Early diffusion-weighted MRI lesions after treatment of unruptured intracranial aneurysms: a prospective study

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OBJECTIVE Diffusion-weighted MRI was used to assess periprocedural lesion load after repair of unruptured intracranial aneurysms (UIA) by microsurgical clipping (MC) and endovascular coiling (EC).

METHODS Patients with UIA were assigned to undergo MC or EC according to interdisciplinary consensus and underwent diffusion-weighted imaging (DWI) 1 day before and 1 day after aneurysm treatment. Newly detected lesions by DWI after treatment were the primary end point of this prospective study. Lesions detected by DWI were categorized as follows: A) 1–3 DWI spots < 10 mm, B) > 3 DWI spots < 10 mm, C) single DWI lesion > 10 mm, or D) DWI lesion related to surgical access.

RESULTS Between 2010 and 2014, 99 cases were included. Sixty-two UIA were treated by MC and 37 by EC. There were no significant differences between groups in age, sex, aneurysm size, occurrence of multiple aneurysms in 1 patient, or presence of lesions detected by DWI before treatment. Aneurysms treated by EC were significantly more often located in the posterior circulation ($p < 0.001$). Diffusion-weighted MRI detected new lesions in 27 (43.5%) and 20 (54.1%) patients after MC and EC, respectively (not significant). The pattern of lesions detected by DWI varied significantly between groups ($p < 0.001$). Microembolic lesions (A and B) found on DWI were detected more frequently after EC (A, 14 cases; B, 5 cases) than after MC (A, 5 cases), whereas C and D were rare after EC (C, 1 case) and occurred more often after MC (C, 12 cases and D, 10 cases). No procedure-related unfavorable outcomes were detected.

CONCLUSIONS According to the specific techniques, lesion patterns differ between MC and EC, whereas the frequency of new lesions found on DWI is similar after occlusion of UIA. In general, the lesion load was low in both groups, and lesions were clinically silent.

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TODAY, microsurgical clipping (MC) and endovascular coiling (EC) are highly developed and well-established modalities for prophylactic treatment of unruptured intracranial aneurysms (UIA). Microsurgical clipping and EC differ in the degree of invasiveness and may also show differences regarding typical complications or long-term efficacy.

Centers offering both types of treatment have to find a consensus on the optimal kind of UIA treatment for each patient based on careful risk–benefit analyses and the patient's preferences. A description of typical complications is mandatory for proper counseling of patients. Ischemic events present the most important complication of both methods, with an immediate impact on the patient in cases

ABBREVIATIONS ACA = anterior cerebral artery; ACoA = anterior communicating artery; DSA = digital subtraction angiography; DWI = diffusion-weighted imaging; EC = endovascular coiling; ICA = internal carotid artery; MC = microsurgical clipping; MCA = middle cerebral artery; mRS = modified Rankin Scale; PCoA = posterior communicating artery; PICA = posterior inferior cerebellar artery; UIA = unruptured intracranial aneurysms.

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TABLE 1. Published studies on the frequency of DWI-detected lesions after endovascular treatment of cerebral aneurysms

Authors & Year	No. of Cases	Presentation of Aneurysm	% Cases w/ DWI-Detected Lesions	% Symptomatic Patients
Altay et al., 2011	133	UIA	30	4.9 (overall)
	65	Ruptured	65	
Biondi et al., 2000	20	Both	10	0
Chung et al., 2008	163	Both	60	3.6,* 1.2†
Cronqvist et al., 2005	14	Ruptured	71	NA
	29	UIA	24	17.2,* 3.4†
Grunwald et al., 2006	50	UIA	42	4
Hahnemann et al., 2014	75	UIA	64	6.7,* 1.3†
Jo et al., 2013	282	UIA	31	1.8
Kang et al., 2013 ¹⁵	382	UIA	55	4.1
Kang et al., 2013 ¹⁴	40	UIA	60	0
Kim et al., 2013 ¹⁷	90	UIA	61	1.1
Lim Fat et al., 2013	135	Both	71	NA
Matsushige et al., 2013	34	UIA	77	0
Rordorf et al., 2001	14	UIA	64	7.1
Sim & Shin, 2012	39	Both	44	10.3
Soeda et al., 2003 ³³	66	UIA	61	22,* 5†
Soeda et al., 2003 ³²	26	UIA	69	27,* 0†

NA = not available.

