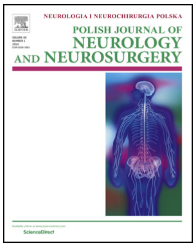
NEUROLOGIA I NEUROCHIRURGIA POLSKA 51 (2017) 116–126

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/pjnns



Original research article

Long-term predictive factors of the morphology based outcome in bare platinum coiled intracranial aneurysms: Evaluation by pre- and post-contrast 3D time-of-flight MR angiography

Fumiaki Ueda [a,*], *Naoyuki Uchiyama* [b], *Masanao Mohri* [b], *Kouichi Misaki* [b], *Osamu Matsui* [c], *Shinya Kida* [d], *Junichiro Sanada* [a], *Jun Yoshikawa* [e], *Hiroyuki Aburano* [a], *Yuichi Yoshie* [a], *Toshifumi Gabata* [a]

[a] *Department of Radiology, Division of Cardiovascular Medicine, Graduate School of Medical Science, Kanazawa University, Japan*

[b] *Department of Neurosurgery, Division of Neuroscience, Graduate School of Medical Science, Kanazawa University, Japan*

[c] *Department of Advanced Medical Imaging, Graduate School of Medical Science, Kanazawa University, Japan*

[d] *Department of Neurosurgery, Fukui Prefectural Hospital, Japan*

[e] *Department of Radiology, Fukui Prefectural Hospital, Japan*

ARTICLE INFO

Article history:
Received 17 May 2016
Accepted 9 January 2017
Available online 21 January 2017

Keywords:
Intracranial aneurysm
Endovascular treatment
Magnetic resonance angiography
Contrast enhancement

ABSTRACT

Purpose: Our aim was to identify long-term predictive factors of the morphology-based outcome (MBO) of bare platinum coiled intracranial aneurysms.

Materials and Methods: A retrospective analysis of 96 bare platinum coiled intracranial aneurysms followed up from 1997 to 2016 using pre- and post-contrast 3D time-of-flight MR angiography (MRA) was performed. Logistic regression analysis was used to identify factors associated with a positive history of surrounding coil mass enhancement (SCME) and poor MBO. Spearman's rank correlation test was used to analyze the relationship between the initial angiographic result (IAR) class, sequential change of the SCME category, and MBO grade.

Results: Factors independently associated with poor MBO were incomplete IAR (OR = 14.94, 95%CI: 2.46, 289.21, $P = 0.002$) and a history of SCME (OR = 4.13, 95% CI: 1.05, 18.65, $P = 0.043$). The MBO grade strongly correlated with the IAR class (correlation coefficient [r] = 0.84, $P < 0.0001$). MBO grade correlated with sequential change of the SCME category ($r = 0.56$, $P < 0.0001$). The sequential change of the SCME category correlated with IAR class ($r = 0.53$, $P < 0.0001$).

Conclusion: Although IAR and its class were strong long-term predictive factors of MBO, a history of SCME and upgrading of sequential change of SCME category were also long-term predictive factors of the MBO of bare platinum coiled intracranial aneurysms.

---

* *Corresponding author at*: Department of Radiology, Division of Cardiovascular Medicine, Graduate School of Medical Science, Kanazawa University, 13-1 Takara-machi, Kanazawa, Ishikawa 920-8641, Japan. Tel.: +81 76 265 2323; fax: +81 76 234 4256.

E-mail addresses: fumiaki@xd6.so-net.ne.jp, fumiaki@staff.kanazawa-u.ac.jp (F. Ueda).

http://dx.doi.org/10.1016/j.pjnns.2017.01.002

1. Introduction

Endovascular embolization with electrically detachable coils is accepted as a primary treatment for intracranial aneurysms. However occlusion of the large aneurysm sac cannot always be achieved, and even if the aneurysm is occluded completely, delayed recanalization, early rerupture, and symptomatic mass effect due to growth of the coiled aneurysm may occur [1–5].

Digital subtraction angiography (DSA) is the standard procedure for the visualization of the hemodynamic and morphological changes of coiled intracranial aneurysms. However DSA is invasive and has some risk of neurological complications [6]. Magnetic resonance angiography (MRA) has been performed as the next best standard alternative for assessing the degree of occlusion and morphology of coiled intracranial aneurysms. Various MRA methods i.e. 3 dimensional (3D) time-of-flight (TOF) MRA, dynamic contrast-enhanced MRA, those performed on a 3 T machine, and a combination of these have been reported [7–9]. Some authors prefer to use contrast medium in the evaluation of large or giant aneurysms [10].

Enlargement of the aneurysmal diameter following coil compaction with or without intraluminal thrombus formation [11,12], and extrusion of coils [5] have been considered to indicate a high risk for rerupture of coiled aneurysms and the need for re-intervention. In addition, several recent reports have noted coiled aneurysm wall enhancement or perianeurysmal enhancement and discussed their etiology and relation to the clinical outcome of coiled aneurysms [13–19].

This prompted us to assess the long-term predictive factors for the morphology based outcome (MBO) of bare platinum coiled intracranial aneurysms using both pre-and post-contrast 3D TOF MRA in this study.

2. Materials and methods

This study was performed in a single center with the approval of the institutional ethics committee, and after informed consent was obtained from all subjects.

In our hospital, all intracranial saccular aneurysms are potential candidates for coiling, and from May 1997 to November 2016, 266 intracranial aneurysms in 246 consecutive patients were treated with various platinum coils.

In this study, we defined the ''long-term follow-up'' as ''more than 12 months'' after coiling therapy based on the definition of Raymond [20]. Duration of the follow-up period was counted from the date of each coiling procedure. Inclusion criteria were patients with coiled aneurysms followed for more than 12 months who underwent both pre- and post-contrast enhanced 3D TOF MRA at 1 week, 1 month, and 6 and 12 months after the coiling therapy. Ninety-six bare platinum coiled intracranial aneurysms were entered into this study.

