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Application of 3D T1-SPACE combined with 3D-TOF sequence for follow-up evaluation of stent-assisted coil embolization for intracranial aneurysm

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ABSTRACT

Objectives: To assess 3D T1-SPACE combined with 3D-TOF sequence for follow-up evaluation of stent-assisted coil embolization for intracranial aneurysm.

Materials and methods: Between Oct 2018 and May 2019, we enrolled 25 patients with intracranial aneurysm who underwent stent-assisted coil embolization. All patients were followed up for 6 to10 months after endovascular treatment (EVT) using 3D-TOF MRA, 3D T1-SPACE and DSA to evaluate aneurysm occlusion and parent artery patency.

Results: With regards to aneurysm occlusion, the specificity of 3D-TOF MRA was 86.9% (20/23) and the accuracy was 84% (21/25). There was no statistical significance ($P = 0.409$) compared with the DSA. The parent artery by 3D-TOF MRA showed that there were 14 patients with grade 3, 8 patients with grade 2 and 3 patients with grade 1. However, 3D T1-SPACE showed that all 25 patients were grade 4, and were clearly displayed without metal artifacts. The comparison of the two MR techniques demonstrated that 3D T1-SPACE was superior to 3D-TOF MRA in the evaluation of parent artery ($P<0.001$).

Conclusions: 3D T1-SPACE sequence provides better image quality and higher accuracy for evaluating stented parent arteries compared to TOF-MRA. This study also shows that 3D-TOF MRA has a merit to evaluate aneurysm occlusion. The combination of these two modalities can be used as an optional follow-up evaluation after EVT of intracranial aneurysms.

Introduction

With improvements in stent materials and endovascular techniques, stents are now being widely used for endovascular treatment (EVT) of intracranial aneurysms. Stents not only increase the embolism density of the coils, but also correct abnormal blood flow at the aneurysmal neck, which to some extent, contributes to flow diversion.[1] However, a few patients suffer from complications after endovascular embolization, such as aneurysm recurrence, in-stent stenosis, and delayed thrombosis. Hence, regular imaging follow-up is still required after endovascular therapy. Digital subtraction angiography (DSA) is the standard imaging modality for follow-up evaluation of cerebral aneurysms. However, it is an invasive procedure with several risks, such as hematoma at the puncture site and thromboembolic complications. Moreover, it is problematic for patients to undergo long-term repeated DSA examinations.

Noninvasive follow-up evaluations using magnetic resonance imaging (MRI) are more commonly used after interventional therapy for intracranial aneurysms. These include 3D time-of-flight magnetic resonance angiography (3D-TOF MRA) and contrast-enhanced MRA (CE-MRA). These modalities have better sensitivity and accuracy for follow-up evaluation of patients with aneurysms who have undergone simple coil embolization.[2] However, they poorly display parent artery patency in patients who have undergone stent-assisted embolization. This is due to the artifacts introduced by the magnetic susceptibility of stents, which can be easily evaluated as false stenosis or occlusion in parent vessels.[3] Three-dimensional T1-weighted sampling perfection with application-optimized contrasts using different flip angle evolutions (3D T1-SPACE) provides

