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Review Article

Microsurgical management of previously embolized intracranial aneurysms: A single center experience and literature review

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Background: Endovascular treatment of intracranial aneurysms (IAs) provides less invasiveness and lower morbidity than microsurgical clipping, albeit with a long-term recurrence rate estimated at 20%. We present our single-center experience and a literature review concerning surgical clipping of recurrent previously coiled aneurysms.

Methods: Retrospective analysis of nine (9) patients' data and final clinical/angiographic outcomes, who underwent surgical clipping of IAs in our center following initial endovascular treatment, over a 12-year period (2010-2022). Regarding the literature review, data were extracted from 48 studies including 969 patients with 976 aneurysms.

Results: 9 patients (5 males - 4 females) were included in the study with a mean age of 49 years. Subarachnoid hemorrhage was the initial presentation in 78% of patients. Aneurysms' most common location was the middle cerebral artery bifurcation (5/9) followed by the anterior communicating artery (3/9) and the internal carotid artery bifurcation (1/9). Indications for surgery were coil loosening, coil compaction, sac regrowth, and residual neck. Procedure-related morbidity and mortality were zero whereas complete aneurysm occlusion was achieved after surgical clipping in all cases (100%). All patients had minimal symptoms or were asymptomatic (mRS 0-1) at the final follow-up.

Conclusions: Surgical clipping seems a feasible and safe technique for selected cases of recurrent previously coiled intracranial aneurysms. A universally accepted recurrence classification system and a guideline template for the management of such cases are needed.

Keywords Intracranial aneurysm, Endovascular embolization, Recurrence, Microsurgery, Microsurgical clippin

INTRODUCTION

Since the establishment of coil embolization as the primary means of treatment for intracranial aneurysms (IAs) in the last 30 years, the volume of endovascular interventions has been steadily increasing. This is due to the fact that coil embolization provides less invasiveness and lower morbidity and mortality than microsurgical clipping. Notwithstanding the fact that coiling has made itself the default treatment option for IAs in many centers, data has shown that the long-term recurrence rate is estimated to be around 20%.[7,12,37] Residual aneurysm neck, rebleeding, coil migration, mass effect, and aneurysm recurrence due to coil compaction, regrowth, or recanalization, signify the need for additional intervention. Retreatment of recurrent aneurysms can be performed either by endovascular techniques or microsurgical clipping. Superiority of each method is a subject of controversy, as neither shows a consistent overall advantage.[11,34,37] Microsurgical treatment of recurrent aneurysms is more intricate than surgery of previously untreated aneurysms, as certain particularities and limitations are present.[37,39,45,57,58]

This retrospective study presents our institution's Neurosurgical Department's experience with surgical re-treatment of recurrent previously coiled aneurysms over a 12-year period. Furthermore, we conducted a literature review and analyzed the accumulated data of the past 25 years regarding surgical indications, treatment strategies, and their outcomes.

MATERIALS AND METHODS

Patient population, initial presentation, and aneurysm recurrence

We retrospectively reviewed the records of nine (9) patients (5 males - 4 females) who underwent additional microsurgical clipping after initial endovascular treatment in our department over a 12-year period (2010-2022). Patients' medical records and radiographic studies were retrospectively reviewed in order to obtain clinical and radiographic data.

All patients underwent follow up with digital subtraction angiography for post embolization evaluation at 6 and 18 months. In some cases where extra information was needed (e.g. preparation for microsurgical clipping), magnetic resonance angiography or computed tomography angiography were done.

The assessment of the angiographic results was conducted based on the Raymond-Roy Occlusion Classification (RROC).[44] Embolization was considered to be complete (Raymond Roy class 1) if there was no contrast filling of the dome, body, or neck of the aneurysm. Neck remnant (Raymond Roy class 2) was defined as residual filling of the neck without opacification of the aneurysmal sac. Residual aneurysm (Raymond Roy class 3) was indicated by the circulation of contrast agent in the dome of the aneurysm. Neurological assessment has been performed preoperatively and at final follow-up by using the modified Rankin scale score.

Meanwhile, modified Rankin Scale (mRS) and Glasgow Outcome Scale (GOS) were used to categorize the literature's patient population into three (3) major categories: Good outcome (mRS 0-2, GOS 5-6), Bad outcome (mRS 3-5, GOS 3-2) and Death (mRS 6, GOS 1).

A medical council composed of an endovascular neurosurgeon and an interventional neuroradiologist was responsible for the evaluation of the retreatment options.

The study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Due to the study's retrospective nature, ethics committee approval was not required.

Literature review selection criteria

The search for studies eligible for inclusion in our review was conducted using PubMed and Google Scholar, incorporating papers whose publication dates range from 2000 to 2021. For our search strategy, we combined, using both 'AND' and 'OR' combinations, the following keywords: endovascular treatment, microsurgical treatment, recurrence, initial treatment, retreatment, embolization, coil, intracranial aneurysms. Studies were only reviewed if the published manuscript was in English. We included studies involving microsurgically retreated cases after initial endovascular treatment with GDCs and accepted studies that are comprised of at least one case. Publications using the same patient population were excluded. There were no anatomical exclusion criteria. Studies with incomplete data regarding patients' sex and age, median latency and post-surgical obliteration rate were still included, while studies with incomplete surgical retreatment and surgical indication data were excluded.

RESULTS

Treatment

A total of 9 patients (5 males - 4 females) were included in our study with a mean age of 49 years (range 46 to 63). Subarachnoid hemorrhage was the initial presentation in 78% (7/9) of patients. (Table 1). Aneurysms' most common location was the middle cerebral artery bifurcation (5/9) followed by the anterior communicating artery (3/9). One aneurysm (1/9) was located at the internal carotid artery bifurcation.

All patients were initially treated by simple coiling. Mean aneurysm diameter was 6.14 mm (range 4 to 17.4 mm). Considering their morphologic characteristics, 7/9 aneurysms had regular whereas 2/9 had irregular shapes. Mean time interval from initial endovascular treatment to surgical clipping was 25.5 months. In every case, the operation was scheduled in a 15-day period from the discovery of the recurrence. Indications for surgery were recanalization alongside coil compaction in 2 IAs, regrowth in 2 IAs, formation of a new bleb in 1 IA, and residual neck in 4 IAs.

Recanalization was defined as the reappearance of contrast filling in a previously successfully occluded aneurysm sac. Residual neck was defined as the persistent post-embolization contrast filling of the original aneurysmal neck without opacification of the aneurysmal sac.[28)44)] Regrowth was defined as enlargement

Table 1. Patients and aneurysms characteristics

Case	Sex/Age	SAH	Location	Size of aneurysm (max diameter) mm	Size of neck (mm)	Dome/ Neck ratio	Interval coiling to clipping (months)	Surgical technique	Indication for surgery (1. Recanalization w/ coil compaction / 2. regrowth / 3. residual neck/)	Obliteration rate (%)	mRS after coiling	mRS after clipping	Post-op complication	Clinical FU after clipping months
1	M/51	X	Acomm	5	4	1.25	9	Clipping	Recanalization w/ coil compaction	100	5	1	NO	12
2	F/47	X	Acomm	7	3	2.33	19	Clipping	Recanalization w/ coil compaction	100	1	0	NO	78
3	F/50	X	MCA	8	4	2	0	Clipping	Regrowth	100	1	1	NO	24
4	M/45	No	MCA	7	4	1.75	17	Clipping	Regrowth	100	0	0	NO	24
5	M/46	No	ICA bifurcation	7	2.5	2.8	5	Clipping	Residual neck	100	1	0	NO	62
6	M/46	X	MCA	8.8	4.9	1.8	16	Clipping	Residual neck	100	0	0	NO	1
7	M/63	X	Acomm	4	4	1	156	Clipping	Regrowth	100	1	0	NO	1
8	F/46	X	r.MCA	17.3	9.82	1.76	8	Clipping	Residual neck	100	1	0	NO	1
9	F/47	X	r.MCA	5	4	1.25	0	Clipping	Residual neck	100	1	0	NO	1

mRS, modified Rankin Scale; Acomm, anterior communicating artery; MCA, middle cerebral artery, ICA, internal carotid artery; r.MCA, right middle cerebral artery of the initial aneurysm sac or the formation of a new daughter sac.

