white arrowheads).
ROIs = regions of interest, O-MAR = metal artifact reduction for orthopedic implants.

placed within 5 mm distance from the metallic object, where the streak artifact was severest. For clips, the ROI was placed at the areas just next to the head or tail portions of the clip along its long axis. ROI for adjacent parenchyma was placed at the nearby brain parenchyma, farther than 10 mm from the metallic object. The mean CT number and the standard deviation (SD) (i.e., image noise) of each ROI were recorded.

Statistical analysis

The qualitative and quantitative variables of the non-O-MAR and O-MAR images were compared using a Wilcoxon signed rank test. The frequency of the variables was compared using a Fisher's exact test. Kappa (κ) statistics with linear weighting and intraclass correlation coefficients (ICCs) were used to assess interobserver agreement. The κ and ICC values of < 0, 0–0.20, 0.21–0.40, 0.41–0.60, 0.61–0.80, or > 0.81 indicated negative, positive but poor, fair, moderate, good, or substantial agreement, respectively. Statistical analyses were performed using MedCalc (version 17.6; MedCalc Software, Mariakerke, Belgium). P values < 0.05 were considered significant.

Ethics statement

The present study protocol was reviewed and approved by the Institutional Review Board of Seoul Metropolitan Government-Seoul National University Boramae Medical Center (approval No. L-2014-165). The requirement for informed consent was waived.

RESULTS

Subject characteristics

A total of 47 treated aneurysms (42 clips and 5 coils) of 36 patients were analyzed. The locations of the aneurysms were the distal internal carotid artery (including the origins of the posterior communicating artery, superior hypophyseal artery, and anterior choroidal artery; n = 8; 19.0%), anterior cerebral artery (n = 13; 27.7%), and middle cerebral artery (n = 26; 55.3%). Twenty-seven patients had a single aneurysm, seven patients had double aneurysms, and two patients had triple aneurysms. The clips of known types were titanium and were 3–9 mm in length. Ten patients who had undergone surgery at an outside hospital had clips of unknown types. All coils were made of platinum.

Qualitative analysis

The results of the qualitative analysis are summarized in **Table 1**. The degree of streak artifact and the confidence in the surrounding vessel depiction were not significantly improved with the use of the O-MAR. The overall interobserver agreements were good to substantial.

Improvement of implant-induced streak artifacts was noted in 8 objects (17.0%, 8/47). However, streak artifacts were aggravated in 11 objects (23.4%, 11/47), and adjacent vessel

Table 1. Comparison between qualitative variables of O-MAR and non-O-MAR images

Qualitative variables		Non-O-MAR	O-MAR	*P* value
Streak artifact	Reviewer 1[a]	2 (2.0–3.0)	2 (2.0–3.0)	0.225
	Reviewer 2[a]	2 (2.0–3.0)	2 (2.0–3.0)	0.231
	κ (95% CI)	0.855 (0.726–0.984)	0.863 (0.757–0.970)	
Vessel depiction	Reviewer 1[a]	2 (2.0–2.75)	2 (2.0–3.0)	0.106
	Reviewer 2[a]	2 (2.0–3.0)	2 (1.0–3.0)	0.121
	κ (95% CI)	0.847 (0.706–0.989)	0.764 (0.623–0.906)	

O-MAR = metal artifact reduction for orthopedic implants, CI = confidence interval.
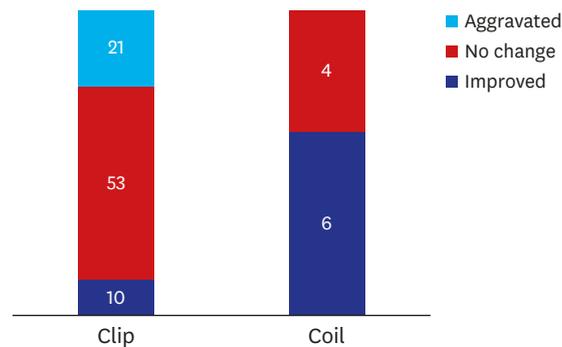[a]Values in parentheses are interquartile ranges.