2.1. *Exclusion criteria*

Aneurysms treated by stent assisted coiling and those associated with another ipsilateral aneurysm treated with a surgical clips were excluded because surgical clips induced a strong metal artifact that interferes with the evaluation. Aneurysms treated with biologically active coils were excluded because those coils overemphasize the contrast effect. Forty-nine aneurysms were excluded because of the absence of pre- or post-contrast enhanced TOF examination, and 44 because of patient refusal of contrast medium use. Twenty-four aneurysms were excluded because the follow-up duration was shorter than 12 months, and 10 because the follow-up examination was performed at another hospital with only pre-contrast 3D TOF MRA. Twenty-one aneurysms present in the cavernous sinus, 5 in contact with a vein or dura mater, 5 treated by stent assisted coiling, 10 associated with another ipsilateral aneurysm treated with a surgical clip, and 2 treated with biologically active coils were also excluded.

2.2. *Diagnostic DSA*

Angiographic procedures were performed on a monoplane C-arm angiographic system. All aneurysmal sizes were always measured prospectively. Before 3D rotational angiography became available (before 2000) in our hospital, we measured aneurysmal size, neck width and maximum height by using the method of a simultaneously positioned metal scale or material of known size (such as a coin) at the same distance from the X-ray tube and X-ray detector as the target aneurysm during the image acquisition of DSA.

Maximum diameter was defined as the largest diameter of all cross-sections along the height of the aneurysm, and neck width was defined as the diameter of the neck cross-section plane perpendicular to the maximum height [21].

2.3. *Endovascular procedure*

Most patients were coiled under general anesthesia by one of three neurosurgeons (N.U., M.M., and K.M.). Systemic anticoagulation with anticoagulant (a bolus of 5000 IU of heparin, followed by continuous infusion of 1000 IU/h) was used from the beginning of treatment in unruptured aneurysms. In ruptured aneurysms, which were treated in the majority of cases within 24–48 h after subarachnoid hemorrhage (SAH), heparin was first given after at least partial occlusion of the aneurysm was achieved. Coils were inserted into the aneurysmal sac until no more could be delivered.

Angiographic findings were recorded immediately after coiling. In cases in which the X-ray photograph did not show any change, routine follow-up DSA was performed at 6 and 12 months and annually thereafter. We defined the findings of DSA performed immediately after coiling as the initial angiographic results (IAR). We decided upon any imaging or symptomatic deterioration to retreat all aneurysms showing an increase in the size of the remnant sac or dilatation of the residual neck including bleb formation with or without maximum diameter dilatation.

2.4. *MR angiography*

Pre-and post-contrast 3D TOF MRA was used for the evaluation of coiled intracranial aneurysms. Three dimensional MIP images, source images, and multiplanar reconstructed (MPR) coronal and sagittal images were used simultaneously for assessment. Slice thickness of source images and MPR images was 0.5 mm after 2008, and 1.0 mm before 2008. All the MR examinations were performed using a 1.5 T or 3 T MR unit (both were Signa; GE Medical Systems, Milwaukee, WI). Three tesla MR was available from 2008. An 8-channel phased-array head coil or bird cage coil was used at 1.5 T, and an 8-channel phased-array head coil was used at 3 T with the following scanning parameters: TR/TE 25/3 ms; flip angle 20°on 1.5 T, 24/3.4; 20° on 3 T. Post contrast enhanced 3D TOF MRA was performed after intravenous injection of 0.1 ml/kg gadolinium contrast medium. Follow-up MRA was performed annually from 12 months after coiling.

2.5. *Methods of analysis*

Because hemodynamic evaluation of coiled aneurysms is difficult by non-invasive imaging, we employed MBO in this analysis. MBO is defined not only by follow-up MRA or DSA at fixed intervals but also by the X ray or clinical result, with the latter two determined by the assessment of the neurosurgeon in charge of the examination at that time. We graded MBO as shown in Table 1, and schematically shown in Fig. 1. The MBO were divided into good or poor (good: grade 1, 2 versus [vs.] poor: grade 3, 4, 5, 6) depending on the necessity for retreatment.

Signs of MBO grade progression have been clarified to include remnant sac dilatation by coil compaction, residual neck growth or extrusion of coils, and maximum diameter dilatation of coiled aneurysms as the major risk factors for rupture or rerupture of coiled aneurysms [5,22–26]. On the other hand, a stable angiographic result during a 12-month is predictive of a low risk of morphological deterioration [25].

Table 1 – Morphology based Outcome Grade.

Grade	Description
1	Completely coiled
2	Remnant sac or residual neck (stable)
3	Remnant sac dilatation
4	Residual neck growth
5	Maximum diameter dilatation
6	Rupture

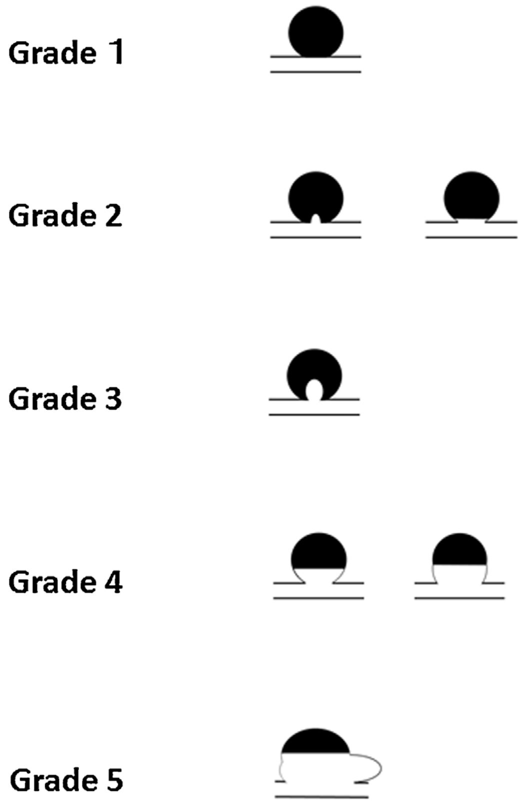


Fig. 1 – Schematic representation of the grade 1–5 of morphology based outcome. Black area shows coil mass.