Clinical outcome

The clinical presentation of our patients before and after microsurgery was evaluated using the modified Rankin Scale (mRS). Mean clinical follow-up after clipping was 22.7 months (ranging from 1 to 78 months). Pre- and postoperative mRS score is presented in Table 1. All patients had good clinical outcomes with preserved or improved mRS scores. Procedure-related morbidity and mortality were zero whereas complete aneurysm occlusion was achieved in all cases after surgical clipping. Neurological assessment at the final follow-up indicated that all patients had minimal symptoms or were asymptomatic (mRS 0-1). Neurological status improved for 6 patients whereas the rest (3/9) remained stable (Fig. 1).

Literature review

We conducted a retrospective review of 48 studies that met our criteria of selection and are presented in Table 2. For the statistical data that follow we used only studies from the table that provided the needed data. Based on the studies above, a total number of 969 patients underwent microsurgical treatment for 976 previously coiled aneurysms. The male-to-female ratio (M:F) was approximately 1:2.

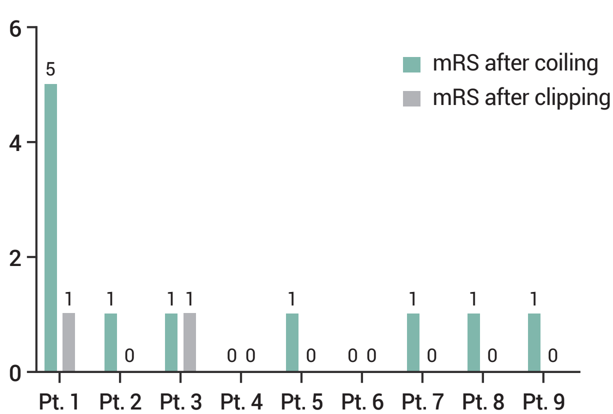

Fig. 1. Pre- vs Postoperative neurological status of the 9 patients that were treated in our center. mRS, modified Rankin Scale

The mean interval between the initial embolization and the microsurgical retreatment in 889 patients (studies with provided data) was 16.12 months. Furthermore, we categorized the surgical indications into 5 major categories: (a) Recurrence, which includes coil compaction, recanalization, and regrowth, (b) Mass Effect (ME), (c) Coil Migration (CM) which includes Coil Protrusion and Coil extrusion, (d) Rebleeding, (e) Residual Aneurysm. For the majority of patients, the surgical indication was recurrence of the aneurysm (59.14%), followed by residual aneurysm (28.63%) (Fig. 2). The treatment strategy was divided into 3 categories: (a) clipping with or without coil extraction, (b) bypass, (c) other treatment strategies such as Parent Artery Occlusion (PAO) and wrapping. As expected, the first choice of retreatment was clipping (91.3%). Fig. 3 presents patients' data concerning retreatment strategies.

Most of the studies (42 out of 48) provided patients' postoperative outcome data (Table 3). According to these, (data available for 868 patients), a good outcome (GOS 4-5, mRS 0-2) was observed in 88.9%, a bad outcome (GOS 2-3, mRS 3-5) in 7.5%, whereas 3.6% died (GOS 1, mRS 6), as illustrated in Fig. 4. Furthermore, 19 out of 48 studies additionally provided the preoperative patients' clinical status (Table 4). According to the data available for 420 patients, the majority of patients remained stable postoperatively and maintained their good preoperative clinical status (GOS 4-5, mRS 0-2) (87.9% preoperatively vs 87.6% postoperatively), as illustrated in Fig. 5.

CASES ILLUSTRATION

Case 2 (Fig. 6)

A 47-year-old female patient presented with SAH due to a ruptured narrow neck anterior communicating artery (ACoA) aneurysm (A, white arrow). The aneurysm had an irregular shape, and the Dome/Neck ratio was 2.33. The patient was initially treated with an endovascular approach using Guglielmi Detachable Coils (GDCs) and full occlusion was achieved (B,

Table 2. Cases of microsurgical management of previously coiled intracranial aneurysms

No.	References	No. of patients and IAs	Sex/Age (M/mean)	Mean interval (months)	Surgical indication (n)					Treatment strategy (n)			Mortality (%)	Postsurgical obliteration rate (%)
					Recurrence	ME	CM	Rebleed	Residual IAs	Clipping	By-pass	Other		
1	Thornton et al. 2000[48]	11/11	2/49	4.36	2	3	3	0	3	11	0	0	0	N/A
2	Makoui et al. 2000[30]	1/1	0/46	0.5	1	0	0	0	0	1	0	0	0	100.0
3	Nomura et al. 2000[35]	6/6	3/49.5	1.17	0	0	1	0	5	6	0	0	0	100.0
4	Boet et al. 2001[3]	8/8	3/47.3	NA	3	0	0	0	5	7	0	1	0	N/A
5	Asgari et al. 2002[2]	5/5	2/47.2	2.3	2	0	1	0	2	5	0	0	0	100.0
6	Conrad et al. 2002[6]	7/7	1/50	2.22	3	0	0	0	4	4	0	3	16.7	100.0
7	Zhang et al. 2003[57]	38/40	11/52	6.0	19	3	1	0	17	31	3	6	7.9	100.0
8	Veznedaroglu et al. 2008[51]	18/18	3/49	N/A	16	1	0	1	0	15	0	3	0	83.3
9	Deinsberger et al. 2003[9]	7/7	3/44.9	5.25	3	0	0	2	2	7	0	0	14.3	NA
10	Yoshida et al. 2005[55]	1/1	0/59	10.0	1	0	0	0	0	1	0	0	0	NA
11	Minh et al. 2006[31]	7/7	1/42	N/A	1	0	0	2	4	7	0	0	0	100.0
12	Raftopoulos et al. 2007[40]	17/17	9/54	17.8	14	0	3	0	0	17	0	0	0	100.0
13	Deshmukh et al. 2006[10]	2/2	1/48.5	19.5	2	0	0	0	0	2	0	0	0	100.0
14	König et al. 2007[22]	10/10	2/46	14.3	10	0	0	0	0	10	0	0	0	NA
15	Tirakotai et al. 2007[49]	8/8	1/49	12.8	2	3	0	1	2	8	0	0	0	100.0
16	Pillai et al. 2007[38]	1/1	0/34	18.0	0	0	0	0	1	1	0	0	0	N/A
17	Lejeune et al. 2008[26]	21/21	10/45	8.33	12	0	0	0	9	19	0	2	0	90.5
18	Klein et al. 2008[21]	13/13	6/43	19.6	10	0	0	3	0	13	0	0	0	100.0
19	Waldron et al. 2009[52]	43/43	9/51	28.0	18	3	0	3	19	33	7	3	0	89.0
20	Harsan et al. 2008[15]	1/1	1/50	15.0	0	1	0	0	0	1	0	0	0	N/A
21	Grasso et al. 2009[13]	2/2	0/38	3.5	1	0	0	1	0	2	0	0	0	100.0
22	Chung et al. 2010[5]	29/29	16/48.1	4.2	10	0	6	5	8	29	0	0	0	NA
23	Kumar et al. 2010[23]	5/5	3/50.4	3.6	1	0	1	2	1	5	0	0	0	100.0
24	Romani et al. 2011[43]	81/82	28/47	12.0	23	3	6	4	46	78	2	2	0	93.9
25	Dorfer et al. 2012[11]	52/52	19/49.9	9.4	49	0	3	0	0	44	5	3	0	88.5

