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Usefulness of 3 Tesla Ultrashort Echo Time Magnetic Resonance Angiography (UTE-MRA, SILENT-MRA) for Evaluation of the Mother Vessel after Cerebral Aneurysm Clipping: Case Series of 19 Patients

Masahito KATSUKI,[1] Norio NARITA,[1] Naoya ISHIDA,[1] Kazuya SUGAWARA,[2] Ohmi WATANABE,[1] Dan OZAKI,[1] Yoshimichi SATO,[1] Yuya KATO,[1] Wenting JIA,[1] and Teiji TOMINAGA[3]

[1]Department of Neurosurgery, Kesennuma City Hospital, Kesennuma, Miyagi, Japan
[2]Department of Radiological Technology, Kesennuma City Hospital, Kesennuma, Miyagi, Japan
[3]Department of Neurosurgery, Tohoku University Graduate School of Medicine, Sendai, Miyagi, Japan

Abstract

It is important to assess the cerebral arteries near the clip after cerebral aneurysm clipping. Contrast-enhanced computed tomography angiography has side effects of contrast medium and radiation exposure. Time-of-flight magnetic resonance angiography (TOF-MRA) is a fast and non-invasive method, but clip-induced artifact limits the assessment around the clip. Recently, 3 tesla MRA with ultrashort echo time called SILENT MRA (GE Healthcare Life Sciences, UK) has been reported to have the potential to overcome these disadvantages. We herein present consecutive 19 cerebral aneurysm patients treated by clipping and evaluated using SILENT MRA. The 19 patients (15 women and 4 men) underwent TOF-MRA and SILENT MRA during the same scan session. Two neurosurgeons independently assessed the visibility of the mother vessel at the clipping site in TOF-MRA and SILENT MRA. We also investigated the factors related to visibility in SILENT MRA. All patients' mother vessels were not described in TOF-MRA, and that of 16 patients (84%) were described in SILENT MRA. Overall agreement was 100% in the two neurosurgeons, and the fixed marginal kappa = 1.00 (95% CI: 0.36–1.00). Univariate analysis revealed that larger aneurysm dome and long clip blade length contributed to the visibility of the mother vessel in SILENT MRA. (p = 0.023, 0.007, each). In conclusion, SILENT MRA can be applied for the assessment of the arteries and aneurysm neck remnants near the clip. Using clips with long blade and ligation with its tip would be related to the visibility of the mother vessels in SILENT MRA.

Keywords: cerebral aneurysm, clipping, less invasive, SILENT MRA, ultrashort echo time magnetic resonance angiography (UTE-MRA)

Introduction

Aneurysmal clipping has been widely performed for cases of both unruptured and ruptured cerebral aneurysms. Considering the possibility of the aneurysm neck remnant, de novo aneurysm, and aneurysm regrowth, follow-up imaging in the acute stage, chronic stage, and the outpatient is important.[1)] Usually, three-dimensional contrast-enhanced computed tomography angiography (3D-CTA) is performed for the evaluation of the clipped cerebral aneurysm and its mother vessel, but it has side effects of contrast medium and radiation exposure.[2)] Time-of-flight magnetic resonance angiography (TOF-MRA) is a fast and non-invasive method, but clip-induced artifact limits assessment of the artery in the vicinity of the clip.[3,4)] Recently, MRA with ultrashort echo time (UTE-MRA) has been attracting and reported to have the potential to overcome these disadvantages.[3,5,6–14)]