We defined the surrounding coil mass enhancement (SCME) as the contrast enhancement effect appearing around the hypointense coil mass not only aneurysmal wall but also contrast filling between the coil mass and aneurysmal intima determined by simultaneous evaluation of both pre- and post-contrast 3D TOF MRA source images and MPR images. Evaluation of the SCME between past and present MRA was performed comparing images obtained from the same static magnetic field MRI. According to previously reported follow-up results about sequential change of aneurysmal wall or perianeurysmal or peripheral/circumferential coil mass enhancement, sequential change of the SCME can be roughly grouped as negative, positive but likely to disappear in future, and progressive [15,16,18]. We modified and applied categorization of the sequential change of the SCME shown in Table 2.

We analyzed the association between the SCME and predictive variables including total duration of follow-up, age, sex, location, multiplicity, ruptured or unruptured, maximum diameter, neck width, and IAR, and then between those predictive variables plus SCME and the MBO.

The IAR was determined based on the degree of aneurysm occlusion according to the Raymond classification: class 1: complete occlusion, class 2: residual neck, and class 3: remnant sac [20,27]. Although sequential change of the SCME in growing aneurysms is difficult to evaluate because of stretching of the aneurysmal wall we defined the increase of the SCME as the appearance of contrast effect at a previously unenhanced portion or increase of contrast effect or thickening at any portion of previous enhancement.

Pre-and post-contrast MR angiography evaluations were performed retrospectively by two of four neuroradiologists with over 10 years' experience who were blinded to the patients' clinical information and previously acquired images. After independent review, when any discrepancies were noted, the evaluation was repeated with a third neuroradiologist added

Table 2 – Categorization of sequential change of the surrounding coil mass enhancement.

Category	Description
0	Continue to be negative
1	Disappear
2	Decrease
3	Stable
4	Appear
5	Increase

Table 3 – Univariate and multivariate analysis of the relationship of evaluation factors to surrounding coil mass enhancement.

		Univariate analysis							Multivariate analysis		
		Surrounding coil mass enhancement									
Evaluation factors		Negative[*] n = 64 (100)	Positive[†] n = 32 (100)	P value		OR	95% CI	P value	OR	95% CI	P value
Total duration of follow-up	Average ± SD month	62.9 ± 38.2	79.0 ± 50.8	0.230							
	Median, 25%IQR, 75%IQR	51, 34, 80	77, 33.8, 114	0.086	1 month increments	1.01	1.00–1.02	0.087	1	1.00–1.02	0.070
Age	Average ± SD year	60.8 ± 8.9	60.6 ± 10.1	0.960	>60 vs. ≦60	1.29	0.55–3.03	0.563			
	Median, 25%IQR, 75%IQR	61, 54, 69	60.5, 53, 71	0.907	1 year increments	1.00	0.95–1.05	0.906			
Sex	Male	25 (39)	13 (41)								
	Female	39 (61)	19 (59)		Female vs. Male	1.07	0.44–2.53	0.883			
Location	Anterior circulation	53 (83)	22 (69)								
	Posterior circulation	11 (17)	10 (31)		Posterior vs. Anterior	2.2	0.81–5.95	0.123			
Multiplicity	Solitary	47 (73)	24 (75)								
	Multiple	17 (27)	8 (25)		Multiple vs. Solitary	1.1	0.42–2.99	0.869			
Ruptured or Unruptured	Unruptured	39 (61)	17 (53)								
	Ruptured	25 (39)	15 (47)		Ruptured vs. Unruptured	1.4	0.58–3.26	0.465			
Maximum diameter	≦10 mm	43 (67)	7 (22)								
	>10 mm	21 (33)	25 (78)		>10 mm vs. ≦10 mm	7.3	2.84–20.90	<0.0001			
	Average ± SD mm	8.4 ± 3.2	11.6 ± 3.2	<0.0001							
	Median, 25%IQR, 75%IQR	8, 7, 10	12, 10, 13	<0.0001	1 mm increments	1.4	1.18–1.67	<0.0001	1.2	1.03–1.52	0.020
Neck width	≦4 mm	41 (64)	8 (25)								
	>4 mm	23 (36)	24 (75)		>4 mm vs. ≦4 mm	5.35	2.23–14.53	0.0002			
	Average ± SD. mm	3.4 ± 1.4	4.7 ± 1.9	0.0007							
	Median, 25%IQR, 75%IQR	3, 2, 4	4, 3.3, 6	0.0003	1 mm increments	1.6	1.23–2.20	0.0004	1.2	0.88–1.73	0.222
Initial angiographic result	Complete	46 (72)	9 (28)								
	Incomplete	18 (28)	23 (72)		Incomplete vs. Complete	6.5	2.61–17.52	<0.0001	3	0.99–9.00	0.052

Note: Data in parentheses are percentages. IQR, interquartile range; OR, odds ratio; CI, confidence interval.

[*] Negative means category 0.

[†] Positive means category 1–5.

Table 4 – Univariate and multivariate analysis of the relationship of evaluation factors to morphology based outcome.

