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► **To cite this version:**

Camillo Sherif, Andreas Gruber, Christian Dorfer, Gerhard Bavinzski, Harald Standhardt, et al.. Ruptured carotid artery aneurysms of the ophthalmic (C6) segment: clinical and angiographic long-term follow-up of a multidisciplinary management strategy. *Journal of Neurology, Neurosurgery and Psychiatry*, 2009, 80 (11), pp.1261. 10.1136/jnnp.2008.170860 . hal-00552759

HAL Id: hal-00552759

<https://hal.science/hal-00552759>

Submitted on 6 Jan 2011

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Ruptured carotid artery aneurysms of the ophthalmic (C6) segment: clinical and angiographic long-term follow-up of a multidisciplinary management strategy

Camillo Sherif, MD, Department of Neurosurgery, Medical University Vienna, Address: Waehringerguertel 18-20, A-1090 Vienna, Austria. E-mail: camillo.sherif@ksa.ch. Tel.: + 43-1-40400-4565, Fax: + 43-1-40400-4566 (**corresponding author**)

Andreas Gruber, MD, Department of Neurosurgery, Medical University Vienna, Address: Waehringerguertel 18-20, A-1090 Vienna, Austria. E-mail: andreas.gruber@meduniwien.ac.at. Tel.: +43-1-40400-4565, Fax: + 43-1-40400-4566 (**contributed equally**)

Christian Dorfer, MD, Department of Neurosurgery, Medical University Vienna, Address: Waehringerguertel 18-20, A-1090 Vienna, Austria. E-mail: christian.dorfer@meduniwien.ac.at. Tel.: + 43-1-40400-4565, Fax: + 43-1-40400-4566

Gerhard Bavinzski, MD, Department of Neurosurgery, Medical University Vienna, Address: Waehringerguertel 18-20, A-1090 Vienna, Austria. E-mail: gerhard.bavinzski@meduniwien.ac.at. Tel.: + 43-1-40400-4565, Fax: + 43-1-40400-4566

Harald Standhardt, MD, Department of Neurosurgery, Medical University Vienna, Address: Waehringerguertel 18-20, A-1090 Vienna, Austria. E-mail: harald.standhardt@meduniwien.ac.at. Tel.: + 43-1-40400-4565, Fax: + 43-1-40400-4566

Engelbert Knosp, MD, Department of Neurosurgery, Medical University Vienna, Address: Waehringerguertel 18-20, A-1090 Vienna, Austria. E-mail: engelbert.knosp@meduniwien.ac.at. Tel.: + 43-1-40400-4565, Fax: + 43-1-40400-4566

Key words: aneurysm, carotid artery, long-term follow-up, multidisciplinary, ophthalmic segment, ruptured

Word Count: 3283 words

Abstract: 248 words

ABSTRACT

Background: The management of ruptured C6 aneurysms remains controversial. Detailed long-term outcome data are still lacking. Thus, the present study provided a detailed long-term follow-up for a multidisciplinary approach combining microsurgical clipping, endovascular embolization and parent artery occlusion with/without bypass-protection.

Methods: In our single-centre analysis of 64 consecutive patients, indications for microsurgery were: superior aneurysm projection, giant/large or wide necked aneurysms and aneurysms at branching sites. Indications for embolization were: narrow necks, neck calcification, close aneurysm relation to the clinoid process or adhesion to the distal dural ring and aneurysm location in the concavity of the carotid siphon curve.

Results: 23 patients (35.9%) underwent microsurgery, 38 patients (59.4%) embolization, 3 patients (4.7%) parent artery occlusion under bypass-protection. Retreatment was required in 20.9% (surgery 8.7%, endovascular 31.6%). Procedure-related transient complications occurred in 10.9% (surgery 13.0%, endovascular 10.5%). Procedure-related permanent morbidities occurred in 6.3% (surgery 8.7%, endovascular 5.3%), including visual deficits in 4.7% (surgery 4.4%, endovascular 5.3%). One endovascular patient died. Angiographic follow-up (29.2 ± 31.9 months) revealed total aneurysm occlusion in 94.4% of the surgical and 82.9% of the endovascular patients. Clinical follow-up (58.7 ± 47.6 months) showed 73.4% of the population reaching GOS 4-5, this data being equivalent to the ISAT outcomes.