Fig. 2. Streak artifact improvement in clips and coils using O-MAR. The streak artifact improvement was significantly more evident in clips compared to coils (P = 0.002).
O-MAR = metal artifact reduction for orthopedic implants.

depiction was worse in 8 objects (17.0%, 8/47). New streak artifacts were noted in 32 objects (68.1%, 32/47). Of 94 interpretations by the two reviewers, 27 objects (28.7%, 27/94) were accompanied by impaired interpretation. All coils (n = 5) on non-O-MAR images showed extensive streak artifacts. However, improvements in the streak artifacts were noted in 60% (6 of 10 interpretations) of the coils, and none showed aggravation of streak artifacts. Overall, a significant difference was observed between the clips and coils regarding streak artifact improvement (P = 0.002) (**Figs. 2** and **3**).

In addition, we noted that 2 or more metallic implants were present in one axial image in 21 patients (58.3%, 21/36). New streak artifacts were significantly more prevalent in these cases than in cases without coexistent metallic objects in one axial image (P = 0.018) (**Table 2**). Of note, in 2 cases in which a clip and a coil mass were coexistent on an axial image, the O-MAR improved the streak artifact and the depiction of the vessels (**Fig. 4**).

Quantitative analysis

The results of the quantitative analysis are presented in **Table 3**. For all ROI locations (immediate vicinity of the metallic implant, adjacent parenchyma, temporalis muscle, and extracranial air), the median CT number was not significantly different between the non-O-MAR and O-MAR images. In contrast, the image noises (SD of the ROI) in the immediate vicinity of the metallic implant and the extracranial air were significantly lower in O-MAR images than in non-O-MAR images in both the precontrast and postcontrast phases (all, P = 0.001 or P < 0.001). In addition, the image noise of the temporalis muscle was only significantly lower for the postcontrast phase of O-MAR images compared to non-O-MAR images (P = 0.015). The image noise in the adjacent parenchyma was not significantly different between non-O-MAR and O-MAR images. The ICC values of areas near the metallic implants ranged from 0.82 to 0.99, suggesting substantial agreement. The interobserver agreements of all but one remaining values were good to substantial; the exception was the image noise of the extracranial air, which ranged from fair to moderate.