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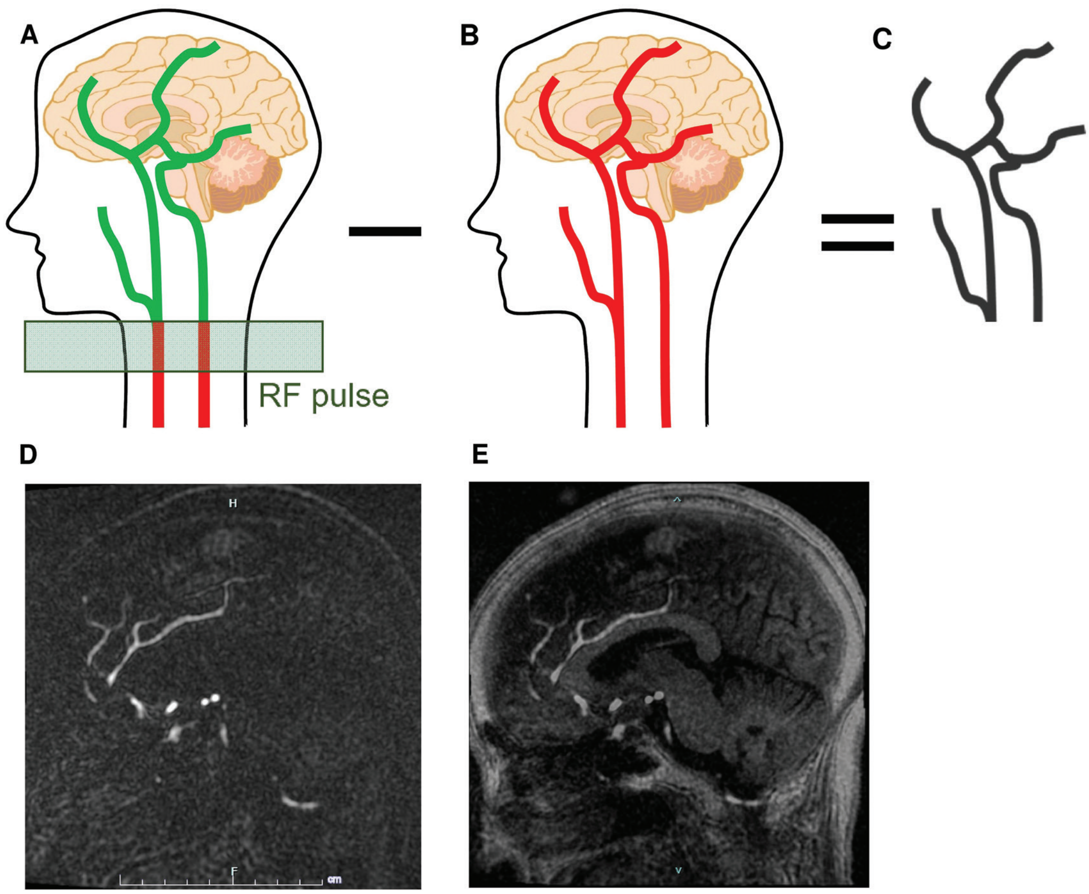

Fig. 1 Schematic explanation of the SILENT MRA. SILENT MRA makes the blood within the carotid arteries "labeled" using a long RF inversion pulse. Once the blood is labeled, it is allowed to flow into the arteries and to be captured by the MR acquisition (A). The collection of a control dataset follows this (B), and these two datasets are subtracted to eliminate the background (C). One of the original SILENT MRA images (D). After adding T1-weighted images to the SILENT MRA images, we can obtain detailed images (E). MRA: magnetic resonance angiography, RF: radiofrequency.

UTE-MRA is a sequence using arterial spin labeling (ASL) technique[15] or inversion recovery pulses[16] as well as subtraction processing.[7,15–17] SILENT MRA[15] (GE Healthcare Life Sciences, Buckinghamshire, UK),[12,14] one of the UTE-MRA sequences, makes the blood within the carotid arteries "labeled" using a long radiofrequency inversion pulse. Once the blood is labeled, it is allowed to flow into the arteries and to be captured by the MR acquisition (Fig. 1A). The collection of a control dataset follows this (Fig. 1B), and these two datasets are subtracted to eliminate the background (Fig. 1C). Then, we can acquire the depiction of the arteries like cerebral angiography (Fig. 1D). After adding T1-weighted images to the SILENT MRA images, we can obtain detailed images similar to the conventional TOF-MRA (Fig. 1E). Notably, UTE-MRA reduces metal artifact,[3,5–7] and its usefulness has been reported for the assessment of the internal flow in the intracranial stent,[8,9,18] moyamoya disease,[19] and arteriovenous malformation.[20,21] However, a few studies reported the usefulness of specific UTE-MRA, such as pointwise encoding time reduction with radial acquisition (PETRA[16]; Siemens Healthcare, Erlangen, Germany)[10,11] and SILENT MRA[12,14] for the assessment of arteries and aneurysm neck remnant in the vicinity of a clip.

We routinely use SIGNA Pioneer 3.0T (GE Healthcare Life Sciences) and perform SILENT MRA[12,15] for the postoperative assessment of the arteries and aneurysm neck remnant after clipping. We hypothesized that SILENT MRA could be a first-line non-invasive imaging modality for follow-up of clipped aneurysms regardless of aneurysm location or treatment method. However, only our one case report[12] and case series with 16 patients[14] describe its utility for the assessment of the arteries in the vicinity of a clip. Therefore, we herein report 19 patients who underwent aneurysm clipping and were evaluated using SILENT MRA as a continuation study of our previous case report.[12] Furthermore, we also statistically investigated the factors related to visibility in SILENT MRA.

Materials and Methods

Study population

This retrospective study included 19 consecutive patients who underwent surgical clipping for ruptured and unruptured aneurysms and were performed TOF-MRA, SILENT MRA between January 2019 and August 2020 in our hospital. No cases were excluded due to severe motion artifact, and all aneurysms were completely clipped without neck remnants, confirmed intraoperatively. All the patients were treated using the fourth-generation YASARGIL Aneurysm Clip System (B. BRAUN, Melsungen, Germany) made of TiAl6V4 titanium alloy (ISO 5832-2).

The study was approved by our hospital's research ethics committee, and we gained written informed consent for this study from all of the patients, the legally authorized representative of the patients, or next of kin of the deceased patients. All methods were carried out in accordance with relevant guidelines and regulations (Declaration of Helsinki). All personal patient information was deleted from the database for this study to protect patient privacy.