Conclusions: Based on favorable neuroradiologic and ophthalmologic outcomes, microsurgery is recommended for superiorly projecting aneurysms - especially aneurysms involving the ophthalmic artery - and for giant/large or wide necked aneurysms. Based on stable aneurysm occlusion and excellent clinical outcomes,

embolization can be recommended for inferiorly/medially projecting small, narrow necked aneurysms.

INTRODUCTION

The surgical management of internal carotid artery (ICA) aneurysms of the ophthalmic segment, also named C6, carotid-ophthalmic or paraclinoid segment can be technically demanding. Previous surgical studies [1-7] have reported higher treatment morbidities and mortalities as compared to other anterior circulation lesions. Therefore endovascular coil embolization has evolved as an alternative treatment option for surgically demanding aneurysms [8-10] despite significantly lower rates of stable aneurysm occlusion.[11-13] Multidisciplinary approaches tried to combine the advantages of both aforementioned techniques.[10, 14-16]

Most of these previous studies focused on unruptured aneurysms.[14, 15, 17, 18] They described technical aspects of treatment without providing detailed clinical, ophthalmologic and angiographic follow-up. There is still a lack of studies reporting on the acute management of ruptured C6 aneurysms.

So the purpose of the present study was to assess the benefits and possible shortcomings of a multidisciplinary treatment strategy for ruptured C6 aneurysms including microsurgical clipping, endovascular coil embolization and parent artery occlusion with/without bypass-protection.

PATIENTS AND METHODS

Patients

We report a consecutive series of 64 patients with proven subarachnoid hemorrhage (SAH) from ruptured C6 ICA aneurysms. All patients were treated at the Medical University of Vienna, Department of Neurosurgery between 01.01.1997-01.01.2007 and prospectively registered in a computerized data base with approval of the Ethics Committee of the Institution.[19]

Neuroradiological examinations

All patients underwent diagnostic intra-arterial angiography, thin-section CT scans and CT-angiography. Fundus sizes were classified as small (<10mm), large (10-25mm) and giant (>25mm). Necks were defined as narrow (\leq 4mm) and wide (>4mm). Thin section CT with bone window depicted possible aneurysm wall calcification. A CT-angiography with three-dimensional reconstructions delineated the anatomy of the aneurysms in relation to adjacent skull base structures and the optic pathways.

Aneurysm classification

The ophthalmic (C6) segment is defined as reaching from the distal dural ring to the origin of the posterior communicating artery.[16] To allow inter-group comparisons with the largest reported series, we applied a classification of Ogilvy et al. [20] (Figure 1): *Transitional aneurysms* originate in the cavernous sinus and extend into the subarachnoid space. *Carotid cave aneurysms* originate at the distal dural ring around the ICA as it enters the subarachnoid space. *Ophthalmic artery aneurysms* arise at the origin or just distal to the origin of the ophthalmic artery. *Posterior carotid wall*

aneurysms arise just distal to the ophthalmic artery on the posterior or the posterolateral wall of the ICA projecting posteriorly or inferiorly. *Superior hypophyseal aneurysms* originate from the medial or inferomedial wall of the ICA, often incorporating perforating branches of the hypophysis.

Treatment selection

An experienced neurovascular team determined the treatment strategy based on the following protocol: Indications for surgical clipping were superior aneurysm projection; giant/large or wide necked aneurysms, aneurysms at branching sites and high embolization risks (complicated parent artery anatomy, atherosclerotic plaques). Indications for endovascular treatment were narrow aneurysm necks, aneurysm location in the concavity of the carotid siphon curve facilitating catheterization, expected surgical difficulties (neck calcification, close aneurysm relation to the clinoid process, aneurysm adhesion to the distal dural ring) and significant internal comorbidities. Endovascular parent artery occlusion with/without bypass-protection was reserved for the management of otherwise untreatable lesions only. It was performed beyond the vasospasm phase and after a preoperative balloon occlusion test (BOT).[21]