DISCUSSION

In the present study, image noise, represented by the SD of the ROI, was significantly reduced on O-MAR compared to non-O-MAR images in the immediate vicinity of the metallic object. Reduced streak artifacts were noted in 17.0% of the metallic implants when
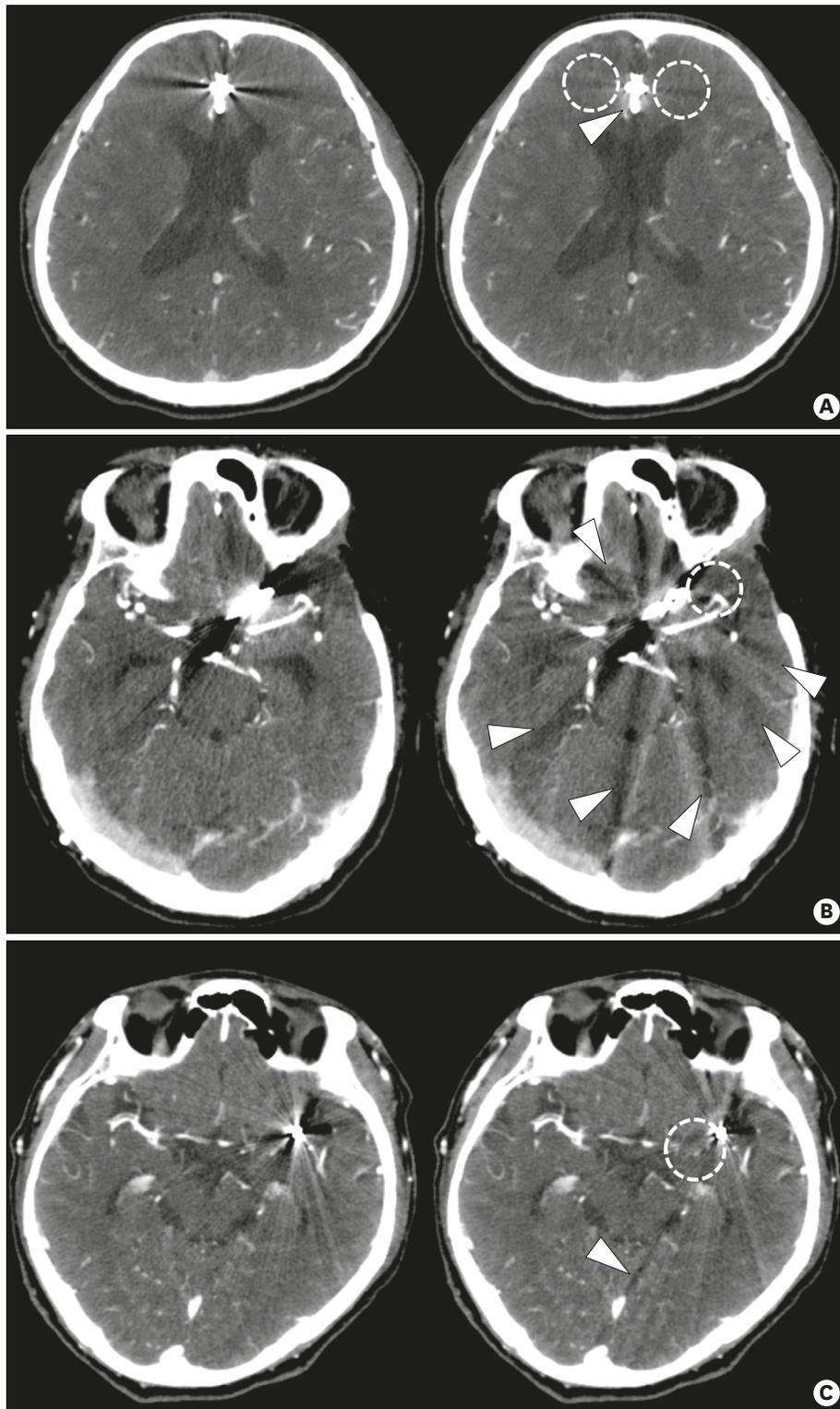
Fig. 3. Non-O-MAR (left) and O-MAR (right) images in the representative cases. (**A**) A surgical clip at right A2/3 junction in a 71-year-old male patient. The O-MAR image shows improved streak artifact (dashed circles), although a vessel is slightly less clearly depicted (arrowhead). (**B**) A 68-year-old male patient who underwent surgical clipping for an anterior communicating artery aneurysm. The O-MAR image shows multiple bands of worsened streak artifacts (arrowheads), while there is a focal area with improved streak artifacts (dashed circle). (**C**) A 73-year-old male patient who underwent coil embolization for an aneurysm at the left middle cerebral artery bifurcation. The streak artifacts are slightly improved on the O-MAR image (particularly in the dashed circle area), but there is a focal aggravation of streak artifact (arrowhead).
O-MAR = metal artifact reduction for orthopedic implants.

Table 2. Effect of coexistent metallic implants on the same axial plane

Grade of new streak artifact	No coexistent objects (n = 15)	Two or more coexistent objects (n = 21)	Total (n = 36)
Grade 1	7	2	9
Grade 2	7	11	18
Grade 3	1	8	9

New streak artifacts were graded on a 3-point scale: 1) no new streaks; 2) new streaks that did not impair the interpretation of adjacent structures; and 3) new streaks that impaired interpretation.

O-MAR was applied. However, the overall degree of the streak artifacts and the confidence of the surrounding vessel depiction were not significantly improved on O-MAR images. The appearance of new streak artifacts that impaired interpretation was noted in 28.7% of the objects using the O-MAR. Overall interobserver agreements between the two reviewers were good-to-substantial, except for the image noise of extracranial air.