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No.	References	No. of patients and IAs	Sex/Age (M/mean)	Mean interval (months)	Surgical indication (n)					Treatment strategy (n)			Mortality (%)	Postsurgical obliteration rate (%)
					Recurrence	ME	CM	Rebleed	Residual IAs	Clipping	By-pass	Other		
26	Lee et al. 2011[24]	6/6	2/46.6	12.9	4	1	0	1	0	0	6	0	0	100.0
27	Aoun et al. 2013[1]	1/1	0/25	8.0	1	0	0	0	0	1	0	0	0	100.0
28	Nakamura et al. 2013[33]	15/15	8/50.6	19.1	12	0	0	0	3	15	0	0	0	100.0
29	Rubino et al. 2014[45]	20/20	8/43.5	NA	7	0	0	0	13	20	0	0	0	95.0
30	Izumo et al. 2015[18]	7/7	1/60.3	28.8	6	0	1	0	0	6	1	0	0	100.0
31	Owen et al. 2015[36]	73/73	15/49	13.5	35	3	0	7	28	59	8	6	0	89.0
32	Daou et al. 2016[8]	111/111	29/50.5	23.0	95	0	0	2	14	105	0	6	0	97.3
33	Wang et al. 2017[53]	19/21	9/51.3	26.0	17	0	0	1	3	18	1	2	0	94.7
34	Kawabata et al. 2017[20]	1/1	0/55	4.0	0	1	0	0	0	1	0	0	0	100.0
35	Toyota et al. 2018[50]	14/14	7/50	12.0	3	0	0	0	11	13	1	0	0	78.6
36	Shtaya et al. 2018[46]	39/40	19/49	18.0	40	0	0	0	0	40	0	0	0	NA
38	Liu et al. 2019[29]	75/76	34/56	7.0	33	0	0	4	39	68	2	6	0	93.3
37	Nisson et al. 2018[34]	53/53	7/51.9	31.2	25	0	0	0	28	53	0	0	0	94.3
39	Wu et al. 2019[54]	48/48	26/46.5	20.2	29	9	0	4	6	48	0	0	0	100.0
40	Yu et al. 2019[56]	25/25	N/A/48.24	NA	25	0	0	0	0	25	0	0	0	100.0
41	Raper et al. 2020[42]	6/6	3/53	7.5	2	0	0	4	0	6	0	0	0	100.0
42	Pirayesh et al. 2021[39]	12/12	5/61.5	55.0	N/A	N/A	N/A	N/A	N/A	8	4	0	0	83.0
43	Moufarrij 2020[32]	1/1	0/38	120.0	0	0	0	1	0	1	0	0	0	100.0
44	Lee et al. 2020[25]	34/34	10/59.7	15.8	21	0	0	12	1	32	2	0	0	N/A
45	Hendricks et al. 2020[16]	1/1	N/A	N/A	1	0	0	0	0	1	0	0	0	100.0
46	Zheng et al. 2021[58]	12/12	3/51.3	8.91	6	1	2	3	0	12	0	0	0	100.0
47	Rahme et al. 2022[41]	1/1	0/44	NA	0	0	0	1	0	1	0	0	0	100.0
48	Hannan et al. 2021[14]	1/1	0/48	12.0	1	0	0	0	0	1	0	0	0	100.0

ME, mass effect; CM, coil migration; IA, intracranial aneurysm

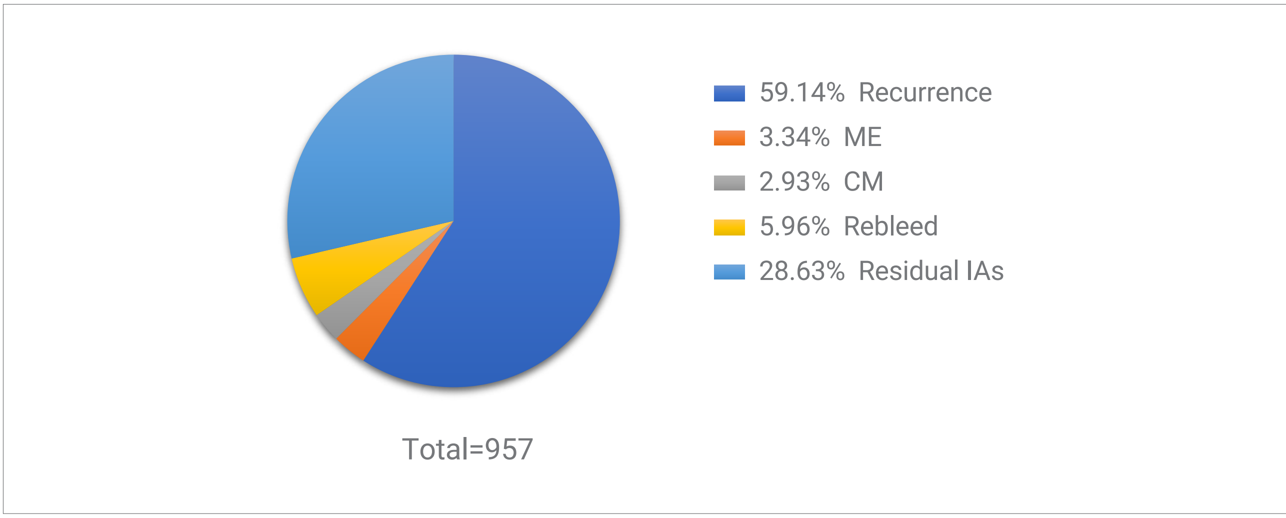

Fig. 2. Indications for microsurgical treatment of 957 previously coiled aneurysms.

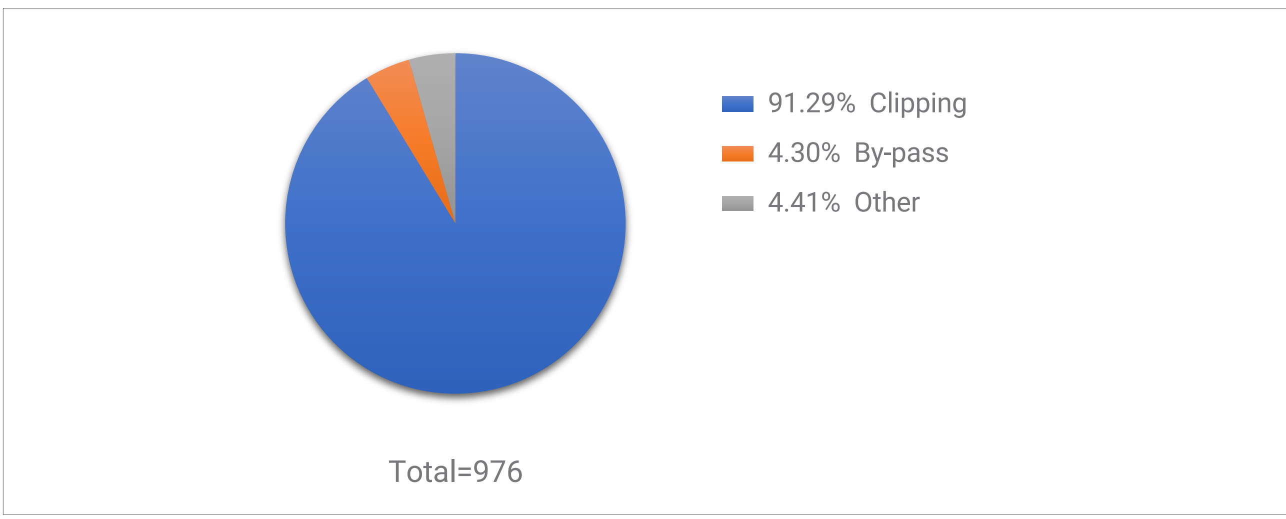

Fig. 3. Use of the different surgical strategies in the treatment of 976 previously coiled aneurysms.