Microsurgical techniques

A standard ipsilateral pterional craniotomy, allowing both subfrontal and transsylvian approaches to the paraclinoid region, was used in all cases.[22] Proximal control of the ICA was obtained by a balloon microcatheter placed in the cervical portion of the ICA before craniotomy, allowing for retrograde suction decompression if necessary. The aneurysm was isolated and clipped using standard microsurgical techniques. Incision of the falciform ligament, partial unroofing of the optic canal, and removal of

the anterior clinoid process facilitated atraumatic manipulation and decompression of optic pathway structures.[23]

Endovascular techniques

All interventional procedures were performed using standard techniques with Guglielmi-detachable-coils (Boston Scientific, Fremont, California), including soft and three dimensional coils. Balloon remodeling techniques were used when indicated.[24] Due to mandatory antiplatelet medication, stent-assisted coiling was not performed in the acute post-SAH period. Two aneurysm recurrences were treated later using stent-assisted reemboization (Neuroform, Boston Scientific, Fremont, California).

Angiographic follow-up

All surgical patients underwent intraoperative angiography. Angiographic follow-up examinations were obtained 6 months and 1-2 years after the intervention. The aneurysms were stratified according to Roy (total occlusion, residual neck, residual aneurysm).[8]

Clinical follow-up

Procedure-related morbidity was defined as any permanent deficit related to treatment. At the final follow-up the overall morbidity/mortality, the Glasgow Outcome Scale (GOS) score and neurological deficits were evaluated. Postinterventional visual field deficits were classified as new deficits according to the patients' statements assuming the aneurysms being asymptomatic before acute SAH.

Statistics

Statistical analysis was performed using SAS 8.02 (SAS Institute Inc., Cary, NC) performing the Mann-Whitney test to compare continuous variables and the Fisher's exact test to compare nominal variables. Data are presented as mean±SD. A p-value <0.05 was considered significant.

RESULTS

Patient Demographics

The female/male ratio was 54/10. The mean patient age was 59.5±11.3 years. Twenty-six patients (40.6%) presented with multiple aneurysms. Twenty-eight patients (43.8%) suffered acute post-hemorrhagic hydrocephalus requiring external ventricular drainages. The interval from SAH to treatment was 3.5±11.5 days. The surgical and endovascular treatment groups were matched for admission Hunt&Hess and Fisher CT grades (Table 1), gender, age, incidence of acute posthemorrhagic hydrocephalus and time interval from SAH to first treatment.

Table 1. Hunt & Hess grades, Fisher grades

Hunt&Hess/ Fisher Grades	embo n= 38 (H&H / F)	Surgery n=23 (H&H / F)	combined n=3 (H&H / F)	total n=64 (H&H / F)
1	10 / 6	6 / 0	1 / 0	17 / 6
2	15 / 10	8 / 6	2 / 3	25 / 19
3	3 / 15	4 / 11	0 / 0	7 / 26
4	6 / 7	3 / 6	0 / 0	9 / 13
5	4	2	0	6

H&H=Hunt and Hess, F=Fisher; emb=embolization, bypass= parent artery occlusion with/without bypass-protection

Aneurysm characteristics

The average aneurysm fundus size was $13\pm 9.3\text{mm}$. The average aneurysm neck size was $3.9\pm 2.1\text{mm}$ (Table 2). Statistical analysis disclosed a significant relation between patient age and aneurysm size ($p<0.01$). When compared to other aneurysm locations, the incidence of ruptured narrow necked aneurysms was significantly higher in superior hypophyseal aneurysm location ($p<0.05$).