* Transient deficit.

† Permanent deficit.

of disabling stroke. Fortunately, complications with severe clinical consequences are rare, and large numbers of cases are needed to compare clinical complication rates.

According to studies for evaluation of endovascular procedures, the detection of new lesions on diffusion-weighted MRI is regarded as a surrogate parameter for assessment of the ischemic treatment risks, with the advantage that clinically silent lesions can also be detected.

Following reports about frequent detection of lesions on diffusion-weighted imaging (DWI) after EC^{1,3,5–8,11–15,17,21,22,29,31–33} (Table 1) and previous studies concerning lesions found on DWI after MC,^{18,19,23} we strove to analyze lesion patterns and lesion load for both modalities in a single-center, interdisciplinary setting. Therefore, we systematically assessed the occurrence of new lesions found on DWI after repair of UIA by MC or EC, with the aim to describe the frequency of specific lesion patterns and the implications for clinical practice.

Methods

Inclusion and Exclusion Criteria

Patients with UIA who were scheduled for MC or EC, and who underwent MRI including DWI sequences the day before and the day after treatment, were prospectively included in this study.

The decision for MC or EC was made by consensus between vascular neurosurgeons and endovascular interventionalists, also considering the patient's preferences. The decision was based on aneurysm parameters (site, size, configuration, calcifications, and thrombosis) assessed on digital subtraction angiography (DSA) as well as on char-

acteristics of the patient (age, comorbidities, and preference of the patient). The study was approved by the local review board. In addition, this study was registered with the ClinicalTrials.gov database (<http://clinicaltrials.gov>), and its registration no. is NCT01490463.

Patients were excluded from the study in any of the following conditions: 1) MRI contraindications, patient's refusal of MRI, or other reasons for missing the MRI within the appropriate time frame; 2) a history of previous aneurysmal hemorrhage; 3) aneurysms > 15 mm; 4) previous treatment of the same aneurysm; 5) use of flow diverters; 6) simultaneous treatment of more than 1 aneurysm; or 7) temporary rapid ventricular pacing during MC.

Microsurgical Treatment

A pterional craniotomy was used as the standard approach for all aneurysms of the anterior circulation or posterior communicating artery (PCoA). Clipping was performed in a standardized microsurgical procedure, opening the sylvian fissure and basal cisterns. In the patient with a posterior inferior cerebellar artery (PICA) aneurysm, a lateral suboccipital approach was used. The patients were kept normovolemic, with a mean arterial pressure of 80–100 mm Hg. Intraoperative monitoring was used routinely, measuring somatosensory and motor evoked potentials.³⁴ Intraoperatively, indocyanine green video angiography was used in all procedures to verify aneurysm occlusion as well as parent vessel perfusion after clipping.²⁷ Because we do not perform intraoperative angiography, all patients underwent postoperative DSA approximately 7 days after the procedure.

Endovascular Treatment

Endovascular coiling was performed under general anesthesia via transfemoral placement of a 5-Fr or 6-Fr guiding catheter. For access to the anterior communicating artery (ACoA) or other difficult approaches, a coaxial access system with a long carotid sheath and an inner guiding or distal access catheter were used. For super-selective catheterization of aneurysms, we preferred a 0.010-in microcatheter–microguidewire combination. For balloon- or stent-assisted coiling, we placed a second or larger guiding catheter and used compliant remodeling balloons or self-expanding microstents. Peri-interventional antithrombotic treatment was administered with a bolus of 5000 IU of heparin and additional heparin (1000 IU/L) in flushing solutions. Aspirin (100 mg) was started the day before intervention and continued for at least 3 months. Patients with wide-necked aneurysms or candidates for stent placement received double antiplatelet therapy, adding 75 mg of clopidogrel for a minimum of 3 months.

Examinations by MRI

Magnetic resonance imaging of the brain was performed on a 3-T whole-body system (Magnetom Verio; Siemens) with an 8-channel phased-array head coil. The protocol included axial T2-weighted images, axial T2-weighted FLAIR images, and axial and coronal single-shot echo-planar DWI (b 1000) with apparent diffusion coefficient maps.

All images were evaluated for consensus by a neuroradiologist (M.W.) and a neurosurgeon (J.P.).