white arrow). In the angiographic follow-up nineteen months later, recanalization of the neck alongside with coil compaction (C, red arrow) was observed, and the patient was admitted for microsurgical retreatment. Right frontotemporal craniotomy was performed, and the aneurysm neck was carefully dissected (D, white arrow). A 45° angled clip was placed at the aneurysm neck beneath the coil mass (E, white arrow). A 100% obliteration rate was accomplished, as demonstrated in postoperative DSA (F, G, white arrow) and follow-up MRA (H). The patient had an uneventful recovery (post-clipping mRS 0).

Case 5 (Fig. 7)

A 46-year-old male patient presented with a ruptured supraophthalmic right ICA aneurysm (A, white arrow) that was emergently embolized by balloon-assisted technique (B, white arrow). During the follow-up period, a newly formed (de novo) aneurysm was observed at the right ICA bifurcation (C, D, red arrow). The Dome/Neck ratio was 2,8 with an irregular shape. Complete endovascular occlusion of the aneurysm by simple coiling was performed (E, red arrow). Five months later, regrowth of the ICA bifurcation aneurysm sac was observed in follow-up DSA (F, red arrow). Intra-

Table 3. Post-operative outcome

No.	References	Good outcome (GOS 4-5, MRS 0-2)	Bad outcome (GOS 2-3, MRS 3-5)	Death (GOS 1, MRS 6)
1	Thornton et al. 2000[48]	10	1	0
2	Makoui et al. 2000[30]	1	0	0
3	Nomura et al. 2000[35]	6	0	0
4	Boet et al. 2001[3]	7	1	0
5	Asgari et al. 2002[2]	2	3	0
6	Conrad et al. 2002[6]	6	0	1
7	Zhang et al. 2003[57]	33	2	3
8	Veznedaroglu et al. 2008[51]	18	0	0
9	Deinsberger et al. 2003[9]	4	2	1
10	Yoshida et al. 2005[55]	1	0	0
11	Minh et al. 2006[31]	7	0	0
12	Raftopoulos et al. 2007[40]	17	0	0
13	Deshmukh et al. 2006[10]	2	0	0
14	König et al. 2007[22]	9	1	0
15	Tirakotai et al. 2007[49]	8	0	0
16	Pillai et al. 2007[38]	1	0	0
17	Lejeune et al. 2008[26]	20	1	0
18	Klein et al. 2008[21]	10	2	1
19	Waldron et al. 2009[52]	36	4	3
20	Harsan et al. 2008[15]	1	0	0
21	Grasso et al. 2009[13]	2	0	0
22	Chung et al. 2010[5]	27	1	1
23	Kumar et al. 2010[23]	5	0	0
24	Romani et al. 2011[43]	71	4	6
25	Lee et al. 2011[24]	6	0	0
26	Aoun et al. 2013[1]	1	0	0
27	Nakamura et al. 2013[33]	14	0	1
28	Izumo et al. 2015[18]	6	1	0
29	Owen et al. 2015[36]	65	5	3
30	Daou et al. 2016[8]	100	8	3
31	Wang et al. 2017[53]	16	2	1
32	Kawabata et al. 2017[20]	1	0	0
33	Shtaya et al. 2018[46]	36	3	0
34	Liu et al. 2019[29]	71	1	3
35	Nisson et al. 2018[34]	48	3	2
36	Wu et al. 2019[54]	42	6	0
37	Yu et al. 2019[56]	19	0	0
38	Pirayesh et al. 2021[39]	7	5	0
39	Moufarrij 2020[32]	1	0	0
40	Lee et al. 2020[25]	25	8	1
41	Zheng et al. 2021[58]	10	1	1

GOS, Glasgow Outcome Scale; MRS, modified Rankins Scale

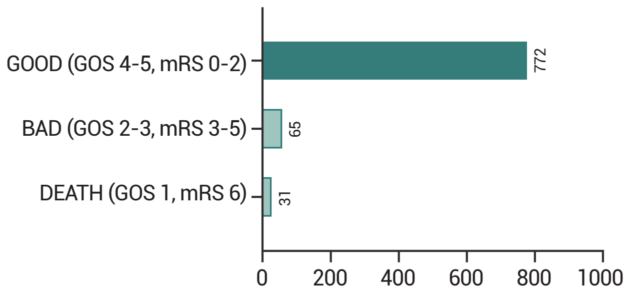

Fig. 4. Post-operative outcome of 868 patients classified as Good (GOS 4-5, mRS 0-2) Bad (GOS 2-3, mRS 3-5) and Death (GOS 1, mRS 6). GOS, Glasgow Outcome Scale; mRS, modified Rankin Scale

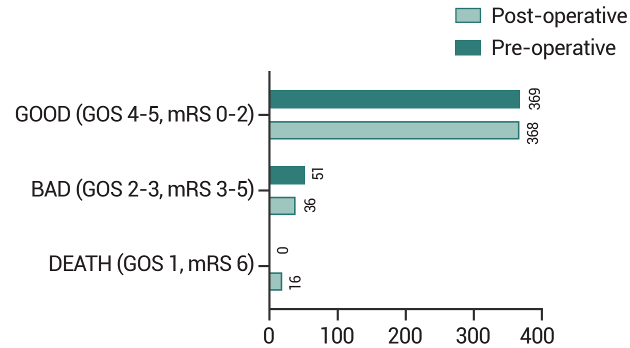

Fig. 5. Pre- vs Postoperative outcome of 420 patients classified as Good (GOS 4-5, mRS 0-2) Bad (GOS 2-3, mRS 3-5) and Death (GOS 1, mRS 6). GOS, Glasgow Outcome Scale; mRS, modified Rankin Scale

Table 4. Pre-operative vs Post-operative outcome

No.	Reference	PreOp clinical situation		PostOp clinical situation		
		Good	Bad	Good	Bad	Death
1	Boet et al. 2001[3]	7	1	7	1	-
2	Veznedaroglu et al. 2008[51]	18	-	18	-	-
3	Raftopoulos et al. 2007[40]	16	1	17	-	-
4	König et al. 2007[22]	9	1	9	1	-
5	Lejeune et al. 2008[26]	19	2	20	1	-
6	Klein et al. 2008[21]	10	3	10	2	1
7	Waldron et al. 2009[52]	36	7	36	4	3
8	Chung et al. 2010[5]	18	5	21	1	1
9	Romani et al. 2011[43]	73	8	71	4	6
10	Lee et al.2011[24]	6	-	6	-	-
11	Aoun et al. 2013[1]	1	-	1	-	-
12	Nakamura et al. 2013[33]	15	-	14	-	1
13	Izumo et al. 2015[18]	6	1	6	1	-
14	Wang et al. 2017[53]	17	2	16	2	1
15	Kawabata et al. 2017[20]	1	-	1	-	-
16	Shtaya et al. 2018[46]	38	1	36	3	-
17	Nisson et al. 2018[34]	45	8	48	3	2
18	Pirayesh et al. 2021[39]	10	2	7	5	-

operative view after right pterional craniotomy shows the neck of the regrowing aneurysm (G, red arrow). Direct clipping of the ICA bifurcation aneurysm was performed. Postoperative DSA confirmed the optimal placement of the clip at the neck of the ICA bifurcation aneurysm (I, red arrow) and complete angiographic aneurysm obliteration (H, red arrow), while the initially ruptured supraophthalmic aneurysm remained stable (H, white arrow). No perioperative complications occurred, while the neurologic status improved from mRS 1 to mRS 0.