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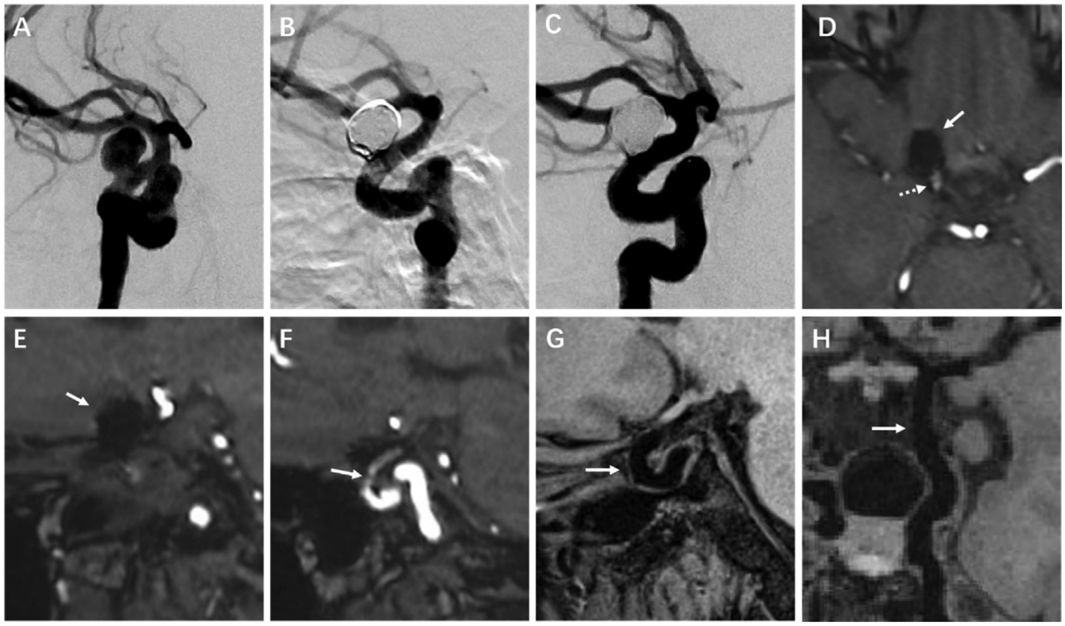

Fig. 1. (A) A 55-year-old woman with a right ophthalmic artery segment aneurysm was treated by stent-assisted coil embolization (Enterprise stent &coils). (B) DSA images were obtained immediately after the treatment. (C) Seven-months follow-up, the DSA showed complete occlusion of the aneurysm. 3D-TOF MRA and 3D T1-SPACE were performed one day after DSA. (D, E) Similarly, 3D-TOF MRA and source images showed total occlusion (The white arrow points to the aneurysm sac and the dotted arrow points to the parent artery). (F) However, the bright blood MRA demonstrated a narrowing of the parent artery (white arrow). (G) 3D T1-SPACE sequence showed that the in-stent lumen was readily visible without metal artifacts (white arrow). (H) Long-axis reconstruction of the black blood sequence for the parent artery (white arrow).

three-dimensional, large-scale, and high spatial-resolution images of the arterial wall, and has demonstrated good results for intracranial vascular lesions.[4] This study assessed the 3D T1-SPACE technique combined with 3D-TOF MRA for the follow-up of intracranial aneurysm patients treated with stent-assisted coil embolization. DSA comparative analysis was performed concurrently to investigate the accuracy and effectiveness of the combined method mentioned above.

Materials and methods

Study population

The study was approved by the ethics committee of Henan Provincial People's Hospital. All clinical practices and observations were conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from each patient before the study was conducted. Between October 2018 and May 2019, 25 patients with intracranial aneurysms treated with stent-assisted coil embolization were prospectively enrolled in our study. Six to ten months after treatment, they were followed up with both MRI and DSA. The inclusion criteria were as follows: patients with intracranial aneurysms treated by stent-assisted coiling; patients who were followed up with two MR imaging techniques (3D-TOF MRA and 3D T1-SPACE) and DSA; and with MRI sequences and DSA performed with an interval of less than 3 days.

Imaging technique for the MRI scans

Both MRI sequences were performed using a 3.0 T Siemens Prisma human MRI scanner (Siemens Medical, Germany). The scanning parameters for 3D TOF-MRA were as follows: TR, 21 ms; TE, 3.45 ms; flip angle, 18°; total acquisition time, 3:36 min; number of sections, 160; section thickness, 0.60 mm; matrix, 320 × 232; field of view, 200 cm × 181 cm. Post-processing and analysis of images were performed using real-time 3D display technology on the Siemens Syngo workstations. Images were reconstructed using maximum intensity projection (MIP), and the aneurysm occlusion was observed using source images (SIs) by multi-planar reformat (MPR). The 3D T1-SPACE scanning parameters were as follows: TR, 900 ms; TE, 14 ms; scanning time, 8:29 min; number of sections, 224; section thickness, 0.50 mm; matrix, 320 × 320; field of view, 170 mm × 170 mm. The contrast agent was gadopentetate (Magenweixian, Germany), which was intravenously injected at a dose of 0.2 mmol/kg 3D thin-layer images were post-processed, and 3D T1-SPACE original images were imported into the Siemens workstations. The long and short axes of the vessels were processed based on the anatomical position of the two ends of the stent. The presence of stenosis, occlusion, or delayed thrombosis in the stent of the parent artery was then evaluated.