Primary End Point

All patients underwent DWI prior to aneurysm repair but after initial DSA. The occurrence of new lesions as detected by DWI on the day after aneurysm treatment was the primary end point; thus lesions on DWI related to DSA prior to aneurysm repair were excluded. Therefore, this MRI (DWI) was compared with the MRI before treatment. For statistical analysis, the lesions detected by DWI were categorized as the following types: A) 1–3 DWI spots < 10 mm, B) > 3 DWI spots < 10 mm, C) single DWI lesion > 10 mm, or D) DWI lesion related to surgical access, which typically were small cortical lesions around the sylvian fissure and did not represent a typical vascular pattern after aneurysm securing (Fig. 1). These categories were based on previous reports of lesions detected by DWI.^{7,11,12,14,21,29,31,33}

Statistical Analysis

Continuous variables were compared using the Mann-Whitney U-test and categorical variables were analyzed using the chi-square or Fisher's exact test as appropriate. A *p* value < 0.05 was considered significant. We used standard commercial software (SPSS Statistics version 21; IBM Corp.).

Results

During the treatment period, 237 UIA (205 patients)

FIG. 1. Classification of DWI-detected lesions. Example for DWI spots < 10 mm (A) after EC of an MCA aneurysm (other lesions not shown; 6 total). Example for a single DWI-detected lesion > 10 mm (B) after EC of a basilar trunk aneurysm and (C) after MC of an MCA aneurysm. Example for a DWI-detected lesion related to surgical access (D) after MC of an ophthalmic artery aneurysm. White arrows denote DWI lesions.

were treated at our institution. The inclusion criteria were met by 99 UIA in 89 patients (Fig. 2). Microsurgical clipping was performed in 62 UIA and EC in 37. The demographic parameters were equally distributed between groups. The most striking difference between groups was distribution of the UIA (Table 2): 58 (93.5%) aneurysms in the MC group were located in the anterior circulation, whereas 20 (54.1%) aneurysms treated by EC were located in the posterior circulation (*p* < 0.001).

Prior to aneurysm treatment, most patients showed no lesions on DWI (56 of 62 in the MC and 34 of 37 in the EC group; *p* = 0.793). For A (1–3 DWI spots < 10 mm), there were 3 patients (4.8%) in the MC and 2 (5.4%) in the EC group. For B (> 3 DWI spots < 10 mm), there was 1 (1.6%) case in the MC group and none in the EC group, whereas for C (single DWI lesion > 10 mm), there were 2 (3.2%) and 1 (2.7%) case in the MC and EC groups, respectively (*p* = 0.888). In 3 patients, the lesions detected by DWI were probably related to a previous angiogram. Microangiopathic genesis was suspected in another 3 patients, the etiology was uncertain in 2 patients, and the lesion in the remaining patient was related to a previous aneurysm treatment.

In the EC group, a stent was placed in 6 patients. The stent procedure was planned in 5 of these patients due to the wide neck of the aneurysm and was necessary in the last patient due to protrusion of a coil into the parent vessel.

FIG. 2. Flow chart showing the included and excluded cases. The occurrence of new DWI-detected lesions was not statistically significantly different ($p = 0.311$). SAH = subarachnoid hemorrhage; WEB = Woven EndoBridge device.

TABLE 2. Demographic parameters of patients and distribution of the aneurysms treated by MC and EC

Parameter	Endovascular	Surgical	p Value
No. of patients	37	62	
Age in yrs, mean $\pm$ SD	52.2 $\pm$ 8.8	53.2 $\pm$ 9.1	0.570*
Female sex, no. (%)	33 (89.2)	49 (79.0)	0.195†
Arterial hypertension, no. (%)	15 (40.5)	26 (41.9)	0.892†
Diabetes mellitus, no. (%)	2 (5.4)	3 (4.8)	1.000‡
Smoker, no. (%)	14 (37.8)	26 (41.9)	0.688†
Aneurysm size in mm, mean $\pm$ SD	7.4 $\pm$ 2.5	7.6 $\pm$ 2.4	0.695*
Multiple aneurysms, no. (%)	14 (37.8)	22 (35.5)	0.814†
Aneurysm site, no.			<0.001‡
ACoA/ACA	6	9	
MCA	2	38	
ICA	9	11	
PCoA	6	3	
BA incl PCA	13	0	
VA/PICA	1	1	

BA = basilar artery; incl = including; PCA = posterior cerebral artery; VA = vertebral artery.

