Objective: In cases of stent-assisted coil (SAC) embolization, visualization of stents with cone-beam CT is interfered significantly by the coil mass with streak artifacts. Metal artifact reduction (MAR), which is the algorithm for contrast-enhanced cone-beam CT, improves visualization of stents. We analyzed our cases of SAC embolization and report efficacy of MAR.

Materials and Methods: We reviewed 37 images of cone-beam CT of 37 aneurysms treated with SAC embolization between 2011 and 2013 in our institution. The 80 kV high-resolution XperCT was performed, and stent images were reconstructed with and without MAR. Neuroradiologists evaluated the following findings using a 3-point scale: stent apposition, stent lumen, and stent strut and anatomy of surrounding small vessels.

Results: By applying MAR, scores of findings listed above were improved at least by 1 point in 83.8%, 86.5%, 89.2%, and 29.7% of the cases, respectively, and overall visibility was improved in all of the cases. Improvement of the total score with MAR did not significantly correlate with aneurysm size ($r = -0.079$).

Conclusion: It was significantly valuable to apply MAR for the images after the SAC embolization treatment to observe stent apposition, stent lumen, and stent strut and surrounding vessels. This technique will also provide valuable information for cases of re-treatment or risk analysis for ischemic complications.

Keywords ▶ stent-assisted coil embolization, visualization, cone-beam CT, metal artifact

Introduction

The development of intracranial stent has extended the range of endovascular treatment of cerebral aneurysms to wide-neck aneurysms and segmental dilatations, which have been difficult to treat so far. In Japan, two stent types are approved, a closed-cell and an open-cell stent as of August 2013. The Enterprise VRD (Cordis Neurovascular, Miami, FL, USA) closed-cell stent was approved in July 2010 and is widely used at present. The Neuroform (Stryker Neurovascular, Fremont, CA, USA) open-cell stent was approved later, in September 2012. The availability of different types of stents requires more knowledge of characteristics and behaviors of each type.\(^1\)\(^-\)\(^4\) Comparison of two stents in technical and clinical complications was also investigated.\(^5\)

Furthermore, careful attention to peri- and postprocedural ischemic complications is required in stent-assisted coil (SAC) embolization. In addition, we are often faced with re-operative cases of aneurysm regrowth or recanalization. For follow-up examinations of patients after SAC, DSA gives the most accurate information of vessels, aneurysm and stent although usefulness of contrast-enhanced magnetic resonance angiography was reported.\(^6\) In addition to two dimensional (2D) information of conventional DSA, 3D visualization with cone-beam CT (CBCT) provides more information of the relationship between vessels and stent. However, the high X-ray absorption of...
platinum coils generates streak artifacts, which may significantly impede visualization of the stent and the surrounding structures.

Metal artifact reduction (MAR) is an application of a reconstruction algorithm for CBCT to reduce the artifacts caused by elements with high X-ray absorption such as clips, coils, and stents. It has been available since December 2011 and was also introduced in our institution. Recently, several papers on visual improvement with MAR have been published, including a report that showed a reduction in coil mass artifacts in SAC using MAR. The present study aims not only to establish the improvement of visibility by MAR in SAC with an observer study, but also explore clinical utility of this method more specific by examining our clinical cases.

Materials and Methods

We treated 37 aneurysms with SAC between 2011 and 2013 in our institution of 36 patients including 23 females (63.9%) and 13 males with an age range of 38–82 years (mean: 61.8). Aneurysm dome size ranged from 2.8 to 18.3 mm (mean: 9.2 mm). There were 24 small aneurysms (<10 mm), 13 large aneurysms (10.0–25.0 mm), and no giant aneurysms (>25.0 mm). Aneurysms were located on the internal carotid artery (ICA) (n = 16), anterior communicating artery (AcomA) (n = 2), anterior cerebral artery (n = 1), basilar artery (BA) (n = 13), and vertebral artery (VA) (n = 5). An Enterprise stent was used in 35 cases, and a Neuroform stent in 2 cases. Contrast material (Iopamidol 300 mg/mL; Nihon Schering, Osaka, Japan) was diluted to approximately 14% with saline for a total of 25 mL, and injected at the rate of 1 mL/sec.

The 80 kV high-resolution XperCT was performed just after SAC and follow-up examination in each patient using an angiography system (Allura Xper FD20/20; Philips Healthcare, Tokyo, Japan) with a flat panel detector (30 × 40 cm). The images were acquired by a 20-second rotational scan at a rate of 30 frames/sec using a detector size of 8 inches, and reconstructed in stent mode with and without MAR. MAR has a two-pass reconstruction algorithm. After the standard filtered back-projection in the first reconstruction of a pre-defined high X-ray absorbed area like a metal part is automatically detected. The detected area is then forward-projected on the original X-ray images. From the original (projected) X-ray data, the high absorption regions are replaced by gray values linearly interpolated from the surrounding scan lines. Finally, a second pass of filtered back-projection makes the metal artifact reduced reconstructed data.