Several studies found that the O-MAR reduces metallic artifacts.[15-19] Kidoh et al.[15] demonstrated that the O-MAR improved the depiction of oral cavity structures by reducing dental metallic artifacts. Jeong et al.[16] found that the O-MAR significantly improved metallic artifacts due to spinal and hip prostheses. Recently, Shim et al.[19] also observed an improvement in image quality using the O-MAR in patients who had undergone reverse total shoulder arthroplasty, although they reported some image degradation and new artifacts such as a pseudocemented appearance and scapular pseudonotching.

Previous studies that used other MAR algorithms to evaluate intracranial metallic implants on CTA or flat-panel detector CT images observed significant improvement in the interpretation of surrounding structures.[10-13] Prell et al.[10] found improved brain tissue modeling and implant visibility using an interpolation-based 3D correction algorithm for MAR; that algorithm was further modified by Psychogios et al.,[11] who achieved a significant reduction of artifacts around metallic implants and improved delineation of the surrounding structures.
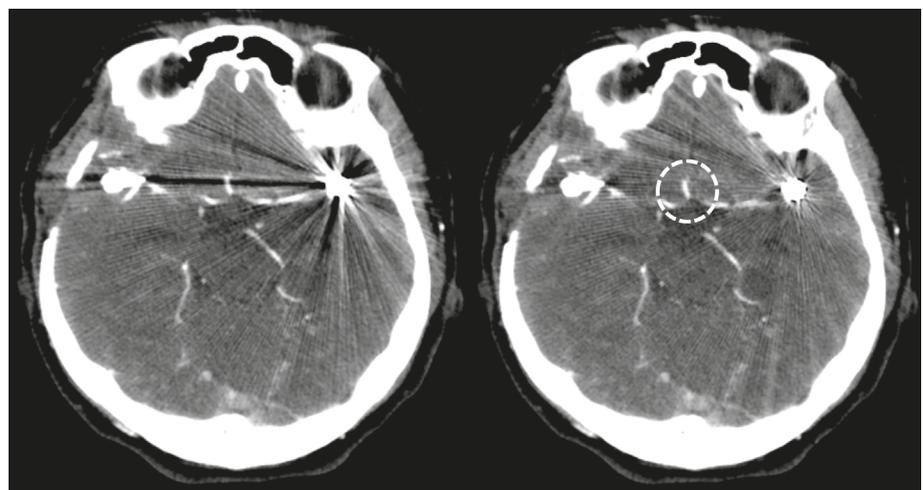

Fig. 4. Non-O-MAR (left) and O-MAR (right) images of a 48-year-old female patient who underwent coil embolization and surgical clipping. The clip at the right middle cerebral artery bifurcation and the coil mass at the left middle cerebral artery bifurcation are present on the same axial image. The streak artifact is markedly improved on the O-MAR image. In addition, a branch of the anterior cerebral artery is more clearly depicted using the O-MAR (dashed circle).
O-MAR = metal artifact reduction for orthopedic implants.