* Mann-Whitney U-test.

† Chi-square test.

‡ Fisher's exact test.

Occurrence of New Lesions as Detected by DWI

Overall, 52 cases (52.5%) showed no new lesions on DWI after aneurysm occlusion. Yet, new lesions were detected by DWI in 27 of 62 cases (43.5%) after MC and in 20 of 37 cases (54.1%) after EC. The occurrence of new lesions on DWI was not significantly different between the groups ($p = 0.311$; Fig. 3).

After MC, the most commonly detected types were C (single DWI lesion > 10 mm [$n = 12$ cases]), A (1–3 DWI spots < 10 mm [$n = 5$ cases]), and D (typical access-related DWI lesions [$n = 10$]). Of the 12 patients with Type C, 11 lesions were < 20 mm. Only 1 patient developed a lesion detected by DWI in the territory of an M_2 branch after clipping of a complex 10-mm, partially calcified middle cerebral artery (MCA) aneurysm with a wide neck. Ten instances of Type D were detected after clipping: 2 of 9 were ACoA (22%), 5 of 38 MCA (13%), 2 of 11 internal carotid artery (ICA; 18%), and 1 of 3 PCoA aneurysms (33%). In 20 cases, temporary clipping was used during the procedure. Of those, no new lesions were detected by DWI in 12 (60%) patients. The use of temporary clipping did not make a statistically significant difference in the occurrence of new lesions found on DWI ($p = 0.640$).

After EC, Type A (1–3 DWI spots < 10 mm) was detected in 14 patients, Type B (> 3 DWI spots < 10 mm) in 5 patients (maximum 9 spots, mean 6.4 spots), and Type C (a single DWI lesion > 10 mm) was visible in 1 patient with a basilar trunk aneurysm. In 2 of the 5 patients with Type B, a temporary thrombus formation was noted dur-

FIG. 3. Occurrence of new DWI-detected lesions after EC (n = 37) and MC (n = 62). The lesion distribution pattern was statistically significantly different between the 2 groups ($p < 0.001$).

ing the procedure and treated by intravenous tirofiban. Tirofiban was given to 1 more patient, who developed Type A. There was no association between aneurysm location and the detection of Type B (1 ophthalmic ICA, 2 basilar tip, 1 ACoA, and 1 MCA aneurysm[s]). The use of the remodeling technique (n = 6; new lesions detected by DWI in 50%) or a stent (n = 6; new lesions detected by DWI in 66%) was not statistically associated with the occurrence of new lesions on DWI ($p = 0.888$).

The difference in the distribution pattern of the lesions detected by DWI between MC and EC was statistically significant ($p < 0.001$). In almost all patients, the lesions detected by DWI were within the treated vascular territories. Only in 1 patient in the MC group and in 2 patients in the EC group was a different vascular territory affected ($p = 0.402$).

Risk Factors for the Occurrence of New Lesions as Detected by DWI

As shown in Table 3, age, aneurysm size, female sex, history of arterial hypertension, diabetes mellitus, smoking, the occurrence of multiple aneurysms, site of the aneurysm, presence of lesions detected by DWI prior to aneurysm occlusion, or the method of aneurysm occlusion did not vary significantly between those patients with and without postprocedural lesions on DWI. Because we could not identify any significant difference for the occurrence of new lesions on DWI in the univariate analysis, we did not perform a multivariate analysis.

When the 2 groups were analyzed separately, we found more lesions on DWI in younger patients in the MC group ($p = 0.037$; Table 4), whereas this trend did not reach statistical significance in the EC group. No other parameters were statistically significant when each group was analyzed separately. Due to the limited numbers of aneurysms, statistical analysis of the influence of aneurysm

TABLE 3. Risk factors for the occurrence of new DWI-detected lesions after aneurysm occlusion

