Blood Flow Assessment of the Neck-bridged Stent Lumen after Stent-assisted Coiling Using 3D-TOF MRA

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Purpose: We evaluated the efficacy of 3D time-of-flight MRA (3D-TOF MRA) using parameters optimized to reduce metal artifacts in follow-up imaging of cerebral aneurysm treatment by stent-assisted coiling (SAC).

Methods: The radiological data from seven patients (eight aneurysms) who underwent SAC for unruptured cerebral aneurysms were retrospectively analyzed. Standard MRA (normal TOF: N-TOF) and stent-mode TOF (S-TOF) imaging using various parameters, such as the flip angle, were performed to compare the signal intensity of the parent blood vessel and the stent lumen.

Results: Stent lumen vascular signal intensity for S-TOF was significantly higher than N-TOF in patients with stent alone (P = 0.012, <0.05). The mean signal reduction rate for LVIS Jr. (Terumo Corporation, Tokyo, Japan) was 39.0% ± 9.6%. For similar size stents signal reduction ranged from 26.1% to 48.9%. The signal reduction rate for double LVIS coiling was 73.2%. Although the size of the neck remnant was overestimated in some patients, it was possible to detect a slow flow volume at the aneurysm neck in all patients.

Conclusion: 3D-TOF MRA for blood flow assessment facilitated the visual recognition of the stent lumen after SAC. Confirmations of aneurysmal neck remnants were also possible. However, the results suggest that differences in the mesh intervals for similar sized braided stents influenced the signal intensity, leading to overestimation of residual aneurysm. This should be further investigated in future studies.

Keywords ▶ three-dimensional time-of-flight magnetic resonance angiography, stent-assist coil embolization, metal artifact, flip angle

Introduction

Recently, various new intracranial stents have been developed, and stent-assisted coiling (SAC) has been increasingly indicated for treatment of cases where conventional coil embolization alone has been considered difficult or insufficient.1–4 However, despite these broader applications, SAC can result in complications such as neck remnant after coil embolization, aneurysmal recanalization, or in-stent stenosis. Therefore, regular dedicated outpatient follow-up is necessary. 3D time-of-flight MRA (3D-TOF MRA) has been routinely performed as a more noninvasive assessment of cerebrovascular disorder in comparison with DSA.5–8 However, because the inherent presence of metal artifacts makes evaluation of the stent lumen, intra-aneurysmal area, and cervical region difficult, follow-up DSA has been considered the gold standard. DSA likewise involves drawbacks such as the risks of a catheter procedure, radiation exposure, potential contrast medium allergy, and difficulty in readily performing the procedure on an outpatient basis.3 In addition, the usefulness of 3.0T contrast-enhanced MRA (CE-MRA) has been reported, but again there is an inherent risk of contrast medium allergy.5,7
Recently, silent scan MRA (Silent MRA; GE Healthcare, Milwaukee, WI, USA) was reported as a non-CE-MRA technique with capabilities such as ultra-short time of echo (UTE) and arterial spin labeling (ASL). Its usefulness for post-SAC follow-up has been suggested; however, expensive hardware renewal is necessary. In this study, we reduced metal artifacts as much as possible by regulating parameters using current MRI devices, devised imaging methods that facilitate visual recognition for clinical follow-up of aneurysms, and obtained favorable results.

### Materials and Methods

The radiographic results from a total of seven patients (eight aneurysms) who underwent SAC for treatment of unruptured cerebral aneurysms were evaluated at our hospital between January 2016 and September 2017. Standard MRA, using the normal TOF (N-TOF) procedure, was performed using the multi-slab method with a 3.0T MR imaging system (Achieva X-series; Philips, Best, the Netherlands) and SENSE NeuroVascular 16-channel coil (Philips) under the following conditions: repetition time (TR), 22 msec; echo time (TE), 3.45 msec; flip angle (FA), 17 degrees; flow compensation (FC), on; field of view (FOV), 160 mm; Matrix, $272 \times 208$ (reconstruct: 512); slice thickness, 1 mm; voxel size, $0.55 \times 0.78 \times 1.00$ mm; the number of acquisitions (NSA) (the number of excitations [NEX]), 2; and water-fat shift (band width), minimum (0.567 pixel/765.9 Hz), while limiting the extent of imaging. The stent-related signal reduction rate was calculated by measuring the mean region of interest (ROI) at three adjoining points on the stent in the maximum intensity projection (MIP) images, and, similarly was measured by calculating the mean ROI in the proximal stent-free area of the treated blood vessel, which is the signal intensity of the parent blood vessel (Fig. 1). Finally, the reduction ratio between the two mean ROIs was calculated as the stent-related signal reduction rate. Furthermore, assessment of aneurysm occlusion compared with DSA as well as the degree of recanalization and the extent of residual aneurysmal neck were evaluated.