Table 2. Aneurysm location, aneurysm size and neck-width

Aneurysm location	embo		surgery		bypass		total n=64	
	N=38		n=23		n=3			
	Size	neck	size	neck	size	neck	size	neck
	s / l / g	n / w	s / l / g	n / w	s / l / g	n / w	s / l / g	n / w
ophthalmic (56.3%)	6/ 9/ 3	13/ 5	5/ 8/ 3	3/ 13	2/ 0/ 0	2/ 0	13/18/ 5	18/ 18
sup. hypophyseal (21.9%)	9/ 0/ 2	10/ 1	2/ 1/ 0	2/ 1	0/ 0/ 0	0/ 0	11/ 1/ 2	12/ 2
carotid cave (4.7%)	1/ 1/ 0	2/ 0	1/ 0/ 0	0/ 1	0/ 0/ 0	0/ 0	2/ 1/ 0	2/ 1
post. carotid wall (14.1%)	5/ 1/ 0	4/ 2	1/ 1/ 0	1/ 1	0/ 1/ 0	0/ 1	6/ 3/ 0	5/ 4
transitional (3.1%)	0/ 1/ 0	1/ 0	0/ 1/ 0	1/ 0	0/ 0/ 0	0/ 0	0/ 2/ 0	2/ 0

embo=embolization, bypass=parent artery occlusion with/without bypass-protection;

size: s=small, l=large, g=giant; neck: n=narrow, w=wide

Treatment

Twenty-three patients (35.9%) underwent microsurgical clipping, including all 15 patients harboring ophthalmic aneurysms directly involving the ophthalmic artery. 38 patients (59.4%) underwent endovascular embolization, including 8 wide necked

aneurysms embolized with balloon remodeling technique. 3 patients (4.7%) required parent artery occlusion under bypass-protection beyond the acute SAH period and after BOT: 2 patients had small ophthalmic aneurysms at the anterior ICA wall at non-branching sites suspicious of blood blister-like aneurysms, whereas in the third patient with a large posterior carotid wall aneurysm, a wide and calcified neck precluded surgical and endovascular treatment in the acute post-SAH period.

Retreatment

Retreatment for insufficiently obliterated aneurysms was required in 8.7% of the surgical vs. 31.6% of the endovascular group, this difference nearly reaching statistical significance ($p < 0.1$). In 2 out of 23 microsurgical patients (8.7%) subsequent follow-up angiographies disclosed residual aneurysms. Both patients underwent successful and stable endovascular treatment after 3 and 7 months, respectively. In 12 out of 38 endovascular patients (31.6%) aneurysm recanalization required retreatment. Of these, 9 aneurysms were reembolized 2 weeks up to 46 months after the first embolization. 2 aneurysms were retreated with stent-assisted reembolization 25 and 61 months after the first treatment. One aneurysm was reoperated 5 months after the first embolization. In all retreated cases we observed only 1 adverse event during early endovascular reembolization.

Complications

There were 3 patients in the surgical subgroup with intraoperative aneurysm rupture (13%) and 2 endovascular patients with postinterventional aneurysm rebleedings (5.2%). New post-therapeutic permanent visual field and acuity deficits were seen in 1 surgical patient (4.4%) and 2 endovascular patients (5.3%).

Permanent procedure-related morbidity and mortality

Of altogether 2 patients (8.7%) in surgical subgroup, 1 patient with a large transitional aneurysm had permanent hemiparesis and aphasia after a thromboembolic event during aneurysm clipping of the atheromatous neck. Another patient with a small blood blister-like ophthalmic aneurysm at the anterior ICA wall suffered from visual field deficits due to intraoperative manipulation of optic pathway structures and 9 minutes temporary balloon-occlusion of the ICA caused by intraoperative aneurysm rupture. (Table 3)

Table 3. Procedure-related morbidity and mortality

	Embo	surgery	bypass	total
procedure-related	n=38	n=23	n=3	n=64
permanent morbidity	2 (5.3%)	2 (8.7%)	0	4 (6.3%)
mortality	1 (2.6%)	0	0	1 (1.6%)

embo=embolization, bypass=parent artery occlusion with/without bypass-protection

Of the 2 patients (5.3%) with permanent procedure-related complications in the endovascular group, one poor H&H grade patient suffered a rebleeding from a partially coiled (50% occlusion) large posterior carotid wall aneurysm 7 days after the initial treatment. This patient was successfully reembolized 2 weeks after the initial hemorrhage but still presents with hemiparesis due to severe vasospasm and visual acuity deficits due to a thromboembolic event at the second intervention. In the second patient with severe internal comorbidities, embolization of a giant ophthalmic

aneurysm resulted in increased aneurismal mass effect and optic nerve compression with consecutive visual field and acuity deficits.