Parameter	No New Lesion, n = 52	New Lesion, n = 47	p Value
Age in yrs, mean $\pm$ SD	53.8 $\pm$ 8.9	51.8 $\pm$ 8.9	0.476*
Aneurysm size in mm, mean $\pm$ SD	7.7 $\pm$ 2.4	7.3 $\pm$ 2.4	0.284*
Female sex, no. (%)	43 (82.7)	39 (83.0)	0.970†
Arterial hypertension, no. (%)	20 (38.5)	21 (44.7)	0.530†
Diabetes mellitus, no. (%)	1 (1.9)	4 (8.5)	0.187‡
Smoker, no. (%)	21 (40.4)	19 (40.4)	0.997†
Multiple aneurysms, no. (%)	15 (28.8)	21 (44.7)	0.102†
Aneurysm site			0.945‡
ACoA/ACA	7	8	
MCA	21	19	
ICA	11	9	
PCoA	6	3	
BA/PCA	6	7	
VA/PICA	1	1	
No. of prior DWI-detected lesions	4	5	0.611†
Aneurysm treatment			0.311†
MC	35	27	
EC	17	20	

* Mann-Whitney U-test.

† Chi-square test.

‡ Fisher's exact test.

location on the occurrence of new lesions detected by DWI is limited. The incidence of new lesions on DWI was higher after EC than after MC of ACoA/anterior cerebral artery (ACA) and MCA aneurysms.

Clinical Outcome

In both groups, most of the lesions detected by DWI were clinically silent. Clinical examinations after 6 months revealed no procedure-related unfavorable outcomes in either group, as judged by the modified Rankin Scale (mRS). Only 1 patient in each group had an mRS score between 3 and 6, neither of which were related to the procedure (Table 5).

Discussion

The setting of this study was based on interdisciplinary consensus between neurosurgeons and neurointerventionalists regarding treatment of UIA by means of MC or EC. We could show that new post-therapeutic lesions were detected by DWI in both groups with similar frequencies but with different patterns. In the majority of cases, these lesions remained asymptomatic, whereas permanent neurological deficits are reported in the literature in approximately 4% of cases (range 0%–10%; Table 1). To our knowledge, this is the first study to prospectively compare the occurrence of new lesions on DWI after an interdisciplinary consensus decision between vascular neuroin-

TABLE 4. Occurrence of new DWI-detected lesions

Parameter	Microsurgical Group, n = 62			Endovascular Group, n = 37		
	No New Lesion, n = 35	New Lesion, n = 27	p Value	No New Lesion, n = 17	New Lesion, n = 20	p Value
Age in yrs, mean $\pm$ SD	54.4 $\pm$ 9.7	51.8 $\pm$ 8.3	0.037*	52.5 $\pm$ 7.4	51.9 $\pm$ 10.0	0.328*
Aneurysm size in mm, mean $\pm$ SD	7.9 $\pm$ 2.5	7.2 $\pm$ 2.3	0.692*	7.3 $\pm$ 2.2	7.4 $\pm$ 2.7	0.774*
Female sex, no. (%)	29 (83)	20 (74)	0.400†	14 (82)	19 (95)	0.217†
Multiple aneurysms, no. (%)	10 (29)	12 (44)	0.195†	5 (29)	9 (45)	0.330†
Aneurysm site, no. (%)			1.0‡			0.651‡
ACoA/ACA		4 of 9 (44)			4 of 6 (67)	
MCA		17 of 38 (45)			2 of 2 (100)	
ICA		5 of 11 (45)			4 of 9 (44)	
PCoA		1 of 3 (33)			2 of 6 (33)	
BA/PCA		0			7 of 13 (54)	
VA/PICA		0 of 1 (0)			1 of 1 (100)	
No. of prior DWI lesions	2	4	0.390‡	2	1	0.584‡

* Mann-Whitney U-test.

† Chi-square test.

‡ Fisher's exact test.

terventionalists and neurosurgeons has been made on the preferred aneurysm treatment. Furthermore, we believe that this study represents the largest number of patients observed after neurosurgical aneurysm repair with respect to this topic.

In this study, the distribution of lesions detected by DWI varied significantly between groups, with Types D (access-related DWI lesions) and C (single DWI lesion > 10 mm) representing the most frequent lesions in the MC group, whereas microembolic spots found on DWI were the predominant lesions in the EC group. For the average patient with new lesions found on DWI, the lesion load was low and clearly below the level of a major branch occlusion.