Case 7 (Fig. 8)

A 63-year-old man was admitted lethargic due to a

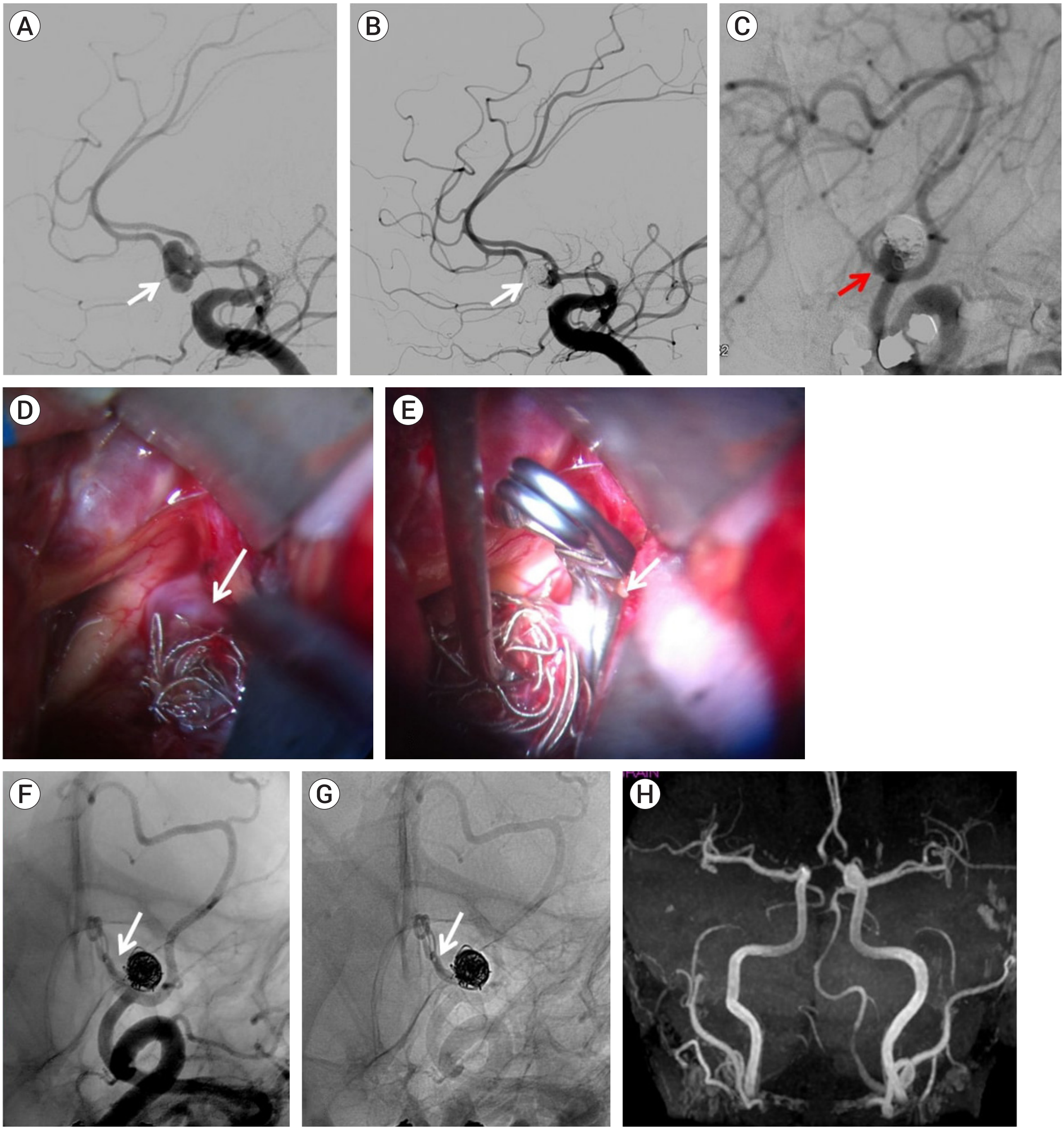

Fig. 6. (A) DSA illustrates a ruptured narrow neck ACoA aneurysm (white arrow). (B) Complete embolization of the aneurysm has been initially performed (white arrow). (C) FU angiogram shows recanalization of the neck (red arrow). (D) Intraoperative view illustrates the neck remnant. (E) A 45° angled clip has been placed below the coil mass (white arrow). (F, G) Postopetrative DSA shows optimal positioning of the clip (white arrow). (H) Postoperative MRA illustrates complete patency of the A2 vessels. DSA, digital subtraction angiography; AcoA, anterior communicating artery; FU, follow up; MRA, magnetic resonance angiography

4 mm ruptured wide-neck ACoA aneurysm (A, black arrow). During embolization using balloon-assisted technique, re-rupture of the aneurysm occurred after deployment of the first coil (B, black arrow). Further embolization with coils, keeping the microcatheter in place, resulted in complete aneurysm occlusion from