### Statistical analysis

The signal reduction rates of N-TOF and S-TOF are presented as the mean ± standard deviation. To compare respective values, the F-test was conducted to evaluate the population variance. Subsequently, the t-test was performed. A P-value of 0.05 was regarded as significant. All statistical analyses were performed using Excel statistical software package (Statcel 3; OMS, Saitama, Japan).

### Results

The mean signal reduction rate of N-TOF was $58.13\% \pm 11.07\%$ (range: 75.10% to 39.43%), and that of S-TOF was $44.75\% \pm 14.03\%$ (range: 73.24% to 26.14%). Overall, there were no significant differences ($P = 0.054$); however, the mean signal reduction rates of N-TOF and S-TOF in patients in whom a stent alone was used were $56.71\% \pm 11.13\%$ (range: 75.10% to 39.43%) and $40.69\% \pm 8.67\%$ (range: 51.85% to 26.14%), respectively, showing...
a significant difference ($P = 0.012$, $<0.05$). In patients treated by LVIS (Terumo Corporation, Tokyo, Japan) alone, the signal reduction rate was 34.7%, while for double LVIS the signal reduction rate was 73.2%. LVIS Jr. stents were used in four patients. The mean signal reduction rate was 39.0% (range: 26.1% to 48.9%). LVIS Jr. 3.5 × 18 mm stents were used in three patients. The mean signal reduction rate was 37.7% (range: 26.1% to 48.9%), showing a marked difference (Table 1). When confirming the efficacy of stents using DSA, the signal intensity decreased with a reduction in the mesh interval (Fig. 2). DSA identified neck remnants in three patients. In these patients, evaluation was also possible using S-TOF. In one patient, the aneurysmal neck remnant could be similarly confirmed in reference to DSA, whereas the neck remnants were overestimated in the other two patients (Fig. 3).

### Discussion

MRA for aneurysms treated by SAC is considered to be inappropriate for follow-up of the aneurysmal neck remnant and evaluation of recanalization in the parent blood vessel and aneurysm because of excessive metal artifact. However, MRA is a safe and convenient imaging modality, and there have been various studies reporting the usefulness of MRA in post-SAC follow-up. With recent advances in techniques, silent MRA was developed to reduce the magnetic susceptibility of stents and coils by facilitating the visualization of blood vessels without the influence of metal artifacts. This novel modality uses a non-contrast-enhanced method with the Silenz pulse sequence (GE Healthcare, Milwaukee, WI, USA), which employs an UTE combined with the ASL method. Irie et al. reported the usefulness of silent MRA for the visual recognition of stent lumenal blood flow in patients who underwent SAC. Furthermore, Takano et al. reported that even a single-wire braided stent, such as the LVIS Jr. stent, which shows a blood-vessel-covering rate of approximately 12% to 21% with an increase in the metal volume per unit area, was useful for detecting helmet-type remnants. Although the usefulness of silent MRA has been verified, expensive hardware renewal is required. With regard to image preparation, silent MRA involves the handling of processed images, while it is impossible to obtain original images, thus making multi angular evaluation difficult. Ikushima et al. conducted an in vitro experiment in which various parameters, such as the FA, TE, band width (BW), and field strength (FS), were optimized using CE-MRA to
Fig. 2 (A) Stent-assisted coil embolization of an IC paraclinoid aneurysm performed with an LVIS Jr. stent (3.5 × 18 mm). White arrow shows the stretch state of LVIS Jr., which indicates a wide mesh spacing. (B) Stent mode MRA showing signal in the stent with a signal reduction rate of 26.1%. (C) Stent-assisted coil embolization, location, and use of stent is same as in (A). White arrow shows a shortened state of LVIS Jr., which indicates a narrow mesh spacing. (D) Stent mode MRA shows a signal in the stent with a signal reduction rate of 48.9%. IC: internal carotid; LVIS: Terumo Corporation, Tokyo, Japan