One poor H&H grade and cardiorespiratory unstable patient, thus unsuitable for operation, with a large ophthalmic aneurysm suffered a fatal rebleeding 2 days after a palliative partial embolization with about 30% aneurysm occlusion (2.6% mortality). There were no intraoperative aneurysm perforations during endovascular coil embolization in this series.

Clinical outcome

The overall management morbidity, including the aforementioned procedure-related morbidities, was 26.6%. There were 5 deaths (2 surgical vs. 3 endovascular patients (including 1 endovascular procedure related death), $p>0.05$) in this series, resulting in 7.8% overall mortality. (Table 4)

Table 4. Final GOS grades

final GOS	embo n=38	surgery n=23	bypass n=3	total n=64
5	23 (60.5%)	6 (26.1%)	2 (66.6%)	31 (48.4%)
4	6 (15.8%)	10 (43.5%)	0	16 (25.0%)
3	4 (10.5%)	4 (17.4%)	1 (33.3%)	9 (14.1%)
2	2 (5.3%)	1 (4.3%)	0	3 (4.7%)
1	3 (7.9%)	2 (8.7%)	0	5 (7.8%)

After a clinical follow-up time of 58.7±47.6 months, 73.4% of the total population reached GOS 4-5, with significantly more endovascular patients reaching a GOS grade 5 when compared to surgery ($p<0.05$). One patient (2.6%) in the endovascular vs. 4 patients (17.4%) in the surgical subgroup suffered from shunt dependent posthemorrhagic hydrocephalus, this difference nearly reaching statistical significance ($p<0.1$).

Final angiographic outcome

The final angiographic follow-up time was 29.2±31.9 months (Table 5). Final angiography demonstrated total aneurysm occlusion in 94.4% of the surgical vs. 82.9% of the endovascular patients ($p>0.05$). (Figure 2)

Table 5. Initial and final angiographic results

	Embo n=38		surgery n=23		total n=61	
	initial DSA n=38	final DSA n=35	initial DSA n=23	final DSA n=18	initial DSA n=61	final DSA n=53
total occlusion	29 (76.3%)	29 (82.9%)	21 (91.3%)	17 (94.4%)	50 (82.0%)	46 (86.8%)
residual neck	7 (18.4%)	5 (14.3%)	1 (4.3%)	1 (5.6%)	8 (13.1%)	6 (11.3%)
residual aneurysm	2 (5.3%)	1 (2.8%)	1 (4.3%)	0	3 (4.9%)	1 (1.9%)

In the surgical subgroup, 18 out of 23 patients (85.7%) were available for angiographic follow-up; of these, one patient (5.6%) harboring a giant ophthalmic artery aneurysm had a small residual neck. In the endovascular subgroup, all 35 patients received follow-up angiography. Aneurysmal neck remnants were identified in 5 patients (14.3%): 2 large and 1 giant ophthalmic artery aneurysm and 2 giant superior hypophyseal aneurysms. In 1 patient (2.8%) of the endovascular subgroup with a giant ophthalmic artery aneurysm, final angiographic follow-up disclosed a residual aneurysm.

DISCUSSION

Treatment selection

Microsurgical clipping

Indications for surgery were:

1) Superior aneurysm projection: These lesions are surgically easier to expose than other C6 aneurysms.[14] Additionally, it was shown for unruptured aneurysms that microsurgical clipping of superior projecting aneurysms results in far higher rates of stable aneurysm occlusion (80-90%) as compared to endovascular therapy (50%).[15] Ihara et al. also found considerable higher rates of 20% endovascular cerebral thromboembolic events **in this subgroup** (including ophthalmic aneurysms involving the ophthalmic artery). To avoid these thromboembolic events in the present series, all 15 lesions underwent microsurgery, resulting in no thromboembolic events. **So we favor surgery for this subgroup.** (Table 6)