Imaging Acquisition

TOF-MRA and SILENT MRA on postoperative day 7 were used for this study, and they were acquired during the same scan session. We performed MRA on postoperative day 7 because of the following reasons. (1) Some cases would have angiographic or symptomatic vasospasms on postoperative day 7. We intentionally investigated the visibility of the mother vessels when the vessels would be relatively narrow due to vasospasm and tested the utility of SILENT MRA. (2) Some cases would still have subarachnoid hemorrhage (SAH) on postoperative day 7, affecting the vessels' visibility, especially in TOF-MRA. Similarly, we investigated the effects of SAH for visibility in the SILENT MRA sequence. We used SIGNA Pioneer 3.0T by a 24-channel head-neck coil. The detailed scan parameters for TOF-MRA: repetition time/echo time, 24/2.8 ms; flip angle, 18 degrees; field of view, 180 × 180 mm; matrix, 182; thickness, 1.0 mm; and acquisition time, 5 minutes 13 seconds. The detailed scan parameters for SILENT-MRA: repetition time/echo time, 751/0.016 ms; flip angle, 5 degrees; field of view, 180 × 180 mm; matrix, 384; thickness, 1.2 mm; and acquisition time, 6 minutes 44 seconds. The images of SILENT MRA were acquired as sagittal images.

3D-CTA before surgery was used to measure the narrowest mother vessel diameter. 3D-CTA examinations were performed using 320-row CT scanner (Aquillion ONE; Canon Medical Systems, Tochigi, Japan). Scan parameters comprised rotation period, 1.0 sec; tube voltage, 100 kV; tube current, 420 mA; slice thickness, 0.5 mm; matrix, 512 × 512; and field of view, 200 mm. Iopamidol was used as a contrast medium.

TOF-MRA image was made with maximum intensity projection (MIP) methods using AW server (GE Healthcare Life Sciences). SILENT-MRA was made with MIP methods and volume rendering (VR) methods using AW server. Both images were used for analysis. 3D-CTA images were made using VR methods using Ziostation2 (Ziosoft, Tokyo, Japan).

Image analysis

The narrowest diameters of the mother vessels within 5 mm of the aneurysm neck were measured using a preoperative 3D-CTA reconstruction image using picture archiving and communication system (SYNAPSE; software version 2.5.3, FUJIFILM Medical Co. Ltd., Tokyo, Japan). In reviewing the images, the window width and level could be modified for evaluation. The distal anterior cerebral artery (ACD) and anterior communicating artery (ACoA) themselves were defined as mother vessels for the ACD and ACoA aneurysms, the posterior communicating (PC) artery for the internal carotid-PC (IC-PC) artery aneurysm, and the M2 portion of the middle cerebral artery (MCA) and its bifurcation for the MCA aneurysm. When the posterior communicating artery was not shown in the 3D-CTA reconstruction image, the internal carotid artery was defined as the mother vessel for the IC-PC aneurysm.

The amount of SAH around the clipping site was assessed in a fluid-attenuated inversion recovery sequence and classified into three groups: no SAH (no hematoma), small SAH (hematoma thickness <10 mm), and large SAH (10 mm ≤ hematoma thickness).

Other variables

In addition to the previous radiological variables regarding MRA or 3D-CTA, we also investigated the age, sex, Hunt and Kosnik grade, surgical approach (bifrontal or pterional), location of the aneurysm, dome and neck size (mm), the direction of the clip against the mother vessel (parallel or perpendicular), clip blade length (mm), its shape (straight, curved, bayonet, fenestrated), and the number of the clips. The presence of angiographic or symptomatic vasospasm when the SILENT MRA was performed was also investigated. Two neurosurgeons, who did not know the patients' information, independently assessed the visibility of the mother vessel at the clipping

Table 1 Patients characteristics

Case No.	Age	Sex	HK Gr.	Approach	Location of an.	Dome (mm)	Neck (mm)	Narrowest mother vessel diameter (mm)
1	58	W	2	F	Lt. ACD	12.00	4.70	0.67
2	67	W	3	F	Lt. ACD	5.00	1.76	0.80
3	46	M	2	F	ACoA	4.46	1.79	1.82
4	49	W	2	F	ACoA	2.40	2.44	1.61
5	71	W	2	F	ACoA	5.75	4.77	1.00
6	76	W	2	F	ACoA	3.58	2.04	1.14
7	81	W	2	P (left)	ACoA	4.00	3.00	1.89
8	70	W	1	P	Rt. IC-PC	3.50	3.50	0.80
9	76	W	2	P	Lt. IC-PC	7.00	2.87	1.48
10	51	W	3	P	Lt. MCA	6.48	3.43	1.70
11	65	M	2	P	Lt. MCA	3.10	2.47	0.49
12	69	W	3	P	Lt. MCA	6.94	4.84	0.71
13	70	W	unrup.	P	Lt. MCA	6.69	2.75	1.03
14	71	W	unrup.	P	Lt. MCA	9.52	1.38	0.80
15	75	W	2	P	Lt. MCA	1.30	1.52	1.40
16	75	W	unrup.	P	Rt. MCA	5.46	2.00	2.03
17	82	M	unrup.	P	Rt. MCA	5.91	4.88	1.50
18	83	W	4	P	Rt. MCA	6.64	3.44	2.00
19	84	M	unrup.	P	Rt. MCA	5.20	2.10	1.60
Median (range)	71 (46-84)	15 Women/ 4 Men	5 unruptured, 14 ruptured	6 bifrontal, 13 pterional	5 ACoA, 2 ACD, 10 MCA, 2 IC-PC	5.46 (1.30-12.00)	2.75 (1.38-4.88)	1.40 (0.49-2.03)