Imaging technique for DSA

Catheterization was performed using a modified Seldinger technique through the femoral artery under local anesthesia. 3D rotational angiography of the target vessels (FD20, Philips, Netherlands) was performed after embolization. After selecting the optimal projection angle of the aneurysm based on the 3D post-processing system of the DSA device, the target lesions were enlarged for 2D angiography to determine whether the aneurysm sac or neck was residual, and to evaluate whether there was patency in the parent vessel.

Image evaluation

The radiological results were categorized as complete occlusion, residual neck, and residual aneurysm after EVT, as per the Raymond classification.[5] The in-stent lumen of the parent artery was evaluated using a 4-point scale as follows[6]: 1, not visible (almost no signal in the stent); 2, poor (structures are slightly visible but with significant blurring or artifacts, not diagnostic); 3, good (good quality diagnostic information with minimal blurring or artifacts); 4, excellent (excellent-quality diagnostic information, the shape depicted is nearly equal to that of DSA). MR and DSA images were independently reviewed by two interventional neuroradiologists (both with >10 years of experience). When a different reading was proposed, a consensus was reached between the two

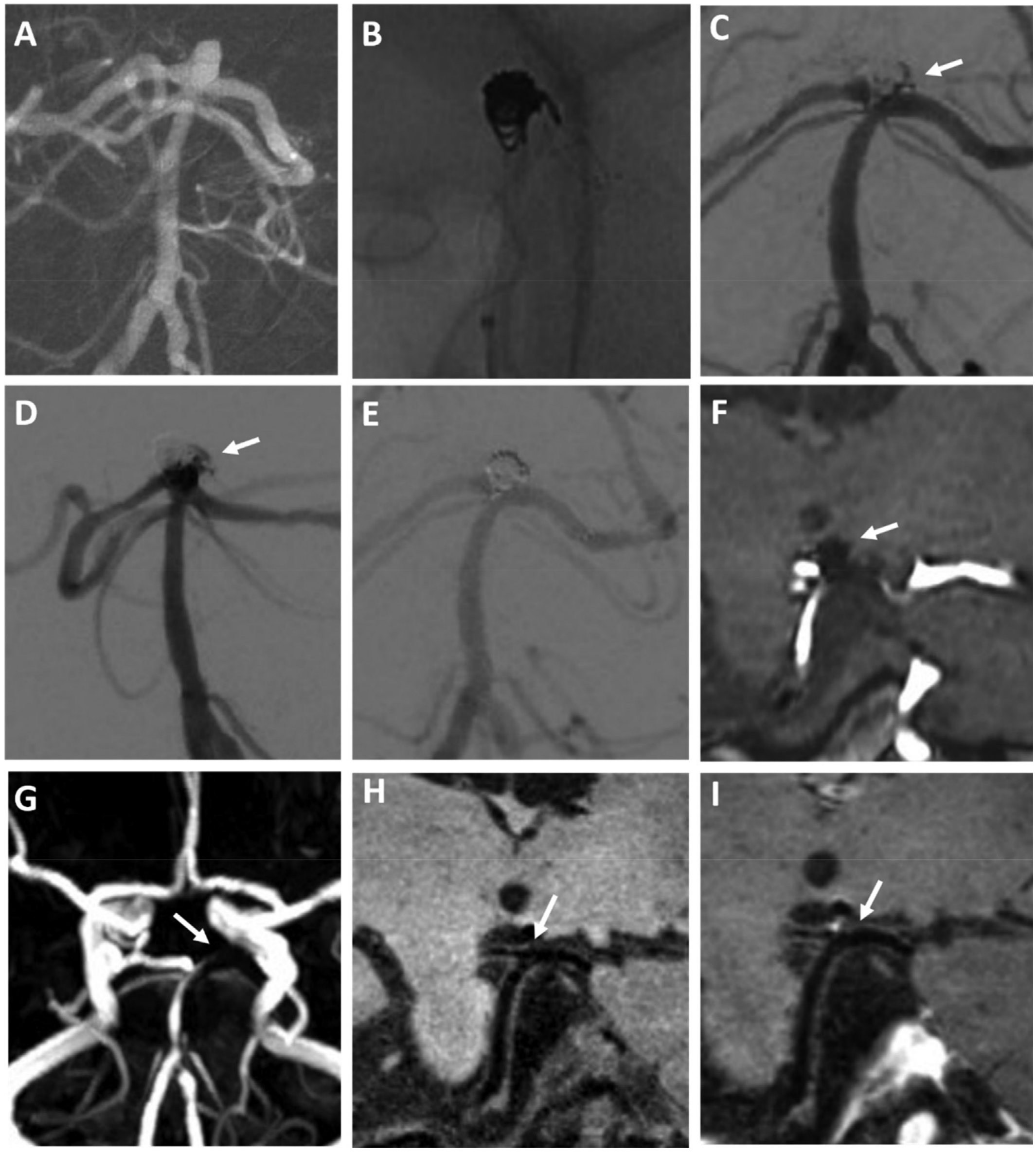

Fig. 2. (A) An 80-year-old woman with a basilar artery aneurysm. (B) LVIS stent-assisted coil embolization. (C, D) Immediate DSA after the treatment showed aneurysm remnants (white arrow). (E) After six months, the aneurysm was complete occlusion in the follow-up DSA. (F) Besides, the 3D-TOF MRA showed total occlusion of the aneurysm, which was consistent with the DSA assessment (white arrow). (G) However, the in-stent blood flow signal was obviously lost with significant blurring (white arrow). (H, I) Then, 3D T1-SPACE sequence demonstrated parent artery patency without the related artifacts (white arrow. I, enhancement scan).

radiologists. 3D-TOF MRA, 3D T1-SPACE, and DSA were evaluated separately without knowledge of either the MRA or DSA examination results. The location of the aneurysms to be evaluated was provided to the readers.

Statistical analysis