For EC, this phenomenon is well known from previous studies, which show incidences of new lesions on DWI of between 10% and 77% (Table 1).^{1,3,5–8,11–15,17,21,22,29,31–33} For the etiology of these DWI-detected lesions, several explanations have been discussed. They may be due to thrombus formation at the catheter or guidewire, microemboli created by packing the aneurysmal sac densely with coils, thrombosis within the aneurysmal sac, or dislocation of coils protruding into the parent vessel. Furthermore, friable arteriosclerotic plaques and iatrogenic dissection of

the parent vessel are possible mechanisms, as is the formation of air bubbles during contrast injection or during the introduction and placement of coils and other materials.^{11,17,26,29,32,33} Some studies suggested that the use of the remodeling technique, older patients, or larger aneurysm size are risk factors, whereas others did not.

Manipulations during the arterial access and in the parent vessel might explain the occurrence of DWI-detected lesions proximal to the treated UIA or lesions in other vascular territories than that of the treated aneurysm.^{31,32} Even after diagnostic angiography alone, new silent lesions were detected by DWI in 26% of patients.² Lesions found on DWI after EC may be reversible, because permanent corresponding lesions were found much less frequently on T2-weighted images of follow-up MRI examinations.^{2,7,22}

Clinically, most of the lesions detected after EC are silent. They may become symptomatic, e.g., in cases with an unfavorable location in highly eloquent brain areas or if showers of multiple microemboli occur. Whether microembolic lesions found on DWI may cause neuropsychological deficits is a matter of controversy.^{14,35} A DWI sub-study of the International Carotid Stenting Study found a significant incidence of new DWI-detected lesions even in extracranial procedures, but no clear neuropsychological correlate of these lesions.⁴

In our study, microembolic lesions detected by DWI after EC occurred despite a relatively aggressive antithrombotic regimen, with regular use of antiplatelet agents, heparin, and heparinized flushing solutions. Today, there is no proof that peri-interventional lesions can be avoided. With an average of 2.5 lesions per case, the lesion load was quite low, and it seems unlikely that neuropsychological changes are caused by single white matter lesions.

For MC, there are very few data on the occurrence of DWI-detected lesions. There are only 2 limited series that routinely assessed postprocedural lesions found on DWI, reporting 7.7%–13.9% new lesions after DWI, with only

TABLE 5. Outcome after 6 months according to the mRS

Outcome After 6 Mos (mRS score)	Endovascular, No. (%)	Surgical, No. (%)	p Value
Favorable (0–2)	36 (97.3)	60 (98.4)	NS*
Unfavorable (3–6)	1 (2.7)†	1 (1.6)‡	

NS = not significant.

* Fisher's exact test.

† One patient died within 6 months after treatment due to an underlying disease (Creutzfeldt-Jakob).

‡ One patient had an mRS score of 3 before treatment due to blindness and remained unchanged post-treatment; 1 patient was lost to follow-up.

0%–2.8% being symptomatic.^{18,19,23} Krayenbühl et al. reported the same series of 36 patients twice with a different focus,^{18,19} whereas Murai et al. focused on MCA aneurysms only (n = 42).²³ Both studies included ruptured and unruptured aneurysms. Because the focus of each study was slightly different, we do not know whether the authors took access-related lesions into account. Murai et al. reported a surprisingly low complication rate compared with randomized controlled trials.²³ In general, ischemic complications based on imaging or clinical symptoms are detected in 2.6%–12.1% of patients after MC treatment of UIA.^{10,16,20,25,36,37} Only 1 of these studies used postprocedural MRI; however, in this study, only symptomatic patients or patients with intraoperative complications underwent MRI.²⁰ Therefore, the rate of silent DWI-detected lesions is probably underrepresented or unknown in all previous studies.

In regard to the small cortical lesions around the sylvian fissure, Ngando et al. suggested that with increasing complexity and invagination of the sylvian fissure, postoperative brain edema and ischemia²⁴ may occur as the result of microsurgical splitting, despite the avoidance of extensive manipulation of the vessels within the fissure as well as the use of retractor systems. Because these techniques are used not only for clipping of aneurysms but in many neurosurgical procedures, the impact of these lesions on the outcomes of patients seems negligible, because usually they do not correlate with neurological deterioration postoperatively.