Table 6. Literature review: follow-up-times, procedure related and overall morbidity/mortality, clinical and angiographic outcomes

	N=patients	clinical follow-up time	procedure related		Overall		good/very good outcome	angiographic total occlusion
			permanent morbidity	Mortality	permanent morbidity	mortality		
Surgery	total/ruptured	months	permanent morbidity	Mortality	permanent morbidity	mortality	GOS 4-5 mRS 0-2	% of patients
Dolenc et al. 99 (10)	143 / 73	-	4.4%	-	7.2%	1.4%	69.5%	-
Raco et al. 08 (29)	104/73	126 mo	5.8%	3.8%	-	-	82.6%	93.2%
Batjer et al. 94 (3)	89 / 39	2 mo	-	-	3%	1%	86.5%	-
Khan et al. 05 (21)	81 / 53	3 mo	13.7%	-	26%	8.7%	60.8%	94.5%
Barami et al. 03 (2)	61 / 14	6 mo	8%	-	14.3%	8.6%	93%	-
Fries et al. 97 (13)	58 / 14	72 mo	-	5.8%	6%	15%	75%	-
Endovascular	total/ruptured	months	permanent morbidity	Mortality	permanent morbidity	mortality	GOS 4-5 mRS 0-2	% of patients
Park et al. 03 (28)	73 / 8	14.4 mo	8.3%	-	9.9%	6.3%	88.9%	72.6%
Thornton et al. 00 (32)	71 / 17	-	3.3%	0%	4.2%	2.2%	-	54%
Roy et al. 97 (30)	28 / 8	24 mo	3.6%	0%	-	10.7%	78.6%	50%
Multidisciplinary	total/ruptured (embo/surg/bypass)	months	permanent morbidity embo/surg	mortality embo/surg	permanent morbidity embo/surg	mortality embo/surg	GOS 4_5 mRS 0-2 embo/surg	% of patients embo/surg
Hoh et al. 01 (18)	238 / 59 (57/180/1)	-	3%, 6%	0%, 2%	22%, 8%	4%, 3%	90%, 74%	44%, 94%
Ihara et al. 03 (20)	112 / 0 (77/34/1)	-	2.6%, 11.5%	-	2.9%, 6.5%	-	-	50-74%, 73%
Boet et al. 05 (7)	18 / - (11/7/-)	-	-	-	-, -	6.6%, 16.6%	-	53%, 87.5%
Sherif et al. 08	64 / 64 (38/23/3)	58.7 mo	5.2%, 8.7%	1.5%, 0%	21.1%, 34.8%	7.9%, 8.6%	76%, 69%	82.9%, 94.4%

2) Aneurysms at branching sites: To avoid the high rates of the above mentioned thromboembolic events, interventional neurosurgeons or neuroradiologists of endovascular series tend to partially embolize aneurysms at branching sites.[11, 15] To avoid this partial embolization we clipped all 15 ophthalmic aneurysm with involvement of the ophthalmic artery. This strategy resulted in a 100% rate of total aneurysm occlusion. Endovascular series reached considerable lower rates of total aneurysm occlusion, e.g. 72% in the series of Park et al..[11] These data demonstrate the superiority of surgery for these aneurysms with respect to parent vessel preservation and total aneurysm occlusion.

3) Giant/large aneurysms: Endovascular series focusing on large/giant unruptured C6 aneurysms reported total aneurysm occlusion rates from 33% [11] to 60% [25] vs. rates of about 80%-90% of total aneurysm occlusion in surgical series.[6, 14, 25] The results of the present series corroborate these data also for ruptured lesions. Whereas only 1 of 3 surgically treated giant aneurysms (33%) showed a residual neck at final angiography, 3 out of 5 embolized giant aneurysms (60%) had neck remnants. So surgery should be performed for these lesions whenever possible.