		Univariate analysis							Multivariate analysis		
		Morphology based outcome									
Evaluation factors		Good: *n* = 78 (100)	Poor: *n* = 18 (100)	P value		OR	95% CI	P value	OR	95% CI	P value
Total duration of follow-up	Average ± SD. month	66.0 ± 40.2	78.0 ± 54.8	0.679							
	Median, 25%IQR, 75%IQR	57.5, 36, 86.3	72.5, 26.8, 125.3	0.290	1 month increments	1.01	0.99–1.02	0.294			
Age	Average ± SD. year	60.4 ± 9.2	62.3 ± 9.3	0.478	>60 vs. ≦60	1.42	0.50–4.21	0.510			
	Median, 25%IQR, 75%IQR	61, 53.8, 68.3	63, 52, 72	0.439	1 year increments	1.02	0.97–1.09	0.430			
Sex	Male	31 (40)	7 (39)								
	Female	47 (60)	11 (61)		Female vs. Male	1.04	0.37–3.09	0.947			
Location	Anterior circulation	63 (81)	12 (67)								
	Posterior circulation	15 (19)	6 (33)		Posterior vs. Anterior	2.10	0.64–6.39	0.209			
Multiplicity	Solitary	59 (76)	12 (67)								
	Multiple	19 (24)	6 (33)		Multiple vs. Solitary	1.55	0.49–4.60	0.443			
Ruptured or Unruptured	Unruptured	47 (60)	9 (50)								
	Ruptured	31 (40)	9 (50)		Ruptured vs. Unruptured	1.52	0.54–4.30	0.429			
Maximum diameter	≦10 mm	47 (60)	3 (17)								
	>10 mm	31 (40)	15 (83)		>10 mm vs. ≦10 mm	7.58	2.27–34.70	0.0006			
	Average ± SD.mm	8.7 ± 3.2	12.6 ± 3.3	<0.0001							
	Median, 25%IQR, 75%IQR	8.5, 7, 11	12, 11, 13.3	<0.0001	1 mm increments	1.41	1.18–1.77	<0.0001	1.22	0.96–1.59	0.107
Neck width	≦4 mm	47 (60)	2 (11)								
	>4 mm	31 (40)	16 (89)		>4 mm vs. ≦4 mm	12.1	3.16–80.16	<0.0001			
	Average ± SD.mm	3.5 ± 1.6	5.1 ± 1.7	0.0004							
	Median, 25%IQR, 75%IQR	3, 2, 5	4.5, 4, 6	0.0004	1 mm increments	1.65	1.22–2.32	0.0009	1.16	0.73–1.84	0.528
Initial angiographic result	Complete	54 (69)	1 (6)								
	Incomplete	24 (31)	17 (94)		Incomplete vs. Complete	38.25	7.22–708.78	<0.0001	14.94	2.46–289.21	0.002
Surrounding coil mass enhancement	Negative	60 (77)	4 (22)								
	Positive	18 (23)	14 (78)		Positive vs. Negative	11.7	3.68–40.34	<0.0001	4.13	1.05–18.65	0.043

Note: Morphology based outcome: good means Grade 1 or 2, poor means Grade 3, 4, 5, or 6 in Table 1.
Data in parentheses are percentages. IQR, interquartile range; OR, odds ratio; CI, confidence interval.

until a consensus was reached. Then we picked out recoiled cases and demonstrated their clinical details.

2.6. *Statistics*

We used the JMP statistical software program (S.A.S. Institute Inc., Version 10.0.1) for data analysis. Although the numeric value of recoiled aneurysms changed during the long follow-up period, we counted even multi-recoiled aneurysms as a single aneurysm and used the data at the first coiling for the statistical analysis. All *P* values less than 0.05 were considered statistically significant. Univariate and multivariate logistic regression analyses were performed to determine the statistical significance between a positive history of SCME and poor MBO between the following factors: total duration of follow-up, age, sex, location, multiplicity, manifestation of occurrence, maximum diameter, neck width, IAR, with SCME added in the case of MBO evaluation. The multivariate model included the predictors with a probability value of 0.1 or less on univariate analysis. For the multivariate logistic regression analysis, aneurysmal size and neck width were classified into the nearest whole number in mm and this 1 mm increment measurement values were used for the statistics. The results are presented as odds ratio (OR) as estimates of relative risk with the 95% confidence intervals (CI).

We used the Spearman's rank correlation test to calculate the correlation coefficients (*r*) between IAR class, MBO grade and sequential change of the SCME category.

3. Results

3.1. *Demographics and initial angiographic results*

Patient age ranged from 33 to 78 years (mean, 60.8, median, 61 years, interquartile range (IQR) = 16 years and 58 (60%) aneurysms were in women and 38 (40%) in men. The mean interval of total follow-up was 68.5 months. Finally our results were all defined by the MRA results. Twenty cases had multiple aneurysms, 5 sets of which were independently counted as 2 aneurysms in our study because they both satisfied our inclusion criteria, while 71 cases had solitary aneurysms. Posterior circulation aneurysms were 21 (22%), and 75 (78%) were located in the anterior circulation. Forty (42%) and 56 (58%) aneurysms presented with and without SAH respectively. Maximum diameter ranged from 3.0 mm to 22.3 mm (average ± SD, 9.5 ± 3.5, median, 9.3). Neck width ranged from 2.1 mm to 9.2 mm (average ± SD, 3.8 ± 1.7, median, 3.2). There was no statistical difference in the total duration of follow-up between negative vs. positive history of the SCME group and good vs. poor MBO group (Tables 3 and 4).

3.1.1. *Univariate and multivariate logistic regression analysis*

Univariate and multivariate analysis of the relation of follow-up duration, demographics, clinical, imaging, and measurement factors with a positive or negative history of the SCME and poor or good MBO were shown in Tables 3 and 4. On the multivariate analysis, maximum diameter in 1 mm increments was the only predictor statistically significantly independently associated with SCME. Both incomplete IAR and a history of SCME were independent predictors that were statistically significant for poor MBO.