ACoA: anterior communicating artery, ACD: distal anterior cerebral artery, F: bifrontal approach, HK Gr.: Hunt and Kosnik grade, IC-PC: internal carotid-posterior communicating artery, MCA: middle cerebral artery, MIP: maximum intensity projection, P: pterional approach, POD: postoperative day, SAH: subarachnoid hemorrhage, unrup.: unruptured aneurysm, VR: volume rendering.

Direction of the clip	Clip	Clip blade length (mm)	Clip shape	SAH amount	Angiographic vasospasm on POD 7	Symptomatic vasospasm on POD 7	Mother vessel visibility in SILENT MRA (MIP)	Mother vessel visibility in SILENT MRA (VR)
Parallel	FT722T, FT760T	6.6, 11.0	Curved, straight	-	-	-	+	+
Perpendicular	FT602T, FT750T	7.8, 9.0	Fenestrated & curved, straight	-	-	-	+	+
Perpendicular	FT720T	7.0	Straight	++	-	-	-	-
Perpendicular	FT700T	3.0	Straight	-	-	-	-	-
Perpendicular	FT752T	8.3	Curved	+	-	-	+	+
Perpendicular	FT728D	7.0	Bayonet	-	-	-	+	+
Parallel	FT752T	8.3	Curved	-	+	+	+	+
Parallel	FT728D, FT700T	7.0, 3.0	Bayonet, straight	-	-	-	+	+
Parallel	FT752T	8.3	Curved	+	+	-	+	+
Parallel	FT750T	9.0	Straight	++	-	-	+	+
Parallel	FT762T	10.2	Curved	-	+	+	+	+
Parallel	FT782T	13.7	Curved	-	-	-	+	+
Perpendicular	FT740T, FT750T	7.0, 9.0	Straight, straight	-	-	-	+	+
Parallel	FT750T	9.0	Straight	-	-	-	+	+
Perpendicular	FT722T	6.6	Curved	+	-	-	-	-
Parallel	FT750T	9.0	Straight	-	-	-	+	+
Parallel	FT750T, FT760T	9.0, 11.0	Straight, straight	-	-	-	+	+
Parallel	FT782T	13.7	Curved	++	+	-	+	+
Perpendicular	FT782T	13.7	Curved	-	-	-	+	+
11 parallel, 8 perpendicular	14 single, 5 double	9.0 (3.0-13.7)		3 moderate, 3 massive	4 angiographic vasospasm	2 symptomatic vasospasm	16 visible (84%)	16 visible (84%)

Table 2 Patient characteristics and difference between visible and invisible groups

Variables (median, range)	Visible (n = 16)	Invisible (n = 3)	p value†
Age (years)	71 (51-84)	49 (46-75)	0.109
Female: Male	13:3	2:1	0.530
Ruptured: Unruptured	11:5	3:0	0.281
Approach			0.222
bifrontal	4	2	
pterional	12	1	
Laterality of aneurysm			Uncalculated
left	8	1	
right	5	0	
center	3	2	
Location of aneurysm			Uncalculated
ACoA	3	2	
ACD	2	0	
MCA	9	1	
IC-PC	2	0	
Dome (mm)	5.83 (3.10-12.0)	2.4 (1.30-4.46)	0.023*
Neck (mm)	2.93 (1.38-4.88)	1.79 (1.52-2.44)	0.085
Narrowest mother vessel diameter (mm)	1.08 (0.49-2.03)	1.61 (1.40-1.82)	0.303
Direction of the clip to the mother vessel			0.058
perpendicular	5	3	
parallel	11	0	
Clip blade length (mm); single clip only (n = 14)	9.0 (7.0-13.7)	6.6 (3.0-7.0)	0.007*
Shape			Uncalculated
straight	3	2	
curved	7	1	
others or multiple	6	0	
Number of clips			0.530
single	11	3	
double	5	0	
Presence of angiographic vasospasm on POD 7	4	0	Uncalculated
Presence of symptomatic vasospasm on POD 7	2	0	Uncalculated
SAH			0.222
none	12	1	
present	4	2	

*$p < 0.05$ by Mann-Whitney U test, †Mann-Whitney U test or Fisher's exact test was performed. ACoA: anterior communicating artery, ACD: distal anterior cerebral artery, IC-PC: internal carotid-posterior communicating artery, MCA: middle cerebral artery, POD: postoperative day, SAH: subarachnoid hemorrhage.

site in TOF-MRA and SILENT MRA referring to the preoperative CTA and intraoperative findings.