Quantitative variables were described as mean ± SD or median (interquartile range), and qualitative variables were described as numbers and percentages. The Kendall coefficient of concordance was used to measure interobserver agreement. The Wilcoxon signed rank test was used to analyze the extent of aneurysm occlusion between DSA and 3D TOF-MRA, and also to analyze the subjective scores of the quality of images of the stented artery. DSA was used as the gold standard to calculate the specificity and accuracy of aneurysm occlusion as evaluated by 3D TOF-MRA. All statistical analyses were performed using SPSS 22.0 software (IBM SPSS Inc., Chicago, IL, USA).

Results

The mean patient age was 56.2 ± 16.0 years (range, 30–80). Eighteen of the 25 patients were women. There were five ruptured aneurysms, and the others had unruptured aneurysms. Twenty cases were in the anterior circulation (Fig. 1). Ophthalmic artery aneurysms accounted for 13/25 cases (52.0%). There were 5 cases of posterior communicating artery aneurysms (20.0%) and 2 cases of clinoid segment of ICA aneurysms (8.0%). In addition, 5 cases were in the posterior circulation (Fig. 2), with 2 intracranial vertebral artery aneurysms (8.0%) and 3 aneurysms at the trunk of the basilar artery (12.0%). With regard to size, 14 (42.0%) patients had a maximal diameter ≤ 5 mm, and 11 (38%) patients had a maximal diameter of 5–10 mm. A total of 25 stents were deployed in this series. Eighteen LVIS (Microvention, Tustin, California, USA) and 7 Enterprise (Codman, Raynham, Massachusetts, USA) stents were used (Table 1).

In this study, after embolization, immediate DSA showed that 15 patients were classified as having Raymond grade I (total occlusion), 5

Table 1
Patient and aneurysm characteristics(n = 25).

Characteristics	
Sex (M/F)	7/18
Age (yr)	56.2 ± 16.0(30–80)
Aneurysm position	
C5	2(8.0%)
C6	13(52.0%)
PComA	5(20.0%)
BA	3(12.0%)
V4	2(8.0%)
Aneurysm size	
≤5mm	14(56.0%)
5–10mm	11(44.0%)
Aneurysm status	
Ruptured	5(20.0%)
Un-ruptured	20 (80.0%)
Stent type	
Enterprise stent	7(28%)
LVIS stent	18(72%)

Abbreviations: ICA, internal carotid artery; C5, clinoid segment of ICA; C6, ophthalmic artery segment; PComA, posterior communicating artery; BA, basilar artery; V4, intracranial segment of the vertebral artery.