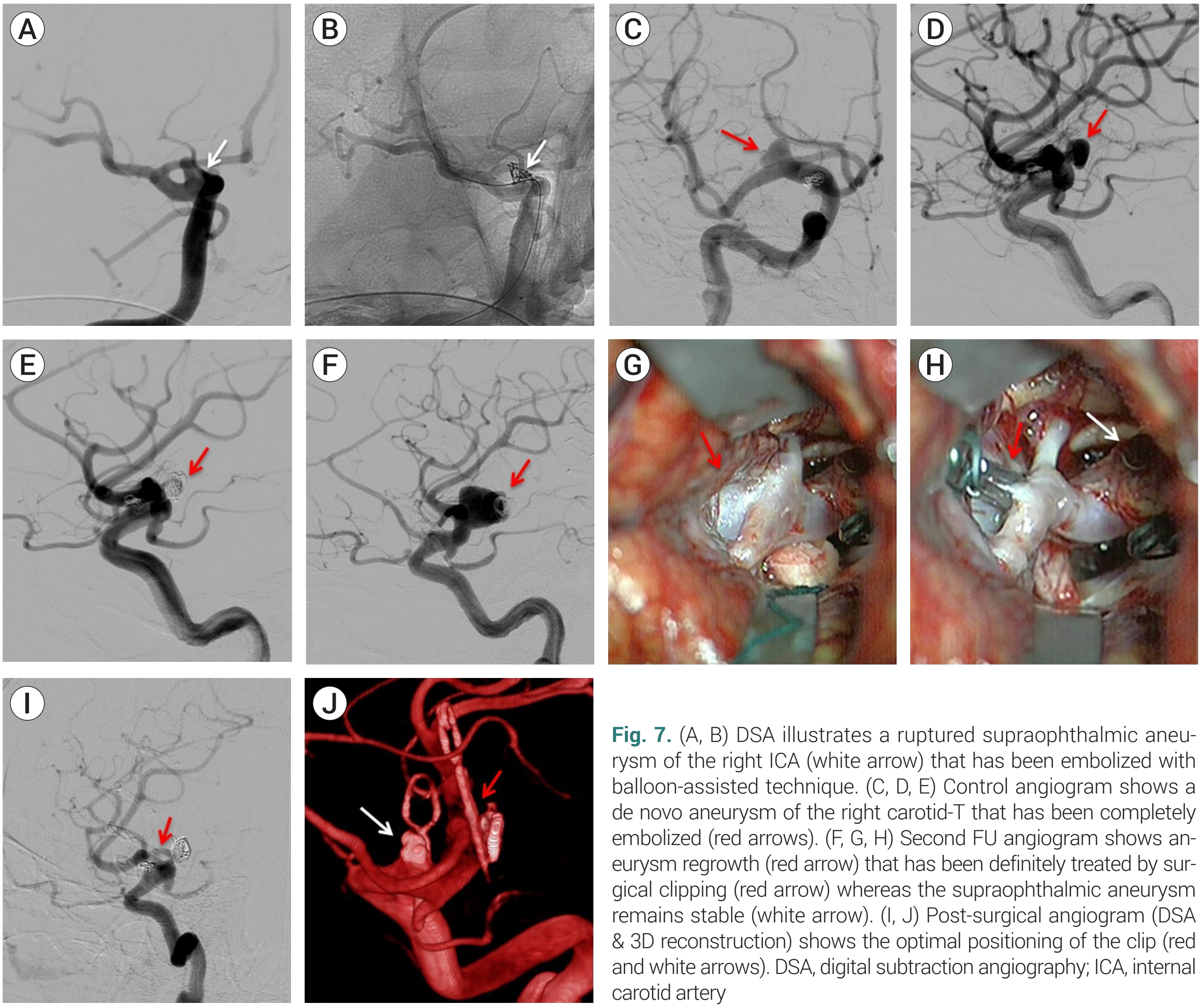

Fig. 7. (A, B) DSA illustrates a ruptured supraophthalmic aneurysm of the right ICA (white arrow) that has been embolized with balloon-assisted technique. (C, D, E) Control angiogram shows a de novo aneurysm of the right carotid-T that has been completely embolized (red arrows). (F, G, H) Second FU angiogram shows aneurysm regrowth (red arrow) that has been definitely treated by surgical clipping (red arrow) whereas the supraophthalmic aneurysm remains stable (white arrow). (I, J) Post-surgical angiogram (DSA & 3D reconstruction) shows the optimal positioning of the clip (red and white arrows). DSA, digital subtraction angiography; ICA, internal carotid artery

outside to inside (C, black arrow). The patient experienced a full recovery and was discharged after 15 days. Nevertheless, a follow-up angiography revealed a newly formed aneurysm projection (C, D, black arrow), which was treated by microsurgical occlusion. Intraoperative view shows the new aneurysm bleb (E, black arrow). A mini-clip was used to occlude the new bleb (F, G, black arrow) followed by aneurysm wrapping. Postoperative angiogram demonstrated complete occlusion of the aneurysm (H, black arrow). No perioperative complications occurred.

DISCUSSION

Types and mechanisms of IAs recurrence

Aneurysms' recurrence rate among patients receiving endovascular treatment is estimated at roughly 20%, a percentage that varies between patients depending on several risk factors.[7)12)37)] Aneurysms with complete occlusion exhibit lower recurrence rates as opposed to inadequately occluded or those with residual neck. Aneurysm sac >10 mm and neck size >4 mm are also significant risk factors. Although some studies report that aneurysm location is not a risk factor, other studies suggest that posterior circulation aneurysms have a