Statistical analysis

To assess the association between the visibility of the mother vessels in SILENT MRA and the variables, we used the Mann–Whitney U test or Fisher's exact test. Clip blade length of the single clip was used for statistical analysis, and those of double clips were excluded because the metal artifacts would be large in the double clips and the length of each clips varied. Interrater agreement for the visibility

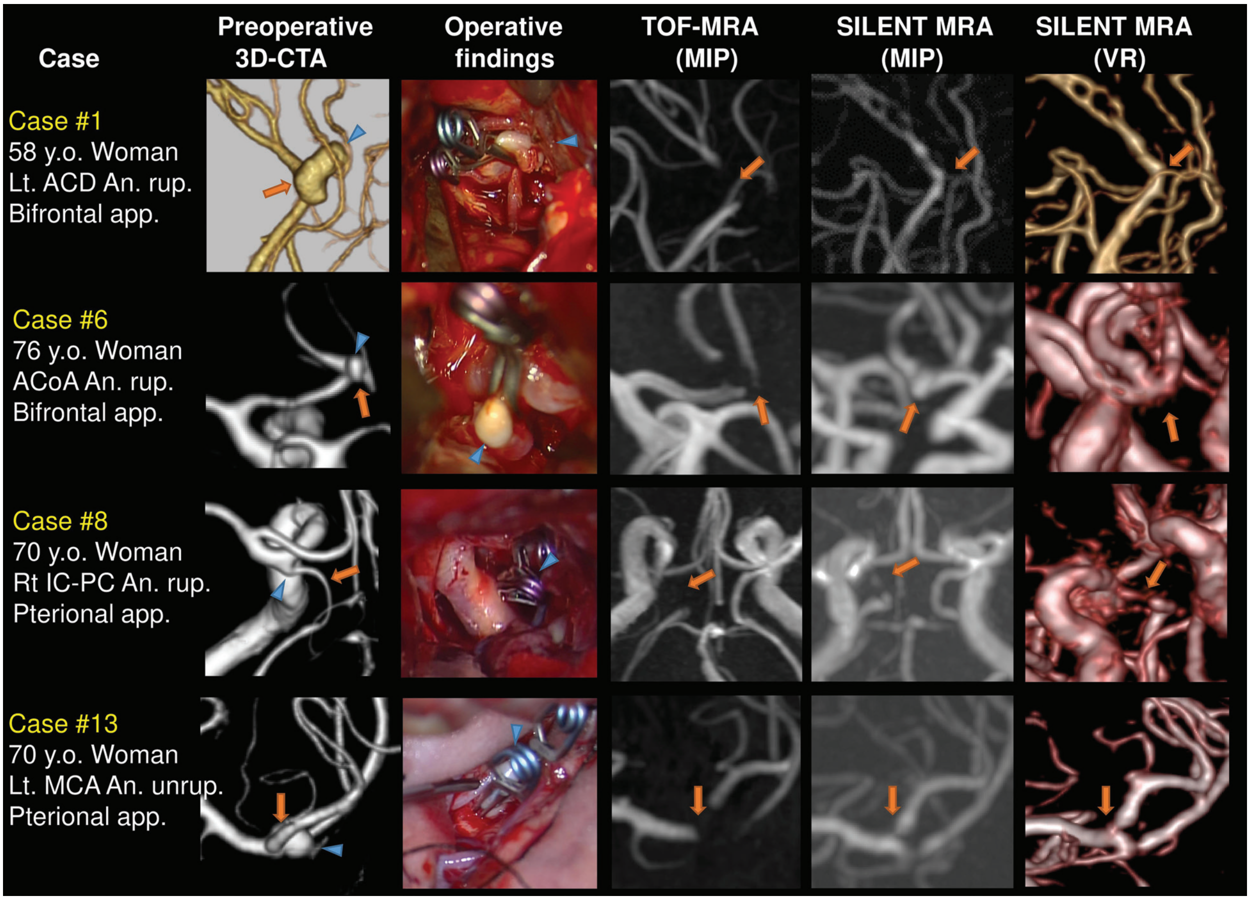

Fig. 2 Representative cases, whose mother vessels were VISIBLE in SILENT MRA. Case 1: A ruptured 12.00 mm left ACD aneurysm was clipped using two clips parallel to the distal part of the anterior cerebral artery. Case 6: A ruptured 3.58mm ACoA aneurysm was clipped using 8.3 mm curved clip perpendicularly to the ACoA. Case 8: A ruptured 3.50 mm right IC-PC aneurysm was clipped using two clips parallel along the narrow posterior communicating artery, and it was revealed in SILENT MRA. Case 13: An unruptured 6.69 mm left MCA aneurysm was clipped using two clips perpendicularly to the bifurcation. Arrows indicate the mother vessels, and arrowheads indicate the aneurysms. ACD: anterior cerebral artery, ACoA: anterior communicating artery, IC-PC: internal carotid posterior communicating, MCA: middle cerebral artery, MRA: magnetic resonance angiography.