3.1.2. *Sequential change of SCME, Morphology based outcome and Recoiled cases*

Sixty-four (67%) aneurysms showed category 0 sequential change of SCME, 14 (15%) category 1, 4 (4%) category 2, 2 (2%) category 3, 4 (4%) category 4 (Fig. 2), and 8 (8%) category 5 (Figs. 3 and 4). Fifty-three (55%) aneurysms were grade 1 MBO, 25 (26%) grade 2, 2 (2%) grade 3, 4 (4%) grade 4, 10 (10%) grade 5, and 2 (2%) grade 6.

Intraluminal thrombosed aneurysms that were categorized as 4, 5 or 6 on sequential change of SCME resulted in maximum diameter dilatation and resulted in MBO grade 5 or 6 being found in 7 aneurysms.

Fig. 2 – (a) Axial source image of three dimensional (3D) post-contrast time-of-flight (TOF) MR angiography (MRA) in 56-year-old-man with 12.2 mm maximum diameter unruptured basilar tip aneurysm obtained at 74 months after coiling shows no definite surrounding coil mass enhancement (SCME). In this case, coiling was performed once and the initial angiographic result was class 2. (b) Axial source image of post-contrast 3D TOF MRA obtained 135 months from coiling shows aneurysm maximum diameter dilatation with intraluminal thrombus (small arrow) and appearance of SCME (arrows). Sequential change of the SCME category was 4 and morphology based outcome grade was defined as 5.

Fig. 3 – (a) Axial source image of post-contrast three dimensional (3D) time-of-flight (TOF) MR angiography (MRA) obtained at 6 months after fourth coiling in a 72-year-old-woman (case 1 in Table 5) with ruptured left internal carotid-posterior communicating aneurysm shows the surrounding coil mass enhancement (SCME) (arrow). This aneurysm's maximum diameter was 10.2 mm at onset. At the fourth coiling, this aneurysm grew to 13.4 mm. In this case, the initial angiographic result after the fourth coiling was class 3. (b) Post-contrast 3D TOF MRA source images obtained 18 months after the fourth coiling show increase of the SCME and maximum diameter dilatation (arrow). Remnant sac dilatation was evident (small arrow). Five months after this MR study, she died of rupture of this aneurysm. Sequential change of the SCME categorized 5 and morphology based outcome grade was judged as grade 6.

Table 5 revealed details of the recoiled aneurysms, with all the incomplete IAR cases that could be followed-up at least 12 months showing sequential change of SCME category 0, 1, 2, 3, and 5 that resulted in MBO grade 1 to 6. There was even one case whose sequential change of SCME category 0 resulted in grade 4 MBO.

3.1.3. *Correlation coefficient analysis*

The MBO grade and IAR the had a statistically strong correlation ($r = 0.84$, $P < 0.0001$). Sequential change of the SCME category and initial angiographic result classification had a moderate correlation ($r = 0.53$, $P < 0.0001$). The SCME category and the MBO grade were moderately correlated ($r = 0.56$, $P < 0.0001$).

4. Discussion

Being able to identify the long-term predictive factors associated with an unfavorable outcome or morphological recurrence of coiled intracranial aneurysms has been a major task in neuroradiology. At present, factors identified as significant predictors of coiled aneurysm recurrence include IAR, increasing follow-up time, posterior circulation, and larger aneurysm [22–26]. Our results showed that the IAR and positive history of SCME were independent predictors of MBO. Moreover, appearance or increase of the SCME correlated with worsening of the MBO.

Bare platinum coiled aneurysmal wall enhancement which is a representative feature of the SCME, had been considered to reflect a normal healing response, although Fanning et al. found that incompletely occluded and recurrent aneurysms more frequently show wall enhancement than completely occluded ones [17]. But in their study the follow-up duration was mostly within 12 months. Moreover they included biologically active coils in their study group, but because of the extension of inflammation to arachnoid membrane or brain parenchyma those emphasize the enhancement [13,17,19]. Brain edema or hydrocephalus induced by coiled aneurysms showing wall enhancement was also reported in coiled aneurysms using bare platinum coils [15,18]. Wall enhancement often appears in large or giant thrombosed aneurysms. Neovascular formation induced by thrombus is considered to be the mechanism underlying the growth of large or giant aneurysms showing aneurysmal wall enhancement [28]. In our study, SCME appeared not only in the aneurysmal wall but also around the border between the coil mass and intraluminal thrombus. This means that neovascular formation at the surface of the coil mass may be the source of thrombus or conversely intraluminal thrombus may form neovessels on the contact surface of the coil mass.

The probability of aneurysm rupture is related not only to its morphology but also its hemodynamic character. Rupture of untreated saccular intracranial aneurysm occurs most frequently at the aneurysm fundus, the second most frequently at the lateral wall, and the least frequently at the aneurysm neck [29]. Rerupture points immediately after coiling have been reported to be both the neck and dome [30]. Maximum diameter dilatation is thought to be a risk factor for rerupture [2–4]. Residual neck dilatation with extrusion of coils resulting in rupture has also been described [5]. The bleb of an aneurysm is its thin bulging portion whose wall is fragile and easily ruptured. Hemodynamic study reveals that the flow velocity in a bleb is low while its nature is turbulent. Large or giant aneurysms also reveal low intraluminal velocity and turbulent property and are often accompanied by an intraluminal thrombus [11]. Intraluminal slow and turbulent flow has a saturation effect on 3D TOF MRA, making it difficult to differentiate intraluminal thrombus from such heterogeneous flow.