Fig. 3 (A) Stent-assisted coil embolization of an IC paraclinoid aneurysm performed with a Neuroform stent (4 × 20 mm). White arrow indicates aneurysmal remnant. (B) Stent mode MRA shows minimal signal in the stent with a visible aneurysmal remnant visible. (C) Stent-assisted coil embolization of an IC paraclinoid aneurysm performed with an LVIS stent (4.5 × 32 mm). White arrow indicates aneurysmal remnant. (D) Stent mode MRA shows overestimation of the aneurysmal remnant compared with DSA. IC: internal carotid; LVIS: Terumo Corporation, Tokyo, Japan; Neuroform: Stryker, Fremont, CA, USA
improve the visibility of the stent lumen. They reported that a high FA value increased the reactive in-stent signal to 65%, whereas there was a decrease in the signal-to-noise (S/N) ratio, suggesting that 1.5T is more effective than 3.0T for reducing noise.\textsuperscript{9)} Choi et al. also indicated that a high FA value improved the in-stent signal, whereas slow flow or turbulence could not be visualized with reduction in the S/N ratio because of the saturation effects of a high FA value, suggesting that aneurysmal neck remnant assessment is difficult using this method.\textsuperscript{10)} In addition, several studies emphasized the usefulness of CE-MRA, in which metal artifacts are reduced through contrast-medium-related short TE effects.\textsuperscript{6)} However, severe complications, such as gadolinium-related nephrogenic systemic fibrosis, and gadolinium deposition in the cerebellar dentate nucleus or pallidum have also been reported. The repeated use of contrast medium should be avoided.\textsuperscript{11,12)} In our study, we regulated/established a method for regulating the pixel and band width to reduce the S/N ratio using a high FA value (30 degrees) on non-contrast-enhanced 3D-TOF MRA, and devised parameters using single-slab imaging. As a result, there was a significant improvement in the visibility of the stent lumen for treatment with stents alone (P = 0.012, <0.05). Evaluation of aneurysm recanalization was overestimated when compared with DSA in two patients, suggesting that slow flow volume is a more sensitive. With the exclusion of false-negative cases, this procedure may be useful as an outpatient follow-up method (Fig. 3). However, our results suggest that, when employing an LVIS Jr. of the same size, the difference in the mesh-size interval is reflected by the signal intensity (Fig. 2). With double LVIS usage, it was impossible to accurately identify the lumen. This may have been because of a sufficient signal intensity was not obtained due to the large metal volume in stenting in addition to disturbances in signal intensity in the siphon region encountered during standard TOF MRA. Furthermore, when using an Enterprise 2 or Neuroform device, where the metal volume is less than LVIS, there was a more marked decrease in the signal intensity, suggesting the influence of the type of metal employed. Consequently, future issues, which need to be addressed, will center on the management of stents containing a large volume of metal, such as the Pipeline embolic device. In such cases, imaging at a higher FA value is required, which may result in a decrease in the S/N ratio. However, our method provides original source images, which may facilitate multiangular configurations and assessment.

\section*{Conclusion}

In this study, we evaluated stent lumen visibility by devising 3D-TOF MRA parameters using current MRI devices and measured the signal intensity in the stent lumen after SAC for unruptured cerebral aneurysms. We found a significant difference, and suggesting the enhanced usefulness of this procedure not only because of the ease and simplicity of use in the outpatient clinic, but also because of the potential for wide application for aneurysm occlusion assessment in general. However, there is a possibility of aneurysmal remnant overestimation, and variables such as differences in mesh intervals for braded stents of the same size, the type of stent/metal, and overall state of stenting may influence overall signal intensity. In the future, these issues should be further investigated.

\section*{Disclosure Statement}

There is no conflict of interest for the primary author and coauthors.

\section*{References}