in TOF-MRA of SILENT MRA was evaluated by Fleiss's fixed marginal multi-rater kappa using Online Kappa Calculator.[22,23] The results were interpreted as poor (<0.40), intermediate to good (0.40–0.75), or excellent (>0.75). Continuous variables are summarized as median (range). A two-tailed $p < 0.05$ was considered statistically significant. We conducted this calculation using SPSS software version 24.0.0. (IBM, Armonk, New York, USA).

Results

Clinical characteristics

Clinical characteristics of the 19 patients (15 women and 4 men) treated by clipping are summarized in Table 1. The median (range) age was 71 (46–84). Six patients had bifrontal approaches and 13 pterional ones. Five patients had aneurysms at the ACoA, 2 patients at the ACD, 10 at the MCA, and 2 at the IC-PC. The median dome size was 5.46 (1.30–12.00) mm, and the median neck length was 2.75 (1.38–4.88) mm. The median narrowest mother vessel diameter was 1.40 (0.49–2.03) mm. In all, 11 clips were applied parallel to the mother vessel, and 8 clips perpendicular to the mother vessel. In total, 14 patients had a single clip, and 5 had double clips. The median blade length was 9.0 (3.0–13.7) mm. Angiographic vasospasms were observed in four patients, and symptomatic ones in two patients. SAH amount was moderate in three patients and massive in the other three patients. All patients' mother vessels were not described in TOF-MRA, and that of 16 patients (84%) were described in SILENT MRA in both MIP methods and VR methods. Overall agreement was 100% in

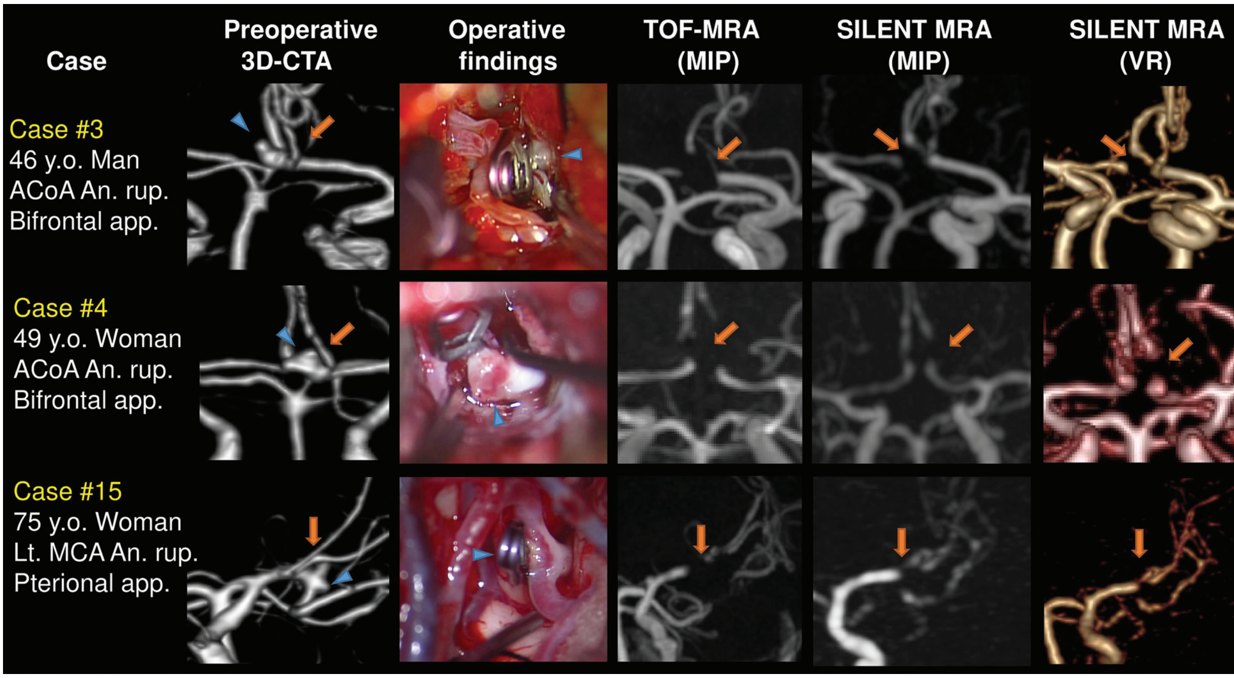

Fig. 3 Three cases whose mother vessels were INVISIBLE in SILENT MRA. Case 3: A ruptured 4.46 mm ACoA aneurysm was clipped using 7.0 mm straight clip perpendicularly to the ACoA. Case 4: A ruptured 2.40 mm ACoA aneurysm was clipped using 3.0 mm short straight clip perpendicularly to the ACoA. Their mother vessels (ACoA) were not described in SILENT MRA. Case 15: A ruptured 1.30 mm left MCA aneurysm was clipped using 6.6 mm curved clip perpendicular to the bifurcation. SILENT MRA did not reveal the origins of the M2 portions. Arrows indicate the mother vessels, and arrowheads indicate the aneurysms. ACOA: anterior communicating artery, MCA: middle cerebral artery, MRA: magnetic resonance angiography.

the two neurosurgeons, and the fixed marginal kappa = 1.00 (95% CI: 0.36–1.00) (Table 1).