4) Wide aneurysm neck: Lesions with wide necks have potential higher endovascular therapy risks of thromboembolic events due to coil protrusion into the parent arteries. To overcome this limitation new endovascular techniques such as stent-assisted coiling or balloon remodeling have been developed. But in acute SAH period stent-assisted coil embolization is problematic, since double antiplatelet therapy is recommended and adjunctive surgical procedures, i.e. placement of EVDs or ICP probes, may be associated with hemorrhagic complications. Alternatively, balloon remodeling may provide appropriate neck bridging during coil embolization in

selected cases.[26] From 2002 on, we applied balloon remodeling techniques resulting in residual aneurysm necks in 4 of 8 cases (50%). Microsurgical clipping of wide necked aneurysms resulted in total aneurysm occlusion in 15 out of 16 lesions (94%). We now clearly favor surgery for wide necked aneurysms.

Endovascular embolization

Indications for endovascular embolization were:

1) Narrow aneurysm necks: Embolization of narrow necked aneurysms led to higher rates of stable aneurysm occlusion of nearly 80% vs. wide necked aneurysms with only 9% in the series of Roy et al.[8] In the present series we found significantly more narrow necked aneurysms at superior hypophyseal location as compared to the other aneurysm locations. In the present series 11 of 14 superior hypophyseal aneurysms (79%) underwent embolization. All aneurysms showed total aneurysm occlusion at final follow-up. Therefore embolization can be recommended for narrow necked aneurysms at non-branching sites.

2) Aneurysm location in the concavity of the carotid siphon curve: These locations facilitate catheterization as the microcatheter can be easily navigated into the aneurysm.[8] Additionally these aneurysms often project inferiorly or medially and are microsurgically more difficult to expose. In the present study 20 out of 27 aneurysm (74%) at carotid cave, superior hypophyseal and posterior carotid wall locations underwent embolization. From these, only 1 patient with a large posterior carotid wall aneurysm suffered from procedure-related permanent morbidity (visual field deficits due to a thromboembolic event). At final angiographic follow-up all small and large lesions showed 100% aneurysm occlusion. Therefore embolization can be recommended for aneurysms in this location.

3) Factors related to expected surgical difficulties (aneurysm neck calcification, close aneurysm relation to the clinoid process, aneurysm adhesion to the distal dural ring): To identify these factors, in all patients a thin section CT and a CT-angiography with 3 dimensional reconstructions was performed. Due to clipping of the atheromatous aneurysm neck 1 patient with a large transitional aneurysm suffered a thromboembolic event with permanent hemiparesis and aphasia. This case with indications for surgery (wide neck, large aneurysm) and against surgery (calcified neck, transitional location) demonstrates the difficulty of decision making in single cases. Learning from this negative experience, the next comparable case (large posterior carotid wall aneurysm, wide and calcified neck) was then objected to endovascular parent artery occlusion under bypass protection, resulting in very good clinical outcome.

Endovascular parent artery occlusion with/without bypass protection

Endovascular parent artery occlusion with/without bypass-protection was reserved for the management of lesions with high potential risks for both surgery and embolization. These risks of direct treatment had to be potentially higher than the risk of spontaneous rerupture before indirect treatment beyond the vasospasm phase. After preoperative BOT, 3 patients in the present series received arterial low-flow bypasses providing satisfactory collateral flow. In 2 cases angiography showed small ophthalmic aneurysms at non-branching sites of the anterior ICA wall suspicious of being blood blister-like aneurysms. **As pointed out by Charbel et al. [27] direct treatment of this lesions seems hazardous due to the high risk of endovascular as well as intraoperative aneurysm rupture of up to 54%.[28]** Also in our series the only microsurgically clipped blood blister-like aneurysm ruptured intraoperatively. As feasibility and efficacy of bypass-surgery for ruptured aneurysms was already shown

by several authors [29, 30] we changed our strategy to parent artery occlusion with/without bypass protection for lesions being suspicious of blood blister-like aneurysms with favourable results in the following 2 cases.

Complications

Aneurysm rebleedings

We observed 2 early rebleedings (5.2%) after partial embolization (30-50% occlusion rate) in poor H&H grade patients with significant internal comorbidities precluding microsurgical clipping. This 5.2% rebleeding rate in the endovascular subgroup of our series is relatively high when compared to the ISAT data reporting 1.8% rebleeding within 30 days of treatment demonstrating the aggressiveness of these lesions.[31] So we tried to achieve higher partial occlusion rates of about 60-75% also for palliative embolization. This strategy was technically feasible and resulted in no more rebleedings in the following 3 comparable cases.