All 37 images with and without MAR of 37 aneurysms were retrospectively reviewed by two experienced neuroradiologists from another department in a blind fashion. The visualization qualities of both reconstructions were evaluated. The diagnostic quality of both reconstructions were scored using a 3-point scale for each of the following features: 1) stent apposition (1 = impossible to evaluate, 2 = partially able to evaluate, and 3 = sufficient for evaluate), 2) stent lumen (1 = impossible to evaluate, 2 = partially able to evaluate, and 3 = sufficient for evaluate), 3) stent strut (1 = impossible to evaluate, 2 = partially able to evaluate, and 3 = sufficient for
Evaluation of Visibility by MAR during SAC Embolization

with the balloon assist technique, and recanalization was revealed by a follow-up angiography. Therefore, an additional SAC was done. Although DSA showed the two coil loops had protruded into the parent artery, CBCT with MAR disclosed that one loop (Fig. 3, arrowhead) was protruding into intra-stent lumen through the stent cell and the other loop (arrow) was beyond the stent and vessel wall. This case received the following scores with and without MAR, apposition: 3 versus 2, lumen: 3 versus 2, strut: 3 versus 2, and vessels: 2 versus 1.

Case 2. A 61-year-old woman with an unruptured basilar-tip aneurysm. She was treated with SAC and additional coil embolization a year after primary operation. The patency of posterior cerebral artery (PCA) was not confirmed by neither working angle nor down-the-barrel view. In the CBCT with MAR on a vertical plane to the stent (short axis view), the stent lumen was patent and the coils packed the “deltoid area” surrounded by the stent and the foot of broad aneurysmal neck (Fig. 4). This case received the following scores with and without MAR, apposition: 3 versus 2, lumen: 3 versus 2, strut: 3 versus 2, and vessels: 2 versus 1.

Case 3. A 49-year-old man with an unruptured right ICA aneurysm. He was treated by SAC (Enterprise). Figure 5 shows an incomplete stent apposition (ISA) with the stent kinking at siphon curve. The aneurysm neck coverage was partial, but the coils were stabilized in the aneurysm. This case received the following scores with and without MAR, apposition: 3 versus 2, lumen: 3 versus 2, strut: 3 versus 2, and vessels: 2 versus 2.

Case 4. A 62-year-old woman with a history of subarachnoid hemorrhage, and a ruptured basilar-tip aneurysm was embolized with platinum coils without adjunctive techniques at that time. A follow-up angiography after 5 years from onset

Results

After application of MAR, scores of each feature were improved at least 1 point, respectively, in 83.8%, 86.5%, 89.2%, and 29.7% of the cases, and no case was scored worse. Improvement of at least 1 point in any features was found in 97.3% of the cases. Observers judged that overall visibility was improved in all of the cases. Comparisons of the average score for each feature and the total score for scans with or without MAR are shown in Fig. 1. The scores of all the features improved significantly after applying MAR. Especially, the average score of stent apposition with MAR is twice as high as without MAR. The relationship between score improvement and aneurysm size is shown in Fig. 2. Improvement of total score with MAR did not significantly correlate with aneurysm size ($r = -0.079$).

Illustrative cases

Case 1. A 42-year-old woman with a large, unruptured aneurysm at the left ICA. She underwent coil embolization evaluate), and 4) anatomy of surrounding small vessels (1 = impossible to evaluate, 2 = able to evaluate parent vessel, and 3 = able to evaluate small vessels as anterior choroidal artery, ophthalmic artery, AcomA, posterior communicating artery, superior cerebellar artery, anterior inferior cerebellar artery, and posterior inferior cerebellar artery). Then, the improvement of overall visibility with MAR was judged as improved, no change, or worsened. Scoring was done with consensus of two observers. In a statistical test, significance of the results was evaluated by means of Fisher’s exact test. A two-tailed significance level of $P < 0.05$ was considered significant. Furthermore, the relationship between score improvement and aneurysm size was studied.

Fig. 3 DSA (a) shows two coil loops that protruded into the parent artery. CBCT without MAR (b) fails to show relevant information due to the coil mass artifacts. In contrast, the same CBCT reconstruction with MAR (c) shows that one loop (arrowhead) is intra-stent lumen and the other loop (arrow) is beyond stent and vessel wall. CBCT: cone-beam CT; MAR: metal artifact reduction.
revealed a recanalization at the aneurysm neck. Therefore, it was re-treated by SAC (Neuroform). The CBCT with MAR during the operation revealed an increased opening of cells on the outer curve of the stent; however, the aneurysm neck of the inflow zone was covered with a triangular strut segment. Then, additional coils were inserted in the inflow zone. This case received the following scores with and without MAR, apposition: 3 versus 2, lumen: 3 versus 3, strut: 3 versus 2, and vessels: 3 versus 2.