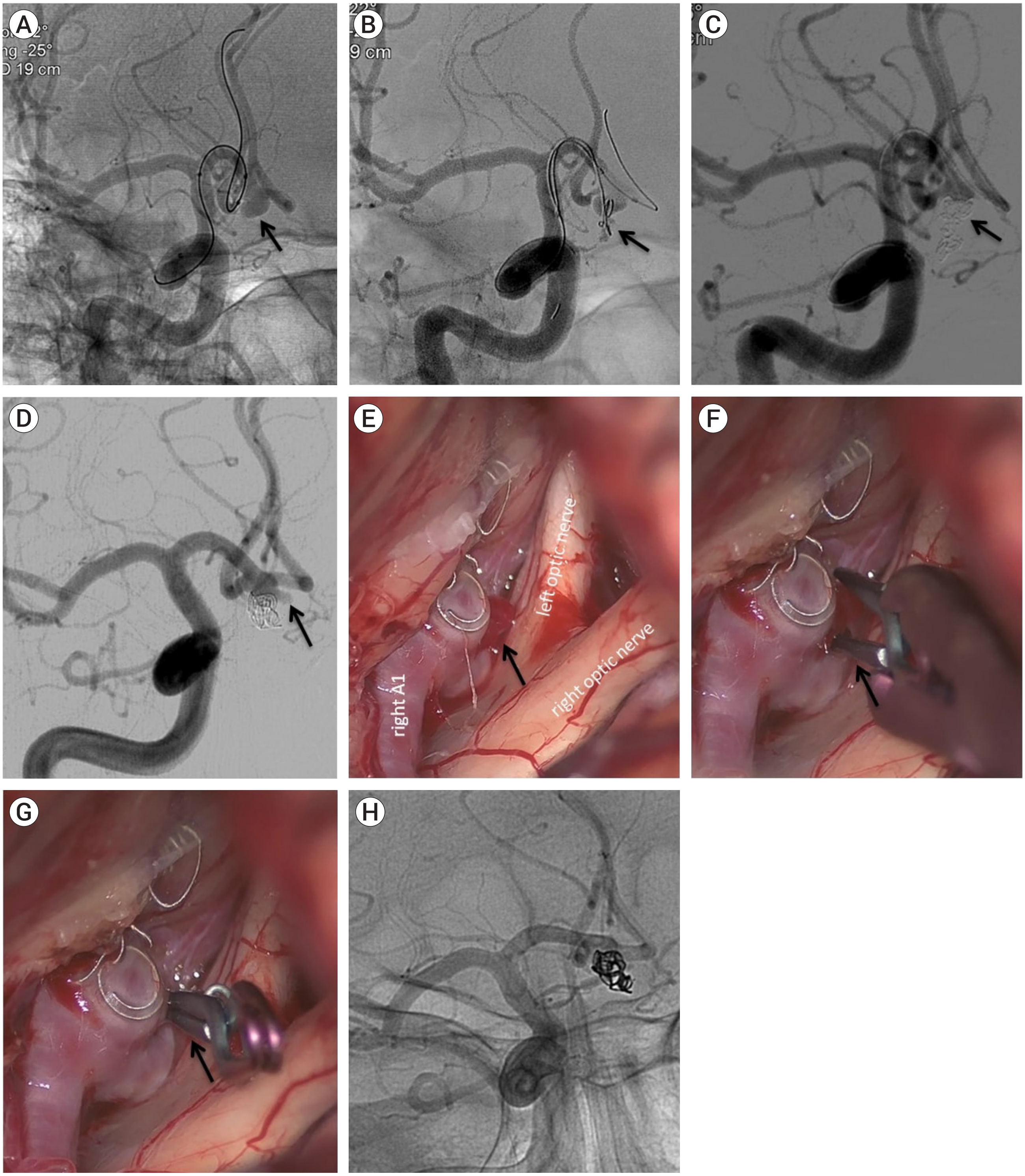

Fig. 8. (A) DSA (subtracted view) shows a ruptured wide-neck ACoA aneurysm (black arrow). (B) During embolization using balloon-assisted technique penetration of the aneurysm occurred after deployment of the first coil (black arrow). (C) Further embolization with coils resulted in complete aneurysm occlusion (black arrow). (D) A FU angiography revealed a newly formed aneurysm projection (black arrow). (E) Intraoperative view shows the aneurysm bleb (black arrow). (F, G) A mini-clip has been used to occlude the new bleb (black arrow) followed by aneurysm wrapping. (H) Post-surgical angiogram shows complete occlusion of the aneurysm (black arrow). DSA, digital subtraction angiography; AcoA, anterior communicating artery

higher rate of recurrence in relation to anterior circulation aneurysms. Previously ruptured aneurysms tend to correlate with an increased probability of recurrence.[7)11)12)42)56)] According to data extracted from our review, we classified the mechanisms of recurrence after endovascular treatment into 4 types based on follow-up angiographies (Fig. 9). Type I: coil loosening; presence of contrast fluid in a diffuse, spotted pattern among intra-aneurysmal coils, caused by a combination of gradual coil loosening and hemodynamic factors. Type II: coil compaction; compression and subsequent volume reduction of coils inside the aneurysm without enlargement of the aneurysmal sac or neck. Type III: aneurysm regrowth; it can be subclassified as follows: IIIa: neck growth with or without coil compaction, IIIb: aneurysmal sac growth with or without coil compaction, IIIc: a new aneurysmal sac formed from the original aneurysmal neck. Type IV: coil migration, which is further subclassified as Type IVa: coil extrusion outside of the aneurysmal sac, and Type IVb: coil protrusion in the parent artery.

Retreatment and rerupture rates after initial embolization

Even though the recurrence rate is about 20%, retreatment is pursued at roughly half of those, i.e. 10% of all embolized aneurysms.[12)42)] On the contrary, ISAT and BRAT trials demonstrated retreatment rates of 17.4% and 20% respectively.[4)47)] Recurrence is the main indication for retreatment, as it may lead to either re-rupture

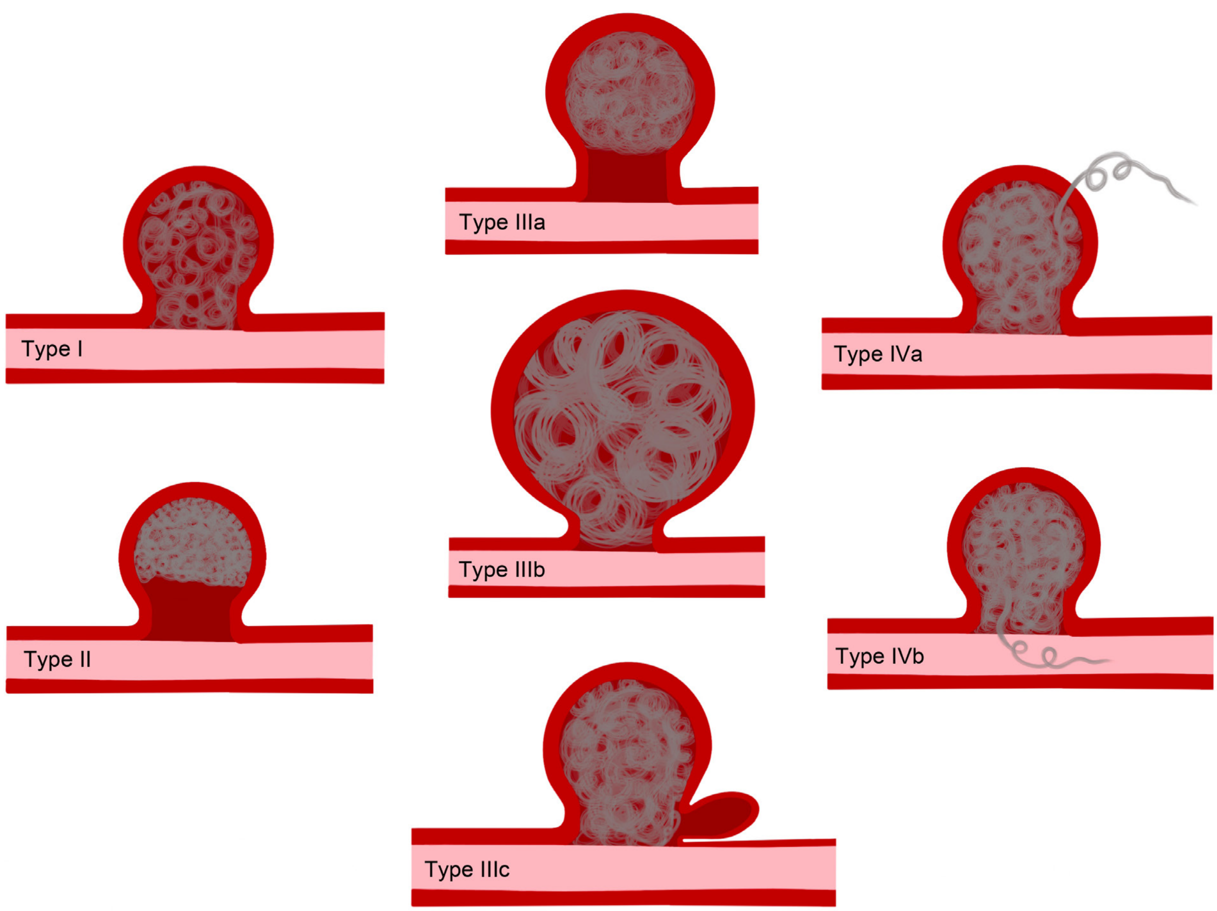

Fig. 9. Recurrence types based on FU angiographies. Type I: coil loosening, Type II: coil compaction, Type III: aneurysm regrowth (IIIa: neck growth with or without coil compaction, IIIb: aneurysmal sac growth with or without coil compaction, IIIc: a new aneurysmal sac formed from the original aneurysmal neck), Type IV: coil migration (Type IVa: coil extrusion outside of the aneurysmal sac, Type IVb: coil protrusion in the parent artery)

or an increased risk of treatment failure.[17] The Cerebral Aneurysm Rerupture After Treatment Trial (CARAT), proved that the obliteration rate of the aneurysmal sac has a direct correlation to the re-rupture risk.[19] More specifically overall re-rupture risk was reported to be: 1.1% for complete occlusion, 2.9% for 91% to 99% occlusion, 5.9% for 70% to 90%, and 17.6% for <70%.[19]

In comparison to clipping, coiling comes with a higher risk of rebleeding, rerupture and retreatment. More specifically, the rebleeding rate after endovascular treatment as presented in the CARAT study (3.4%) is higher than that of clipping (1.3%).[19] Similar results are presented by Hulsbergen et al. with a rebleeding rate of 2.1% and 1.1% in initial endovascular and clipping treatment respectively.[17] Furthermore, ISAT demonstrates a 2.1% rebleeding rate after initial embolization and 1% after surgical clipping.[4] According to the BRAT trial, 20% of patients who received endovascular treatment required retreatment in the long term, in comparison to less than 1% of patients who went through surgical treatment.[47] Retreatment rates of cerebral aneurysms increased over time after endovascular treatment, thus indicating the need for long-term follow-up after the aforementioned procedure.[4]