patients as grade II (residual neck), and 5 patients as grade III (residual aneurysm). The Kendall coefficient of concordance was 0.688 ($P < 0.05$). The mean follow-up period was 7.32 ± 1.57 (range, 6–10) months. On follow-up DSA, 23 patients were evaluated as having complete occlusion, 1 patient had a residual neck, and 1 patient had a residual sac. 3D-TOF MRA was used to evaluate the residual aneurysm lumen, and classified 21 patients as grade I, 3 patients as grade II, and 1 patient as grade III (Table 2). Three patients had different evaluations under the two methods. DSA showed that the aneurysms were completely occluded, whereas 3D-TOF MRA showed that 2 patients had residual necks and 1 patient had a residual sac. 3D-TOF MRA for evaluating aneurysm occlusion had a specificity of 86.9% (20/23) and an accuracy of 84% (21/25). There was no statistically significant difference ($P = 0.409$) when compared with DSA. On 3D-TOF MRA findings of the parent artery, there were 14 patients with grade 3, 8 patients with grade 2, and 3 patients with grade 1. However, 3D T1-SPACE showed that all 25 patients were grade 4 and were clearly displayed without artifacts. Among them, 1 patient had in-stent stenosis, which was consistent with the DSA results (Fig. 3). The comparison of the two MR techniques demonstrated that 3D T1-SPACE was superior to 3D-TOF MRA in the evaluation of the parent artery ($P < 0.001$) (Table 3).

Discussion

The application of stents has become the preferred interventional treatment for intracranial wide-neck and micro-small aneurysms. In the recent years, with the use of bio-modified coils and intracranial stents with higher metal coverage, recurrence rates after EVT of intracranial aneurysms have reduced significantly.[7] Postoperative recurrence of aneurysm is associated with the aneurysm neck remnant, degree of aneurysm filling, size, and location of the aneurysm.[8] For patients with poor vascular conditions (i.e., inconsistent antiplatelet therapy and poor control of high-risk factors for arteriosclerosis), in-stent stenosis or occlusion after stent-assisted coiling may occur. Hence, it is necessary to have long-term follow-up evaluation after stent-assisted embolization for intracranial aneurysms.

All patients in this study underwent Enterprise or LVIS stent-assisted embolization. With regard to the follow-up evaluation of aneurysm occlusion, the accuracy was 84% (21/25) when compared to DSA. The thrombus formed by the coils after embolization had distinctly lower signals on 3D-TOF MRA, and was clearly distinguishable from the high signals of blood flow in the parent artery or the residual aneurysm sac. Hence, this imaging technique has the merit of detecting residual flow or aneurysm recurrence. However, on 3D-TOF MRA, the metal artifacts of the stent and its magnetic shielding effect could cause false observations of stenosis or occlusion.[9,10] Conversely, in our preliminary study, the coils and thrombus in the aneurysm sac were observed as a low-medium mixed signal intensity on 3D T1-SPACE sequence. It contained various factors such as thrombus organization, fibrosis, and coil-related low signal intensities. However, blood flow also showed low signal intensity in this sequence. Thus, 3D T1-SPACE was unavailable to evaluate the residual aneurysm lumen. In our study, the original images of the parent artery and the axial reconstructed images were analyzed using a 3D T1-SPACE sequence, and the results showed that the in-stent lumen was clearly displayed without metal artifacts. Hence, we demonstrated the utility of 3D-TOF MRA for follow-up evaluation of aneurysm occlusion and 3D T1-SPACE sequence for evaluation of the parent artery after stent-assisted embolization.

For postoperative follow-up after using a simple coil for the treatment of intracranial aneurysm, 3.0T 3D-TOF MRA had high accuracy and specificity for aneurysm remnants. Therefore, this MRA technique has been recommended as a routine modality for aneurysm follow-up.[11,12] However, in patients with stent-assisted embolization, signal loss in the stent implantation area owing to magnetic susceptibility artifacts and radio frequency shielding, manifests as in-stent stenosis or interruption. Therefore, the reliability of bright blood MRA is poor for follow-up evaluation of intra-stent conditions. Takayama et al. found that 3.0T 3D-TOF MRA had difficulty evaluating parent artery patency due to the influence of stent artifacts on the magnetic field.[13] Similarly, Thamburaj et al. showed that the bright blood 3D-TOF sequence had a false positive rate of 55%–60% for evaluating parent vessels.[14]