Table 3. Comparison of the quantitative variables in O-MAR and non-O-MAR images

Quantitative variables			Pre-contrast			Post-contrast		
			Non-O-MAR	O-MAR	P value	Non-O-MAR	O-MAR	P value
Vicinity of metallic implant	CT number (HU)	Average of R1 and R2	35.8	35.9	0.307	50.43	49.27	0.303
		ICC (95% CI)	0.975 (0.955–0.986)	0.980 (0.965–0.989)		0.966 (0.939–0.981)	0.962 (0.932–0.978)	
	Image noise (SD)	Average of R1 and R2	11.88	10.96	< 0.001[a]	14.39	12.03	< 0.001[a]
		ICC (95% CI)	0.982 (0.968–0.990)	0.986 (0.975–0.992)		0.969 (0.945–0.982)	0.972 (0.951–0.984)	
Adjacent parenchyma	CT number (HU)	Average of R1 and R2	39.10	38.30	0.965	46.76	46.76	0.489
		ICC (95% CI)	0.846 (0.740–0.911)	0.975 (0.955–0.986)		0.822 (0.702–0.897)	0.982 (0.968–0.990)	
	Image noise (SD)	Average of R1 and R2	7.84	7.57	0.557	9.47	9.74	0.743
		ICC (95% CI)	0.422 (0.153–0.631)	0.959 (0.928–0.977)		0.944 (0.902–0.969)	0.959 (0.928–0.977)	
Temporalis muscle	CT number (HU)	Average of R1 and R2	60.21	60.04	0.753	61.95	61.90	0.026[a]
		ICC (95% CI)	0.764 (0.623–0.858)	0.725 (0.570–0.833)		0.888 (0.806–0.936)	0.866 (0.776–0.922)	
	Image noise (SD)	Average of R1 and R2	13.37	13.76	0.815	13.59	13.08	0.015[a]
		ICC (95% CI)	0.857 (0.757–0.918)	0.857 (0.757–0.918)		0.923 (0.864–0.956)	0.907 (0.839–0.947)	
Extracranial air	CT number (HU)	Average of R1 and R2	−998.49	−997.95	0.594	−997.94	−997.71	0.355
		ICC (95% CI)	0.905 (0.830–0.947)	0.525 (0.354–0.676)		0.902 (0.828–0.944)	0.905 (0.836–0.946)	
	Image noise (SD)	Average of R1 and R2	5.52	5.67	< 0.001[a]	5.45	5.69	< 0.001[a]
		ICC (95% CI)	0.358 (0.113–0.567)	0.361 (0.111–0.571)		0.398 (0.158–0.595)	0.407 (0.194–0.593)	

O-MAR = metal artifact reduction for orthopedic implants, CT = computed tomography, HU = Hounsfield unit, SD = standard deviation, ICC = intraclass correlation coefficient, CI = confidence interval, R1 = reviewer 1, R2 = reviewer 2.
[a]Statistically significant results.

In our study, although we also observed a significant reduction in image noise near metallic objects, the overall image quality determined by qualitative assessment was not significantly improved by the O-MAR. This was supported by the high overall interobserver agreement by the two reviewers. However, this disagreed with previous studies that used the O-MAR in other body parts. We postulate that the discrepant results may be due to the fact that the O-MAR was optimized to reduce streak artifacts caused by orthopedic implants, which tend to be large.[14] Huang et al.[20] evaluated 3 commercially available MAR methods including the O-MAR and found that MAR methods generally did not successfully reduce the artifacts caused by dental fillings, where small metallic implants are located in a heterogeneous environment that includes the teeth and air cavities. Thus, relatively small intracranial metallic objects may not be accurately recognized and removed from the sinogram. In addition, target lesions containing 2 or more metallic objects on the same axial plane seemed to have significantly impacted the image quality. Thus, the inadvertent inclusion of many lesions treated with multiple clips in our study may have resulted in an apparent poor outcome when using the O-MAR compared to previous studies. A future study using a phantom to validate these findings would be valuable.

Interestingly, the image quality for the combination of a coil mass and a clip in 2 cases in our study was improved by the O-MAR (**Fig. 4**). It is generally known that CTA is better for

the evaluation of patients who underwent aneurysm clipping,[21] whereas MR angiography is better for patients who underwent embolization using platinum alloy coils for an aneurysm.[22] Titanium clips generally produce less severe streak artifact than platinum coils, because titanium has a lower mass attenuation coefficient.[23,24] If the patient underwent both surgical clipping and coil embolization for aneurysms, selection of the most appropriate imaging modality would be problematic. Our results suggest that in such cases, it may be helpful to perform a CTA with the O-MAR. Although more time-consuming, a side-by-side comparison of non-O-MAR and O-MAR images can provide more information about the surrounding structures, as recommended by the vendor.[14]

The CT numbers in the various structures were not significantly different between non-O-MAR and O-MAR images except for temporalis muscle on postcontrast scan. Although there is no plausible explanation for this result, new streak artifact generated by O-MAR might have affected the CT number in the distant structures. Image noises in the temporalis muscle on postcontrast scan and extracranial air both on pre- and post-contrast scans were also significantly different between non-O-MAR and O-MAR images. The lower density of extracranial air compared to other structures might have contributed to the significant difference.