Case 5. A 57-year-old man with an unruptured left ICA aneurysm. He was treated by SAC (Enterprise). In a 6-month follow-up angiography, CBCT with MAR revealed mild in-stent stenosis (ISS). This case received the following scores with and without MAR, apposition: 3 versus 2, lumen: 3 versus 2, strut: 3 versus 2, and vessels: 2 versus 2.

Case 6. A 62-year-old woman with an unruptured right ICA aneurysm. She was treated by SAC (Enterprise). Coils loops were found to overlap the stent as observed in the working angle and in the down-the-barrel view in DSA. CBCT with MAR detected coils migrated between the stent and the parent vessel. This case received the following scores with and without MAR, apposition: 3 versus 2, lumen: 3 versus 2, strut: 3 versus 2, and vessels: 2 versus 1.

**Discussion**

CBCT has proven to be an efficient method for the evaluation of stent deployment and apposition, as it can reveal conditions such as kinking and conformability to the vessels. During SAC of cerebral aneurysms, it is the only method to fully reveal the relationship between the stent and the coils. However, metal artifacts caused by coil masses may severely reduce the diagnostic quality of CBCT data. Therefore, it is difficult to evaluate the protrusion of coils into the parent vessel, ISA after coiling and ISS on follow-up. These are risk factors of peri- and postprocedural ischemic complications. MAR provides a possibility to reveal these problems and hence facilitates clinical decision-making.

In SAC operation, it is important to appreciate whether or not the extra-aneurysmal coil loop is protruding into the intra-stent lumen. In a wide-neck aneurysm or a segmental...
dilatation, it is difficult to separate an aneurysm and the parent vessel in a working angle. As coils are placed around the outside of the stent, coils overlapping the stent increasingly obscure the parent vessel in the working angle. In this scene, the passage of coils through the stent cell into the intra-stent lumen is difficult to detect and may result in thrombosis or occlusion of the parent vessel. Observation in a down-the-barrel view (tunnel view) is a useful method to observe if the loop is intra- or extra-stent lumen.17,18) The overlap of coils on the stent in a working angle is separated as a “deltoid area” (Fig. 9, B1) as seen in Case 2. However, a down-the-barrel view is not always possible to achieve because of vessel shape or limited motion range of the flat panel. CBCT can reconstruct a 3D image in free cross sections in a workstation unlike conventional DSA, and the image on the vertical plane to the stent enables to distinguish stent lumen, aneurysm, and “deltoid area” as seen in Case 1. These findings can be recognized with MAR during insertion of coils, so we can re-sheath the coil during operation, when the loop is judged to be herniating into intra-stent lumen. This image may be useful to fuse form aneurysms or segmental dilatations as well as wide-neck aneurysms, especially in cases that a down-the-barrel view is difficult to be performed (Fig. 9).

Fig. 6 Stent apposition around the aneurysm neck is not able to be recognized by DSA (a) and CBCT without MAR (b). CBCT with MAR (c) detects an increase in opening of cells on the outer curve of Neuroform stent; however, the aneurysm neck of the inflow zone is covered with a triangular strut segment (arrow). Then, additional coils were inserted in the inflow zone (d). CBCT: cone-beam CT; MAR: metal artifact reduction

Fig. 7 In-stent stenosis is not apparent in DSA. CBCT with MAR reveals mild in-stent stenosis (double arrows). CBCT: cone-beam CT; MAR: metal artifact reduction

Fig. 8 It is difficult to distinguish that coil loops are intra-stent or extra-stent in DSA (a) and CBCT without MAR (b). CBCT with MAR detects coils migrating between stent and parent vessel (c). CBCT: cone-beam CT; MAR: metal artifact reduction
required additional intervention with angioplasty or surgical bypass. A degree of stenosis was measured in conventional DSA in these studies. CBCT with MAR may provide more information of the stenotic site, and a criterion for judgment whether to continue anti-platelet therapy or not.

There are several limitations of MAR. At first, the visibility in large aneurysms is difficult to improve because the larger the amount of metal, the more streak artifacts are produced; MAR will delete signals of stent and contrast material altogether. Actually in this study, aneurysm size tended to be larger in cases that did not show an improvement in visibility. Second, positional relationship of coils and stent becomes a problem. Metal artifacts tend to occur along the direction of the X-ray beam. Therefore, in case of coils and stent being in the same plane to the scanning line, a visual improvement is more difficult. Finally, evaluation of intra-aneurysmal structures such as identification of loose-packing area, recanalization, and thrombosis in the aneurysm is difficult because the area coils are very close and cannot detect although MAR was applied.

### Conclusion

Although there are limitations to reducing artifacts, MAR improves visibility of CBCT imaging of SAC to some degree, and provides adequate clinical information in most of the cases. We conclude that CBCT with MAR is a valuable method to evaluate conditions of stent and vessels during operation and follow-up.

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All authors have no conflict of interest.

References