Apart from lesions due to surgical access, the most common lesions found on DWI were Type C (single DWI lesion > 10 mm). The DWI-detected lesion pattern suggests occlusion of small perforators as the most probable cause of these lesions, which were predominantly detected after MC of aneurysms at bifurcations and a significant number of perforators such as MCA bifurcation aneurysms. In MCA aneurysms, MC is generally preferred to EC due to the complex anatomical features, including a wide neck, incorporation of 1 or more M₂ branches into the aneurysm's neck, and the origin of perforators.^{9,16,28} In a CT-based study, infarctions were detected in 26% of cases after MC of MCA aneurysms, and the authors concluded that the high density of perforators in MCA aneurysms represents a special risk.³⁰ Atherosclerotic changes and neck calcification may be associated with higher risks of branch occlusions at the MCA bifurcation.³⁴ Direct manipulation of tiny vessels may also cause DWI-detected lesions. In this study, with 1 exception, the lesion size did not exceed a maximal diameter of 20 mm. None of these lesions was associated with an unfavorable outcome.

Limitations of the Study

First, the number of patients is limited in this study, although to our knowledge it is the largest study to assess the occurrence of new DWI-detected lesions after MC and EC. In addition, there is asymmetry between treatment arms, with 62 UIA treated by MC and only 37 by EC. This may be related to a trend at our institution to favor MC over EC, especially in younger patients, to achieve a better long-term outcome and to avoid further controls by follow-up imaging. Furthermore, this study was not a

randomized controlled trial but was focused to achieve the best treatment for each case, as judged by an interdisciplinary consensus based on the International Study of Unruptured Intracranial Aneurysms criteria.³⁶ Thus, this study loses some power due to the unbalanced numbers between groups, while it gains strength because it reflects the daily practice in most modern neurovascular centers.

The different patterns and mechanisms of lesions found on DWI after EC and MC make comparison between the 2 groups difficult. This is reflected by the categories we used to describe the DWI-detected lesions, which might fit better for some of the lesions than for others. Because most previous reports have focused on endovascular aneurysm treatment, the categories we used were based predominantly on embolic lesions. Although the nature of lesions found on DWI after MC might differ and, for example, perforator lesions might occur more frequently, these lesions are often small too, and their clinical impact varies significantly with the location of the lesion.

Furthermore, many patients were not included in the study due to the relatively strict inclusion criteria, which led to exclusion of many cases in which more complex techniques were used. This may have caused a bias toward standard cases with lower treatment risks for both modalities.

Because there are various studies that have reported the impact of silent DWI-detected lesions on the neuropsychological outcomes of the patients, thorough neuropsychological testing of the patients before and after treatment would have been warranted.

Perspectives on the Study Results

Similar to the results of other studies, DWI has shown its potential to detect the integrity of the brain parenchyma after microsurgical or endovascular procedures, although the impact of these lesions on clinical outcomes is not clear. This study confirmed that even subtle and subclinical lesions can be detected, which may correlate with the risk of embolism or branch occlusion. For EC, the avoidance of thromboembolism by antithrombotic medication and testing for aspirin or clopidogrel resistance may lower the rate of microemboli. Further efforts should be made to avoid injection or infusion of micro-air bubbles during catheterization or introduction of implants. For surgical cases, we try to avoid clipping of aneurysms with heavily calcified necks and to apply new techniques to increase safety for the patient.

Further studies with less-rigid exclusion criteria may underline the role of DWI as a means of quality control. A study with a larger number of cases may contribute to defining risk groups and to changing treatment assignment in cases with increased endovascular or surgical risks.

Conclusions

Lesions detected by DWI occur with similar frequencies after MC or EC of UIA. The lesion patterns are significantly different, with a predominance of microembolic lesions after EC and lesions due to surgical access or small branch occlusions after MC. In general, the lesion load was low in both arms, and most of the lesions remained clini-

cally silent. Further DWI studies are warranted to define risk groups and to increase the safety of UIA treatment.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Platz, Güresir, Berkefeld, Seifert. Acquisition of data: Platz, Wagner, Güresir, You, Konczalla, du Mesnil de Rochemont. Analysis and interpretation of data: Platz, Wagner, Berkefeld, Seifert. Drafting the article: Platz, Wagner. Critically revising the article: Güresir, du Mesnil de Rochemont, Berkefeld, Seifert. Reviewed submitted version of manuscript: Platz, Wagner, Berkefeld, Seifert. Approved the final version of the manuscript on behalf of all authors: Platz. Statistical analysis: Platz. Study supervision: Berkefeld, Seifert.

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