3.0T CE-MRA is a commonly used technique that provides a robust blood flow signal with the use of gadolinium contrast agents. It can identify slow blood flow in recurrent aneurysms. This imaging technique improves detection sensitivity of the residual sac and reduces metal artifacts associated with the stent to a certain extent, and hence has better accuracy.[15–17] However, in a meta-analysis performed by Amerongen et al., it did not show better results compared to 3D-TOF MRA.[18] A thrombus in the aneurysm sac will cause false positive results, and stents will additionally cause certain signal attenuation. Marciano et al. demonstrated that the accuracy of 3.0T TOF-MRA and CE-MRA was not high in evaluating aneurysm remnants and parent artery patency in patients with stent-assisted coil embolization.[3] Furthermore, Irie et al. used silent MRA to evaluate patients with aneurysms after stent-assisted embolization. The results demonstrated that it was superior to 3D-TOF MRA in determining in-stent blood flow signals, but would cause a certain amount of false positive results for evaluating parent vessel patency.[6] Hence, the focus of the current study was on how to further reduce the metal artifacts of the stents, as well as to improve the image quality and accuracy of MR angiography to evaluate such patients.

High-resolution (HR)-MRI has been increasingly used for the diagnosis and treatment of cerebrovascular diseases, i.e., for investigating the

Table 2
Evaluation of aneurysm occlusion using DSA and 3D-TOF MRA.

Methods	Number of aneurysms	Total occlusion	Neck remnant	Aneurysm remnant	Z value	P value
DSA	25	23	1	1	−0.826	0.409
3D-TOF MRA	25	21	3	1		

Abbreviations: TOF, time-of-flight.

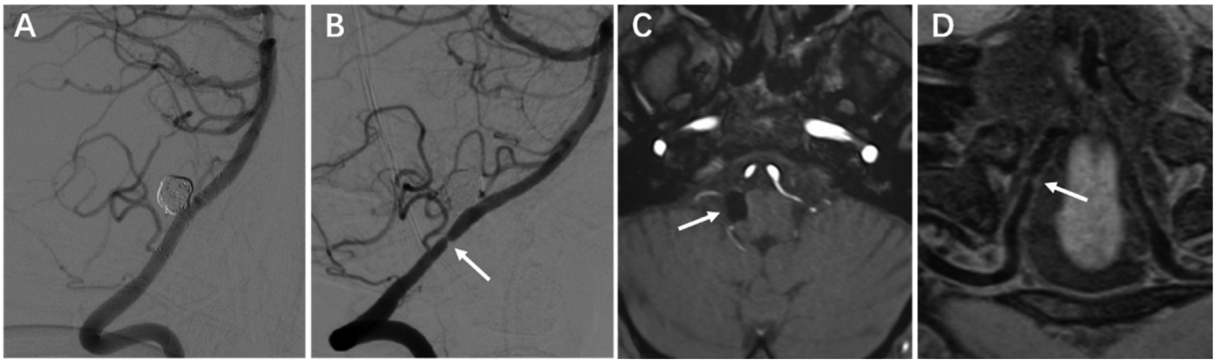

Fig. 3. (A) A 48-year-old man with a right intracranial vertebral artery aneurysm treated by stent-assisted coiling (LVIS stent). (B) At Six-months follow-up, the DSA showed complete occlusion of the aneurysm with localized in-stent stenosis (white arrow). Similarly, 3D-TOF MRA and source images showed total occlusion of the aneurysm (C, white arrow) and 3D T1-SPACE sequence showed the same localized in-stent stenosis (D, white arrow).

Table 3
Evaluation of parent vessel patency using 3D- T1 SPACE and 3D-TOF MRA.