In addition to the retrospective design, several limitations of this study should be considered. First, sources of aggravating streak artifacts other than overlapping metallic objects on the same axial plane could not be systematically analyzed. The size of the coil mass, length and orientation of the surgical clips, and location of the metallic implants were not considered in the analysis. A phantom study is necessary to focus on various factors that may influence O-MAR performance. Second, we did not compare the O-MAR to other MAR algorithms, so we could not evaluate its added value compared to others. Because MAR algorithms can be applied during post-processing of raw CT data, the algorithms can be compared without an additional CT scan. Third, the reviewers interpreted both O-MAR and non-O-MAR images side by side without blinding, both because the effect of the O-MAR was evident, and because the reviewers were asked to assess the presence of new artifacts after applying the O-MAR.

In conclusion, the use of the O-MAR in patients with metallic implants significantly reduces image noise near the implant. However, the degree of the streak artifacts and surrounding vessel depiction were not significantly improved on O-MAR images.

ACKNOWLEDGMENTS

REFERENCES

1. Kato Y, Nair S, Sano H, Sanjaykumar MS, Katada K, Hayakawa M, et al. Multi-slice 3D-CTA - an improvement over single slice helical CTA for cerebral aneurysms. *Acta Neurochir (Wien)* 2002;144(7):715-22.
   PUBMED | **CROSSREF**
2. Wintermark M, Uske A, Chalaron M, Regli L, Maeder P, Meuli R, et al. Multislice computerized tomography angiography in the evaluation of intracranial aneurysms: a comparison with intraarterial digital subtraction angiography. *J Neurosurg* 2003;98(4):828-36.
   PUBMED | **CROSSREF**

3. Silverman PM, Spicer LD, McKinney R Jr, Feldman DB. Computed tomographic evaluation of surgical clip artifact: tissue phantom and experimental animal assessment. *Comput Radiol* 1986;10(1):37-40.
   PUBMED | CROSSREF

4. Barrett JF, Keat N. Artifacts in CT: recognition and avoidance. *Radiographics* 2004;24(6):1679-91.
   PUBMED | CROSSREF

5. De Man B, Nuyts J, Dupont P, Marchal G, Suetens P. Metal streak artifacts in X-ray computed tomography: a simulation study. *IEEE Trans Nucl Sci* 1999;46(3):691-6.
   CROSSREF

6. Lee MJ, Kim S, Lee SA, Song HT, Huh YM, Kim DH, et al. Overcoming artifacts from metallic orthopedic implants at high-field-strength MR imaging and multi-detector CT. *Radiographics* 2007;27(3):791-803.
   PUBMED | CROSSREF

7. van der Schaaf I, van Leeuwen M, Vlassenbroek A, Velthuis B. Minimizing clip artifacts in multi CT angiography of clipped patients. *AJNR Am J Neuroradiol* 2006;27(1):60-6.
   PUBMED

8. Kalender WA, Hebel R, Ebersberger J. Reduction of CT artifacts caused by metallic implants. *Radiology* 1987;164(2):576-7.
   PUBMED | CROSSREF

9. Lell MM, Meyer E, Kuefner MA, May MS, Raupach R, Uder M, et al. Normalized metal artifact reduction in head and neck computed tomography. *Invest Radiol* 2012;47(7):415-21.
   PUBMED | CROSSREF

10. Prell D, Kyriakou Y, Struffert T, Dorfler A, Kalender WA. Metal artifact reduction for clipping and coiling in interventional C-arm CT. *AJNR Am J Neuroradiol* 2010;31(4):634-9.
    PUBMED | CROSSREF

11. Psychogios MN, Scholz B, Rohkohl C, Kyriakou Y, Mohr A, Schramm P, et al. Impact of a new metal artefact reduction algorithm in the noninvasive follow-up of intracranial clips, coils, and stents with flat-panel angiographic CTA: initial results. *Neuroradiology* 2013;55(7):813-8.
    PUBMED | CROSSREF