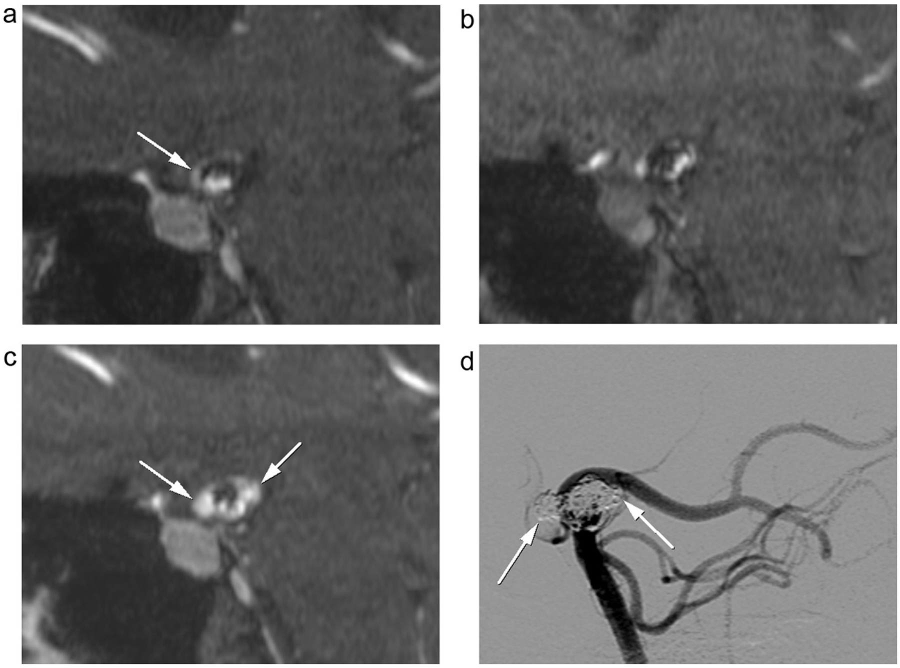


Fig. 4 – (a) Post-contrast three dimensional (3D) time-of-flight (TOF) MR angiography (MRA) sagittal reconstructed 0.5 mm slice image of a 62-year-old-man (case 9 in Table 5) with ruptured basilar tip aneurysm obtained at 42 months from second coiling shows the surrounding coil mass enhancement (SCME) (arrow). (b) Pre-and (c) post-contrast enhanced TOF MRA sagittal reconstructed image obtained at 82 months from the second coiling shows enlargement of the SCME (arrows). Sequential change of the SCME was category 5. Two months later, rerupture occurred and a third coiling was performed. Morphology based outcome grade was judged to be 6. (d) Digital subtraction angiography immediately after recoiling shows that additional coils were inserted into both anterior and posterior blebs (arrows), but the initial angiographic result was judged as class 3.

Nagahara et al. reported that wall enhancement was frequently observed on ruptured aneurysms [31]. Su et al. reported that aneurysmal wall enhancement is a common phenomenon that in most cases remains stable over years [32]. We consider that the mechanism underlying the aneurysmal wall enhancement of post-embolization intracranial aneurysm may not be attributable to a single etiology, but rather to a complicated overlap of multiple etiologies. Some of these have already been reported [13,17,19]. So we employed SCME as an evaluation maker.

SCME includes many pathological phenomena such as vasa vasorum proliferation in the coiled aneurysm wall, granulation or inflammation of perianeurysmal arachnoid membrane or brain parenchyma, neovascular formation between intraluminal thrombus and coil mass, and recurrent or newly developed vascular flow such as bleb formation. Some incompletely coiled aneurysms have revealed negative SCME during all follow-up periods, suggesting that such aneurysms should be monitored carefully using other imaging methods such as X-ray photography and DSA. Such incomplete IAR aneurysms are subjected to less mechanical or biological effects from the coil mass on the aneurysm intima because the embolization achievement is weak, or the character of the aneurysmal intima is less likely to reveal any response to coils. Completely coiled aneurysms often showed category 1 or 2, suggesting that some decrease of the SCME might be the most desirable clinical course.

Small aneurysms that are completely occluded and remain stable at 6 months follow-up or those showing a stable angiographic result after a 12-month interval may be at low risk for morphological deterioration. Large unstable aneurysms that need recoiling should be carefully followed. Coil compacted aneurysms with an initially small diameter but whose residual neck or remnant sac is small, stable, and impossible to recoil are followed without retreatment. Large aneurysms that reveal a slow flow remnant sac with maximum diameter dilatation or a bleb at the residual neck showing isointensity to the coil mass may have a lumen that is occasionally overlooked and not subjected to post-contrast 3D TOF MRA [10]. Such aneurysms or ones with an intraluminal thrombus require a change in the therapeutic strategy with recoiling undertaken as soon as possible. Such aneurysms show category 4 or 5 sequential change of the SCME.

5. Limitations

This study was conducted in only a single university, rather than a multicenter study. The study design was a retrospective review and can be said to have been a little after fitted. Some MR angiographic technical differences were present between the cases of early follow-up cases and more recently coiled cases. The introduction of rotational angiography machine and appearance of 3 T MRI may also have affected our results. Our definition of MBO has two standards being defined by not only the MRA findings but also the clinical feature of aneurysmal rupture. The final decision of MBO was decided

Table 5 – Case presentation of recoiled aneurysms.