Methods	Number of stents	Not evaluable		Evaluable		Z value	P value
		1 point	2 points	3 points	4 points		
3D T1-SPACE	25	0	0	0	25	−6.580	<0.001
3D-TOF MRA	25	3	8	14	0		

Abbreviations: SPACE, sampling perfection with application-optimized contrasts by using different flip angle evolutions. TOF, time-of-flight.

characteristics of intracranial vascular plaques and predicting the bleeding risk of unruptured aneurysms.[19,20] Annular enhancement of the HR-MRI intracranial aneurysm wall could be used as an indirect marker of the inflammatory reaction.[21] Texakalidis et al. showed that enhancement of the aneurysmal wall was associated with aneurysm rupture, and it may be an effective non-invasive imaging method for the assessment of aneurysm rupture risk.[22] Black blood MR imaging can clearly display the vascular wall with a low signal by inhibiting the blood flow effect. Compared to previous HR-MRI technology that had limited scanning ranges and long image acquisition times, 3D T1-SPACE uses isotropic volume scanning for 3D-HR reconstruction at any level.[23] It has the advantages of wide coverage and short scanning times, and is capable of panoramic imaging of the intracranial artery wall. Hence, this study used a 3D T1-SPACE sequence for evaluating the parent vessel after stent-assisted embolization. This is the first study to perform this assessment.

Our study has several limitations. First, it was prospective; however, the patient cohort size was small. The results should be validated using larger multicenter patient cohorts with long-term evaluation. Second, Enterprise and LVIS stents are commonly used for embolization of intracranial aneurysms, and are laser-cut and braided structures, respectively. Different stent meshes, metal coverage, and stenting technologies may have different shielding effects on MRI scans. Third, multiple flow diverters are currently available for the treatment of complex cerebral aneurysms. Therefore, this type of patient should be followed up with new MR techniques in future studies.

Conclusions

For patients with intracranial aneurysms who have undergone stent-assisted coil embolization, evaluation of aneurysm occlusion and parent artery patency is essential during postoperative follow-up. In our study, 3.0T 3D T1-SPACE showed clear in-stent lumina and could accurately determine the patency of parent vessels. 3D-TOF MRA could completely evaluate aneurysm remnants. The combination of these two modalities can be used for routine non-invasive follow-up evaluation for stent-assisted coil embolization of intracranial aneurysms.

Patient consent

Written informed consent was obtained from patients for publication of these case reports and any accompanying images.

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Ethical approval

All procedures performed in studies involving human participants were approved by the ethics committee of Henan Provincial People's Hospital and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Consent for publication

All the authors have consented for publication of this manuscript.

Author Contributions

1 guarantor of integrity of the entire study: Qiuji Shao, Qiang Li, Tianxiao Li

2 study concepts and design: Qiuji Shao, Qiang Li, Tianxiao Li, Yingkun He

3 literature research: Qiuji Shao, Li Li, Qiaowei Wu

4 clinical studies: Qiuji Shao, Qiang Li, Li Li, Yingkun He

5 experimental studies / data analysis: Qiuji Shao, Qiaowei Wu, Kaitao Chang

6 statistical analysis: Qiuji Shao, Qiaowei Wu, Kaitao Chang
7 manuscript preparation: Qiuji Shao, Qiang Li
8 manuscript editing: Qiuji Shao, Tianxiao Li, Li Li

Declaration of competing interest

The authors declare that they have no conflicts of interests to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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References