12. Pjontek R, Onenkoprulu B, Scholz B, Kyriakou Y, Schubert GA, Nikoubashman O, et al. Metal artifact reduction for flat panel detector intravenous CT angiography in patients with intracranial metallic implants after endovascular and surgical treatment. *J Neurointerv Surg* 2016;8(8):824-9.
    PUBMED | CROSSREF

13. Hung SC, Wu CC, Lin CJ, Guo WY, Luo CB, Chang FC, et al. Artifact reduction of different metallic implants in flat detector C-arm CT. *AJNR Am J Neuroradiol* 2014;35(7):1288-92.
    PUBMED | CROSSREF

14. Philips CT. Clinical science. Metal artifact reduction for orthopedic implants (O-MAR) (white paper). http://clinical.netforum.healthcare.philips.com/us_en/Explore/White-Papers/CT/Metal-Artifact-Reduction-for-Orthopedic-Implants-(O-MAR). Accessed on October 29, 2017.

15. Kidoh M, Nakaura T, Nakamura S, Tokuyasu S, Osakabe H, Harada K, et al. Reduction of dental metallic artefacts in CT: value of a newly developed algorithm for metal artefact reduction (O-MAR). *Clin Radiol* 2014;69(1):e11-6.
    PUBMED | CROSSREF

16. Jeong S, Kim SH, Hwang EJ, Shin CI, Han JK, Choi BI. Usefulness of a metal artifact reduction algorithm for orthopedic implants in abdominal CT: phantom and clinical study results. *AJR Am J Roentgenol* 2015;204(2):307-17.
    PUBMED | CROSSREF

17. Kwon H, Kim KS, Chun YM, Wu HG, Carlson JN, Park JM, et al. Evaluation of a commercial orthopaedic metal artefact reduction tool in radiation therapy of patients with head and neck cancer. *Br J Radiol* 2015;88(1052):20140536.
    PUBMED | CROSSREF

18. Kohan AA, Rubbert C, Vercher-Conejero JL, Partovi S, Sher A, Kolthammer JA, et al. The impact of orthopedic metal artifact reduction software on interreader variability when delineating areas of interest in the head and neck. *Pract Radiat Oncol* 2015;5(4):e309-15.
    PUBMED | CROSSREF

19. Shim E, Kang Y, Ahn JM, Lee E, Lee JW, Oh JH, et al. Metal artifact reduction for orthopedic implants (O-MAR): usefulness in CT evaluation of reverse total shoulder arthroplasty. *AJR Am J Roentgenol* 2017;209(4):860-6.
    PUBMED | CROSSREF

20. Huang JY, Kerns JR, Nute JL, Liu X, Balter PA, Stingo FC, et al. An evaluation of three commercially available metal artifact reduction methods for CT imaging. *Phys Med Biol* 2015;60(3):1047-67.
    PUBMED | CROSSREF

21. Wallace RC, Karis JP, Partovi S, Fiorella D. Noninvasive imaging of treated cerebral aneurysms, Part II: CT angiographic follow-up of surgically clipped aneurysms. *AJNR Am J Neuroradiol* 2007;28(7):1207-12.
    PUBMED | CROSSREF

22. Wallace RC, Karis JP, Partovi S, Fiorella D. Noninvasive imaging of treated cerebral aneurysms, part I: MR angiographic follow-up of coiled aneurysms. *AJNR Am J Neuroradiol* 2007;28(6):1001-8.
    PUBMED | CROSSREF

23. Boas FE, Fleischmann D. CT artifacts: causes and reduction techniques. *Imaging Med* 2012;4(2):229-40.
    CROSSREF

24. Kataoka ML, Hochman MG, Rodriguez EK, Lin PP, Kubo S, Raptopolous VD. A review of factors that affect artifact from metallic hardware on multi-row detector computed tomography. *Curr Probl Diagn Radiol* 2010;39(4):125-36.
    PUBMED | CROSSREF