Case	Age. years, Sex	Location	Ruptured or Unruptured Reason for recoiling	Duration of previous coiling to recoiling (months)	Maximum diameter (mm)	Neck width (mm)	Initial angiographic result class	Sequential change of surrounding coil mass enhancement category #	Morphology-based outcome grade #
1	72, F	PCoA	Ruptured	0	10.2	5.1	2	STTM	STTM
			Coil compaction and regrowth	3	11.2	5.2	3	STTM	STTM
			Coil compaction and regrowth	9	12.8	5.3	3	STTM	STTM
			Coil compaction and regrowth	10	13.4	7.4	3	5	6
2	53, M	ACoA	Ruptured	0	13.5	8.9	3	STTM	STTM
			Coil compaction and regrowth	10	15.6	8.4	3	STTM	STTM
			Coil compaction and regrowth	7	20.2	8.1	3	5	5
3	54, F	MCA	Ruptured	0	8.0	5.3	3	STTM	STTM
			Coil compaction and regrowth	5	10.2	5.0	3	STTM	STTM
			Coil compaction and regrowth	6	12.0	5.1	3	5	5
4	60, F	ACoA	Unruptured	0	10.4	3.0	3	2	3
			Coil compaction	13	10.1	3.2	3	2	3
			Coil compaction	28	10.9	3.3	3	1	2
5	53, F	BA tip	Unruptured	0	12.0	4.7	3	STTM	STTM
			Coil compaction	7	12.4	4.2	2	3	3
6	50, F	MCA	Ruptured	0	13.4	3.8	2	0	4
			Coil compaction	19	13.7	3.2	3	0	3
7	73, F	BA tip	Ruptured	0	16.3	5.5	2	5	STTM
			Coil compaction and regrowth	24	18.8	5.5	2	5	5
8	60, M	PICA	Unruptured	0	12.2	4.3	3	STTM	STTM
			Coil compaction	11	12.0	4.1	3	1	3
9	62, F	BA tip	Ruptured	0	8.8	5.3	2	3	3
			Coil compaction and regrowth	57	9.3	5.2	2	5	5
			Rerupture	84	13.0	6.2	3	5	6
10	68, F	PCoA	Unruptured	0	20.2	5.2	2	3	3
			Coil compaction	28	20.1	5.9	2	1	1

Note: # Surrounding coil mass enhancement and morphology-based outcome were categorized and judged at least 12 months after previous coiling.
STTM: shorter than twelves months; PCoA: posterior communicating artery; ACoA: anterior communicating artery; MCA: middle cerebral artery; BA: basilar artery; PICA: posterior inferior cerebellar artery.

based on the inspection and experience of the neurosurgeon in charge of the patients at that time. Our results may also had been potentially been influenced by this lack of uniformity. Follow-up reading of sequential change of SCME required much time for the interpretation of each case. Although evaluation of pre-and post-contrast MR angiography was performed in a blinded manner, this method lacks accuracy, because some of the neuroradiologists who participated in this study are in charge of daily MRA reading. Statistically, we simply classified the SCME into only negative or positive depending on the presence/appearance or not during the total follow-up, but this bisection is rather rough and the based on relatively little evidence. Finally even with the permission of the ethics committee and patient's consent, the usage of contrast medium itself should be reconsidered.

6. Conclusions

Incomplete IAR and a history of SCME are the long-term predictive factors for poor MBO of bare platinum coiled intracranial aneurysms. The MBO grade correlated with sequential change of the SCME category

Ethical Standards and Patient Consent

We declare that all human and animal studies were approved by the Ethics Committee of Lund University and were therefore performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. We declare that all patients gave informed consent prior to inclusion in this study.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgements and financial support

We have no financial disclosure.

Ethics

The work described in this article has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans; Uniform Requirements for manuscripts submitted to Biomedical journals.

REFERENCES

[1] Ferns SP, Majoie CBLM, Sluzewski M, van Rooij WJ. Late adverse events in coiled ruptured aneurysms with incomplete occlusion at 6-month angiographic follow-up. AJNR Am J Neuroradiol 2010;31:464–9. http://dx.doi.org/10.3174/ajnr.A1841

[2] Kaku Y, Yoshimura S, Kokuzawa J, Sakai N. Clinical and angiographic results of intra-aneurysmal embolization for cerebral aneurysms and histopathological findings in an aneurysm treated with GDC. Interv Neuroradiol 2003;9: 35–40.

[3] Li MH, Gao BL, Fang C, Gu BX, Cheng YS, Wang W, et al. Angiographic follow-up of cerebral aneurysms treated with Guglielmi detachable coils: an analysis of 162 cases with 173 aneurysms. AJNR Am J Neuroradiol 2006;27:1107–12.

[4] Dorfer C, Gruber A, Standhardt H, Bavinszki G, Knosp E. Management of residual and recurrent aneurysms after initial endovascular treatment. Neurosurgery 2012;70:537–54. http://dx.doi.org/10.1227/NEU.0b013e3182350da5

[5] Veznedaroglu E, Benitez RP, Rosenwasser RH. Surgically treated aneurysms previously coiled: lessons learned. Neurosurgery 2004;54:300–5. http://dx.doi.org/10.1227/01.NEU.0000103223.90054.C2

[6] Kaufmann TJ, Huston III J, Mandrekar JN, Schleck CD, Thielen KR, Kallmes DF. Complications of diagnostic cerebral angiography: evaluation of 19826 consecutive patients. Radiology 2007;243:812–9.

[7] Anzalone N, Scomazzoni F, Cirillo M, Righi C, Simionato F, Cadioli M, et al. Follow-up of coiled cerebral aneurysms at 3T: comparison of 3D time-of-flight MR angiography and contrast-enhanced MR angiography. AJNR Am J Neurorsdiol 2008;29:530–6. http://dx.doi.org/10.3174/ajnr.A1166

[8] Kaufmann TJ, Huston 3rd J, Cloft HJ, Mandrekar J, Gray L, Bernstein MA, et al. A prospective trial of 3T and 1.5T time-of-flight and contrast-enhanced MR angiography in the follow-up of coiled intracranial aneurysms. AJNR Am J Neuroradiol 2010;31:912–8. http://dx.doi.org/10.3174/ajnr.A1932

[9] Pierot L, Portefaix C, Boulin A, Gauvrit JY. Follow-up of coiled intracranial aneurysms: comparison of 3D time-of-flight and contrast-enhanced magnetic resonance angiography at 3T in a large, prospective series. Eur Radiol 2012;22:2255–63. http://dx.doi.org/10.1007/s00330-012-2466-6

[10] Jäger HR, Ellamushi H, Moore EA, Grieve JP, Kitchen ND, Taylor WJ. Contrast-enhanced MR angiography of intracranial giant aneurysms. AJNR Am J Neuroradiol 2000;21:1900–7.