Relationship between visibility in SILENT MRA and variables

We performed the Mann–Whitney U test and Fisher's exact test. Large aneurysm dome size and long clip blade length contributed to the visibility of the mother vessel in SILENT MRA (p = 0.023, 0.007. each) (Table 2).

Representative cases as visible in SILENT MRA

We herein describe the representative cases of clipped aneurysms at each location. **Case 1**: A ruptured 12.00 mm left ACD aneurysm was clipped using two clips parallel to the distal part of the anterior cerebral artery. **Case 6**: A ruptured 3.58 mm ACoA aneurysm was clipped using 7.0 mm bayonet clip perpendicularly to the ACoA. **Case 8**: A ruptured 3.50 mm right IC-PC aneurysm was clipped using two clips along the narrow posterior communicating artery, and the posterior communicating artery was revealed in SILENT MRA. **Case 13**: An unruptured 6.69 mm left MCA aneurysm was clipped using two clips perpendicularly to the bifurcation. TOF-MRA did not describe the mother vessels, but SILENT MRA described them. Arrows indicate the mother vessels, and arrowheads indicate the aneurysms (Fig. 2).

Cases as invisible in SILENT MRA

We herein describe the three cases whose mother vessels were not revealed in SILENT MRA. **Case 3**: A ruptured 4.46 mm ACoA aneurysm was clipped using 7.0 mm straight clip perpendicularly to the ACoA. **Case 4**: A ruptured 2.40 mm ACoA aneurysm was clipped using 3.0 mm short straight clip perpendicularly to the ACoA. Their mother vessels (ACoA) were not described in both TOF-MRA and SILENT MRA. **Case 15**: A ruptured 1.30 mm left MCA aneurysm was clipped using 6.6 mm curved clip perpendicular to the bifurcation. Both TOF-MRA and SILENT MRA did not reveal the origins of the M2 portions. Arrows indicate the mother vessels, and arrowheads indicate the aneurysms (Fig. 3).

Discussion

We previously published the case report on the utility of SILENT MRA in the same way as this study.[12] As a continuation study, we herein report 19 patients who underwent aneurysm clipping and were evaluated using SILENT MRA, and this report contains a relatively large number of clipped cases compared to previous reports.[14] The mother vessels were revealed in 16 of the 19 patients (84%). Also, in the univariate analysis, aneurysm dome size and clip blade length were larger in the visible group compared to the invisible group in SILENT MRA. This statistical analysis is a novel point compared to our previous case report.[12]

SILENT MRA and other modality

SILENT MRA can minimize the phase dispersion of the labeled blood flow signal, and decrease the metal artifact derived from clips. Therefore, SILENT MRA can describe cerebral arteries like cerebral angiography, leading to the flow visualization in the vicinity of the clip.[12,14] Also, SILENT MRA can improve visualization of turbulent flow by minimizing flow-related signal dropout,[24] and the SILENT MRA detect blood flow independently on the flow direction because of the ASL preparation pulse.[8] Therefore, the visualization of the aneurysm remnant[10] or tortuous artery like IC-PC in SILENT MRA can be better than that in TOF-MRA. Also, SILENT MRA can suppress background compared to TOF-MRA, leading to increased better quality image even in the presence of T1 hyperintense lesions such as intracranial hemorrhage, hematoma, Rathke's cleft cyst, or paranasal sinus retention cyst.[24]

The disadvantages of SILENT MRA were as follows: the total required time is longer in SILENT MRA than that in TOF-MRA because SILENT MRA needs ASL preparation[7] and subtraction processing.[17] As another problem, the signal in UTE-MRA is weaker than that in TOF-MRA, especially in the distal part from the neck where blood was labeled.[3] Furthermore, ASL may not always be performed if there is severe neck carotid artery stenosis or metal around the neck, such as an intubation tube cuff.[12] Also, the cost and the availability of the 3 tesla magnetic resonance imaging (MRI) are problems.[17] Furthermore, in this study, all patients were treated using the fourth-generation YASARGIL Aneurysm Clip System made of TiAl6V4 titanium alloy (ISO 5832-2). We could not investigate metal artifacts from other clips made of other materials. Therefore, a detailed study must be done, although we should pay attention to the torque, translational force, and the metal temperature in the 3 tesla magnetic fields.[25,26]

Mother vessel visibility in SILENT MRA

Compared to the Gönner's first study[3] on the assessment of the clipped artery with UTE-MRA with a TE of 2.4 ms, SILENT MRA with a much shorter TE of 0.016 ms can obtain better quality images and smaller metal artifact of clips. Besides, 3 tesla MRI improves image quality compared to 1.5 tesla MRI,[10,12] and SIGNA Pioneer 3.0T can obtain with a broad range in a shorter time compared to old MRI types of equipment. This difference would be because of the advances in MRI quality and performance, especially in the technology of much shorter TE.