Endovascular retreatment

A reasonable retreatment strategy is the endovascular approach. Li et al. in their study, report that out of 1385 aneurysms that were initially treated endovascularly, 5.6% were retreated by further re-embolization. This percentage represents 51.6% of the total number of recurrent aneurysms.[27] Comparable results are seen in a study conducted by Dorfer et al, in which 59.1% of recurrent aneurysms received endovascular treatment as the second approach.[11]

The endovascular retreatment strategy is considered an effective approach, especially in cases that are presented with coil compaction and recanalization, however, it does not show similar effectiveness when it comes to aneurysm regrowth.[11,58] Although morbidity rates in endovascular retreatment are lower compared to the microsurgical approach, this advantage may be offset by the higher rates of incomplete aneurysm occlusion and recanalization.[39,42] Endovascular retreatment techniques include standard coiling, stent-assisted coiling, balloon-assisted coiling, covered stents, and flow diversion.

Microsurgical retreatment

Despite the fact that microsurgical clipping of recurrent, previously embolized aneurysms may be a technically demanding technique, it may be a safer and more effective definitive treatment option when compared to endovascular retreatment.[42] Pirayesh et al. suggest that major indications for microsurgical retreatment are aneurysm recanalization and regrowth, while another indication worth mentioning is neck remnant after partial endovascular coiling.[39] Wang et al. mention to their paper that while recoiling is preferred because is minimally invasive, surgical clipping offers definitive closure of the aneurysm and can be used in cases presented with mass effect, broad neck aneurysms and cases with recanalization after repeated coiling. To achieve surgical clipping adequate neck for the placement of the clip is needed. However, no method can evaluate and predict sufficiently the success of microsurgical treatment in a previously embolized aneurysm. [53] Moreover, according to Yu et al., microsurgical treatment is suggested for type III-V aneurysm recurrence according to their classification. These types include aneurysms with formation of a new neck remnant, with or without coil compaction in the initial aneurysmal sack (III, IV), and aneurysms with a newly regrown aneurysmal sac from the initial aneurysmal neck (V). Contrariwise, for large and giant recurrent aneurysms and specifically for Types I and II, (I, pure recanalization inside the aneurysm sac; II, pure coil compaction without aneurysm growth), surgical clipping is not suggested, due to high rates of morbidity.[56]

Neck width to compaction height ratio (N:H) <0.5, coil width to compaction height ratio (C:H) <2.5 and compaction height (H) >2 mm, seem to be positive predictive factors of aneurysmal suitability to clipping, with C:H being the index with the highest predictive value.[52)58)]

There are several reported microsurgical techniques for the treatment of previously coiled aneurysms. The main is direct clipping, with the clip being placed underneath the coils.[36)52)] When this technique is not feasible, other techniques may be applied. Aneurysm trapping or proximal occlusion of the parent artery combined with bypass may be an alternative option in order to exclude dysplastic recurrent aneurysms, not amenable to direct clipping, from brain circulation.[36)52)58)] Parent Artery Occlusion alone could be also used in case of adequate retrograde flow distal to the aneurysm. In order to convert an unclippable aneurysm, due to inadequate neck remnant, into a clippable one, temporary clips may be placed to trap the aneurysm, followed by opening of the aneurysmal sac, removal of the formed thrombus and mobilization of the coils away from the aneurysmal neck.[52)58)] Rubino et al. suggest that the coil removal should be avoided due to the unwieldiness and the possibility of surrounding structures' injury, as even in cases of absolute indication, coil extraction is associated with an increased chance of poor outcome.[45)] Wrapping with muslin or cotton aims to reinforce the aneurysm wall through inflammation and scar tissue formation. This technique may also be combined with clipping.[36)52)]

Present study

Retrospectively reviewing 9 cases that have been treated in our department, the surgical indication was aneurysm recurrence in 55.6% (5/9 pts) and residual aneurysm after initial embolization in 44.4% (4/9 pts). These percentages are comparable to those extracted from the literature, with recurrence reported to be the leading indication for surgical treatment, followed by residual aneurysm. Complete aneurysm occlusion was achieved for all our patients after additional surgical clipping (100%).

No mortality or morbidity related to the surgical procedure was observed in our series. Neurological assessment at the final follow-up indicated that all patients had minimal symptoms or were asymptomatic (mRS 0-1). All patients either remained stable or showed improvement as compared to their neurological status prior to retreatment (Fig. 1).

The findings derived from our study correspond to the literature's data, indicating that microsurgery is a safe and efficient retreatment option for recurrent IAs.

Study limitations

Some factors may have introduced bias to our institutional study's results. First and foremost, it is composed of a small relatively young patient population, while 88.9% (8/9) of our patients were in good clinical status preoperatively. Only one patient was preoperatively in a poor clinical condition with an mRS score of 5 but fortunately ended up with major improvement presenting a postoperative mRS score of 1. Another factor that may have favored the surgical procedure is that all aneurysms were located in the anterior circulation. Moreover, none of our cases exhibited giant-sized aneurysms (mean diameter 6.1 mm; range 4-17.3 mm). Last but not least, none of the patients presented with rebleeding, thus decisions regarding the need for retreatment were based on the systematic clinical and angiographic follow-up. However, technical operative difficulties were not absent from this study. In 55.6% (5/9) of the patients, a branch was originating from aneurysm's neck whereas a wide neck aneurysm (≥4 mm in diameter) was present in 77.8% (7/9) of cases.

Considering our literature review, although a large number of studies are included, several of them are constituted of a small number of patients and the majority are retrospective studies without control groups. Therefore, they are vulnerable to selection bias and statistically significant conclusions about the ideal treatment modality cannot be exported. The same limitations also apply to our institutional cases. Moreover, aneurysms that were admitted for microsurgical retreatment were accessible and selected as feasible for direct clipping, making the use of the aforementioned technique an attractive option. Thus, direct comparison of its efficacy and effectiveness with the other techniques is not possible. Last, due to the lack of standardized protocols and criteria for the ideal retreatment technique, the treatment decision is usually made by the treating neurosurgeon and neuroradiologist on a case-by-case basis. Hence, it may vary between different centers.

CONCLUSIONS

Although treatment of recurrent aneurysms after coil embolization is still a controversial topic, microsurgical retreatment appears to be a safe and efficacious approach for recurrent, previously embolized aneurysms. Our institutional study results are in accordance with those previously reported in the literature. Data extracted from the literature review indicated 4 different pathogenetic mechanisms of recurrence: Type I: coil loosening; Type II: coil compaction; Type III: aneurysm regrowth; Type IV: coil migration. Furthermore, we categorized the surgical indications of retreatment into 5 major categories: (a) Recurrence, which includes coil compaction, recanalization and regrowth, (b) Mass Effect, (c) Coil Migration which includes Coil Protrusion and Coil extrusion, (d) Rebleeding, (e) Residual Aneurysm. Currently, there is still no absolute retreatment strategy algorithm and the choice between endovascular coiling and microsurgery remains under debate. Therefore, the establishment of a broadly accepted recurrence classification system and a guideline template for the management of recurrent, previously coiled aneurysms based on their particular morphologic characteristics and pathogenesis is necessary in future studies.

Disclosure

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

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