[11] Ferns SP, van Rooij WJ, Sluzewski M, van den Berg R, Majoie CBLM. Partially thrombosed intracranial aneurysms presenting with mass effect: long-term clinical and imaging follow-up after endovascular treatment. AJNR Am J Neuroradiol 2010;31:1197–205. http://dx.doi.org/10.3174/ajnr.A2057

[12] Lawton MT, Hinojosa AQ, Chang EF, Yu T. Thrombotic intracranial aneurysms: classification scheme and management strategies in 68 patients. Neurosurgery 2005;56:441–54.

[13] Meyers PM, Lavine SD, Fitzsimmons BF, Commichau C, Parra A, Mayer SA, et al. Chemical meningitis after cerebral aneurysm treatment using two second-generation aneurysm coils: report of two cases. Neurosurgery 2004;55: E1222–7.

[14] Gauvrit JY, Leclerc X, Pernodet M, Lubicz B, Lejeune JP, Leys D, et al. Intracranial aneurysms treated with Guglielmi detachable coils: usefulness of 6-month imaging follow-up with contrast-enhanced MR angiography. AJNR Am J Neuroradiol 2005;26:515–21.

[15] Horie N, Kitagawa N, Morikawa M, Tsutsumi K, Kaminogo M, Nagata I. Progressive perianeurysmal edema induced after endovascular coil embolization. J Neurosurg 2007;106:916–20.

[16] Wallace RC, Karis JP, Partovi S, Fiorella D. Noninvasive imaging of treated cerebral aneurysms, part 1: MR

angiographic follow-up of coiled aneurysms. AJNR Am J Neuroradiol 2007;28:1001–8.

[17] Fanning NF, Willinsky RA, terBrugge KG. Wall enhancement, edema, and hydrocephalus after endovascular coil occlusion of intradural cerebral aneurysms. J Neurosurg 2008;108:1074–86. http://dx.doi.org/10.3171/JNS/2008/108/6/1074

[18] Misaki K, Uchiyama N, Mohri M, Hirota Y, Hayashi Y, Hamada JI. Unusual delayed hydrocephalus after bare platinum coil embolization of an unruptured aneurysm. Neurol Med Chir 2010;50:581–5.

[19] Turner RD, da Costa LB, terBrugge KG. A multicenter registry of hydrocephalus following coil embolization of unruptured aneurysms: which patients are at risk and why it occurs. J Neurointerv Surg 2013;5:207–11. http://dx.doi.org/10.1136/neurintsurg-2011-010194

[20] Raymond J, Guilbert F, Weill A, Georganos SA, Juravsky L, Lambert A, et al. Long-term angiographic recurrences after selective endovascular treatment of aneurysms with detachable coils. Stroke 2003;34:1398–403.

[21] Raghavan ML, Ma B, Harbaugh RE. Quantified aneurysm shape and rupture risk. J Neurosurg 2005;102:355–62.

[22] Thormton J, Debrun GM, Aletich VA. Follow-up angiography of intracranial aneurysms treated with endovascular placement of Guglielmi detachable coils. Neurosurgery 2002;50:239–50.

[23] Johnston SC, Dowd CF, Higashida RT, Lawton MT, Duckwiler GR, Gress DR. Predictors of rehemorrhage after treatment of ruptured intracranial aneurysms: the cerebral aneurysm rerupture after treatment (CARAT) study. Stroke 2008;39:120–5.

[24] Campi A, Ramzi N, Molyneux AJ, Summers PE, Kerr RS, Sneade M, et al. Retreatment of ruptured cerebral aneurysms in patients randomized by coiling or clipping in the international subarachnoid aneurysm trial (ISAT). Stroke 2007;38:1538–44.

[25] Holmin S, Krings T, Ozanne A, Alt JP, Claes A, Zhao W, et al. Intradural saccular aneurysms treated by Guglielmi detachable bare coils at a single institution between 1993 and 2005: clinical long-term follow-up for a total of 1810 patient-years in relation to morphological treatment results. Stroke 2008;39:2288–97. http://dx.doi.org/10.1161/STROKEAHA.107.508234

[26] Chalouhi N, Tjoumakaris S, Gonzalez LF, Dumont AS, Starke RM, Hasan D, et al. Coiling of large and giant aneurysms: complications and long-term results of 334 cases. AJNR Am J Neuroradiol 2014;35:546–52. http://dx.doi.org/10.3174/ajnr.A3696

[27] Roy D, Milot G, Raymond J. Endovascular treatment of unruptured aneurysms. Stroke 2001;32:1998–2004.

[28] Krings T, Alvarez H, Reinacher P, Ozanne A, Baccin CE, Gandolfo C, et al. Growth and rupture mechanism of partially thrombosed aneurysms. Interv Neuroradiol 2007;13:117–26.

[29] Crawford T. Some observations on the pathogenesis and natural history of intracranial aneurysms. J Neurol Neurosug Psychiat 1959;22:259–66.

[30] Dmytriw AA, Pickett GE, Shankar JJS. Rupture of aneurysms in the immediate post-coiling period. J NeuroInterv Surg 2014;6:6–8. http://dx.doi.org/10.1136/neurintsurg-2012-010588

[31] Nagahata S, Nagahata M, Obara M, Kondo R, Minagawa N, Sato S, et al. Wall enhancement of the intracranial aneurysms revealed by magnetic resonance vessel wall imaging using three-dimensional turbo spin-echo sequence with motion-sensitized driven-equilibrium: a sign of ruptured aneurysms? Clinical Nuroradiol 2014;21:1–7. http://dx.doi.org/10.1007/s00234-014-1355-z

[32] Su IC, Willinsky RA, Fanning NF, Agid R. Aneurysmal wall enhancement and perianeurysmal edema after endovascular treatment of unrupture cerebral aneurysms. Neuroradiology 2014;56:487–95. http://dx.doi.org/10.1007/s00234—014-1355-x