1. Müller M, Brockmann C, Afat S, et al. Temporary stent-assisted coil embolization as a treatment option for wide-neck aneurysms. *AJNR Am J Neuroradiol*. 2017;38: 1372–1376.
2. Ferré JC, Carsin-Nicol B, Morandi X, et al. Time-of-flight MR angiography at 3T versus digital subtraction angiography in the imaging follow-up of 51 intracranial aneurysms treated with coils. *Eur J Radiol*. 2009;72:365–369.
3. Marciano D, Soize S, Metaxas G, et al. Follow-up of intracranial aneurysms treated with stent-assisted coiling: comparison of contrast-enhanced MRA, time-of-flight MRA, and digital subtraction angiography. *J Neuroradiol*. 2017;44:44–51.
4. Lu SS, Ge S, Su CQ, et al. MRI of plaque characteristics and relationship with downstream perfusion and cerebral infarction in patients with symptomatic middle cerebral artery stenosis. *J Magn Reson Imag*. 2018;48:66–73.
5. Raymond J, Guilbert F, Weill A, et al. Long-term angiographic recurrences after selective endovascular treatment of aneurysms with detachable coils. *Stroke*. 2003; 34:1398–1403.
6. Irie R, Suzuki M, Yamamoto M, et al. Assessing blood flow in an intracranial stent: a feasibility study of MR angiography using a silent scan after stent-assisted coil embolization for anterior circulation aneurysms. *AJNR Am J Neuroradiol*. 2015;36: 967–970.
7. Zhang Y, Yang M, Zhang H, et al. Stent-assisted coiling may prevent the recurrence of very small ruptured intracranial aneurysms: a multicenter study. *World Neurosurg*. 2017;100:22–29.
8. Yu LB, Yang XJ, Zhang Q, et al. Management of recurrent intracranial aneurysms after coil embolization: a novel classification scheme based on angiography. *J Neurosurg*. 2018:1–7.
9. Choi JW, Roh HG, Moon WJ, et al. Optimization of MR parameters of 3D TOF-MRA for various intracranial stents at 3.0T MRI. *Neurointervention*. 2011;6:71–77.
10. Timsit C, Soize S, Benaissa A, et al. Contrast-enhanced and time-of-flight MRA at 3T compared with DSA for the follow-up of intracranial aneurysms treated with the WEB device. *AJNR Am J Neuroradiol*. 2016;37:1684–1689.
11. Lavoie P, Gariépy JL, Milot G, et al. Residual flow after cerebral aneurysm coil occlusion: diagnostic accuracy of MR angiography. *Stroke*. 2012;43:740–746.
12. Cho WS, Kim SS, Lee SJ, et al. The effectiveness of 3T time-of-flight magnetic resonance angiography for follow-up evaluations after the stent-assisted coil embolization of cerebral aneurysms. *Acta Radiol*. 2014;55:604–613.
13. Takayama K, Taoka T, Nakagawa H, et al. Usefulness of contrast-enhanced magnetic resonance angiography for follow-up of coil embolization with the enterprise stent for cerebral aneurysms. *J Comput Assist Tomogr*. 2011;35:568–572.
14. Thamburaj K, Cockroft K, Agarwal AK, et al. A comparison of magnetic resonance angiography techniques for the evaluation of intracranial aneurysms treated with stent-assisted coil embolization. *Cureus*. 2016;8:e909.
15. Akkaya S, Akca O, Arat A, et al. Usefulness of contrast-enhanced and TOF MR angiography for follow-up after low-profile stent-assisted coil embolization of intracranial aneurysms. *Intervent Neuroradiol*. 2018;24:655–661.
16. Behme D, Malinova V, Kallenberg K, et al. Unenhanced time-of-flight MR angiography versus gadolinium-enhanced time-of-flight MR angiography in the follow-up of coil-embolized aneurysms. *J Neurol Surg Cent Eur Neurosurg*. 2016;77: 400–405.
17. Ally MQ, Sheng G, Halfan SN, et al. Effectiveness of MRA on embolized intracranial aneurysms: a comparison of DSA, CE-MRA, and TOF-MRA. *J. Intervent. Med*. 2018;1: 32–41.
18. van Amerongen MJ, Boogaarts HD, de Vries J, et al. MRA versus DSA for follow-up of coiled intracranial aneurysms: a meta-analysis. *AJNR Am J Neuroradiol*. 2014;35: 1655–1661.
19. Al-Smadi AS, Abdalla RN, Elmokadem AH, et al. Diagnostic accuracy of high-resolution black-blood MRI in the evaluation of intracranial large-vessel arterial occlusions. *AJNR Am J Neuroradiol*. 2019;40:954–959.
20. Matsushige T, Shimonaga K, Ishii D, et al. Vessel wall imaging of evolving unruptured intracranial aneurysms. *Stroke*. 2019;50:1891–1894.
21. Wang GX, Gong MF, Zhang D, et al. Wall enhancement ratio determined by vessel wall MRI associated with symptomatic intracranial aneurysms. *Eur J Radiol*. 2019; 112:88–92.
22. Texakalidis P, Hilditch CA, Lehman V, et al. Vessel wall imaging of intracranial aneurysms: systematic review and meta-analysis. *World Neurosurg*. 2018;117: 453–458.e1.
23. Okuchi S, Fushimi Y, Okada T, et al. Visualization of carotid vessel wall and atherosclerotic plaque: T1-SPACE vs. compressed sensing T1-SPACE. *Eur Radiol*. 2019;29:4114–4122.