Kyeong[14] reported the utility of SILENT MRA in 126 patients treated by 60 stent-assisted coil embolization, 46 simple coiling, 4 simple stenting, and 16 clipping. They discussed the image quality of SILENT MRA using 5-point assessment scale. The overall 126 image quality scores of TOF-MRA and SILENT MRA were 4.04 ± 0.22 and 4.64 ± 0.48, respectively ($p < 0.001$), so SILENT MRA was superior to TOF-MRA in the image quality. In the subgroup analysis of the 16 clipped patients, the image quality scores of TOF-MRA and SILENT MRA were 1.4 ± 1.0 and 3.7 ± 0.9, respectively ($p < 0.001$). This trend that SILENT MRA is superior to TOF-MRA to evaluate mother vessels was the same as our present study. However, their 5-point image quality scores of the clipped patients were smaller than those of the patients treated by simple coiling (4.5 ± 0.8) and simple stenting (3.8 ± 1.2). Therefore, delineation of the mother vessel after clipping in SILENT MRA seemed inferior to those after coiling or simple stenting. There would be reasons why SILENT MRA sometimes does not describe the clipped arteries.

Takubo[11] reported the clip artifact characteristics in the 3 tesla UTE-MRA with PETRA[16] (MAGNETOM Skyra; Siemens Healthcare). They used a homemade phantom (width 90 mm, depth 90 mm, and height 50 mm) containing a mixture of 0.125 mmol/L gadopentetate dimeglumine to mimic white matter and agarose solution. In their study, the clip head artifacts were larger than that of the clip blade, and they varied depending on the direction to the static magnetic field. Considering these clip-induced artifact characteristics, the distance between the clip head and the mother vessels would be related to the capability of vessel delineation.

Our results showed that aneurysm dome size and clip blade length were larger in the visible group compared to the invisible group in SILENT MRA. In Fig. 2, the visible cases, we used clips with long blades and ligated the aneurysm neck using relatively tips of the clips. The clip heads were distant from the mother vessels. While in Fig. 3, the invisible cases, we used clips with relatively short blades and ligated the aneurysm neck with whole blades, so the clip heads were close to the neck and mother vessels. On comparing Figs. 2 and 3, we hypothesized that the closer the clip head is to the mother vessel, the poorer the mother vessel delineation. Aneurysm dome size was also related to the visibility, and its neck was almost statistically significant (p = 0.085, Table 2) in the univariate analysis. We think that our results were acquired from the univariate analysis, so the aneurysm dome size and neck length would be confounders of the clip blade length. Considering clinical application, while a detailed study is necessary, aneurysm clipping intentionally using a long clip with ligation by the blade tip might allow for follow-up with SILENT MRA without the need for 3D-CTA.

Limitations

First, the sample size was small, and we performed only univariate analysis using the Mann–Whitney U test and Fisher's exact test, and the number of the patients in the invisible group was very small as 3. We should continue to study what kind of aneurysm, clip shape, and surgical procedure, like how to apply the clip, can be applied to SILENT MRA for the vessel evaluation. Second, we did not perform 3D-CTA nor cerebral angiography after operations, so we could not compare the images of SILENT MRA to them. We need postoperative 3D-CTA or cerebral angiography, which would be helpful to reveal the difference between the visible and invisible groups. Third, SILENT MRA images with MIP and VR techniques can differ depending on the radiology technician, leading to over and underestimation. Fourth, SILENT MRA needs longer acquisition time and subtraction procedure, so we would take unuseful images from patients who cannot keep resting during the MRA acquisition.

Conclusions

SILENT MRA can be applied for the assessment of arteries and aneurysm neck remnant in the vicinity of a clip, and the mother vessels were revealed in 16 of the 19 patients (84%). Using clips with long blade and ligation with its tip would be related to the visibility of the mother vessels in SILENT MRA.

Ethics

This study was approved by our hospital ethics committee. The patients in our report provided written consent forms.

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Conflicts of Interest Disclosure

The authors report no conflicts of interest concerning the materials or methods used in this study, or the findings presented in this paper. No sources of financial or material support were received. This article and content of this study were not published or presented previously.

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Corresponding author: Norio Narita, MD, PhD
Department of Neurosurgery, Kesennuma City Hospital, 8-2 Akaiwasuginosawa, Kesennuma, Miyagi 988-0181, Japan.
e-mail: nnarita@mbr.nifty.com