Visual field and acuity deficits

Assuming that all patients had had asymptomatic aneurysms before SAH, one surgical patient (4.4%) and 2 endovascular patients (5.8%) suffered from new posttherapeutic permanent visual deficits. These findings are within the range of previous surgical (0-2.7%) [32, 33] and endovascular series (1.3-2.2%) [11, 12] focusing on unruptured aneurysms. In 1 microsurgical patient (small blood blister-like ophthalmic aneurysm) intraoperative aneurysm rupture resulted in temporary ICA trapping and intraoperative manipulation of optic pathway. This manipulation is known to be the main reason for postoperative new visual deficits in surgical series.[6, 14, 17, 34]

From the 2 endovascular patients with visual field deficits, 1 patient (large posterior carotid wall aneurysm) suffered from a thromboembolic event. To minimize further thromboembolic events, patients with large and giant aneurysms were then objected to microsurgery whenever possible. The second endovascular patient (giant non-branching ophthalmic aneurysm) showed postinterventional slowly progressive visual worsening due to the coil mass effect with optic pathway compression. So 1 of 3 endovascular patients with giant ophthalmic aneurysms had permanent visual field deficits vs. no new visual deficits in the corresponding microsurgical subgroup. Comparably, Heran et al. described worsening of visual deficits following endovascular therapy of unruptured large/giant C6 aneurysms in 25%.[26]

Clinical outcome

After a mean clinical follow-up period of 58.7 ± 47.6 months, 73.8% of our patients enjoyed excellent and good GOS outcomes (Table 5). These results are comparable with the ISAT outcome data at one year follow-up with excellent and good outcomes in 72.8% (surgery 69.1% vs. embolisation 76.5%).[31] Significantly more endovascular patients reached GOS grade 5 in this series when compared to surgery. Our overall morbidity including procedure-related morbidity was 26.6%. Overall mortality reached 7.8%, without mortality in patients with initial H&H grades 1-3. Again, these results are nearly within the range of the ISAT one year follow-up outcome data (18.2% morbidity (mRS 3-5); 9% mortality). Thus the presented concept based on clearly predefined therapy indications showed that even ruptured C6 aneurysms- supposed to be very aggressive lesions- can be treated with the same low morbidity and mortality rates as other ruptured anterior circulation aneurysms.[31] Interestingly, at final follow-up altogether 1 endovascular patient (2.6%) vs. 4 surgical patients (17.4%) suffered from shunt dependent post-

hemorrhagic hydrocephalus, this difference nearly reaching statistical significance ($p < 0.1$).

Angiographic outcome

After a mean follow-up period of 29.2 ± 31.9 months, angiography demonstrated permanent total aneurysm occlusion in 94.4% of the surgical vs. 82.9% of the endovascular patients. Whereas the surgical occlusion-rate concurs with the results of previous series, the endovascular rate of total aneurysm occlusion is considerably higher than that reported in the majority of recent endovascular (50-72%) and multidisciplinary (44-66%) series (Table 6). **This favourable outcome may reflect** the defined treatment selection together with the progress of endovascular techniques. It should be pointed out that the considerably higher reintervention rate in the endovascular group (31.6% endovascular vs. 8.7% surgery) did not all adversely affect the final clinical outcome.

LIMITATIONS

The present study is not a prospective randomised comparative study. The decision on the treatment strategy was based on experience.

CONCLUSIONS

Based on favorable ophthalmologic and neuroradiologic outcomes, surgery can be recommended as first-line treatment for superiorly projecting aneurysms - especially for aneurysms involving the ophthalmic artery - and for giant/large or wide necked aneurysms. Based on stable aneurysm occlusion and excellent clinical outcomes, endovascular embolization can be recommended for inferiorly or medially projecting small and narrow necked aneurysms in the concavity of the carotid siphon curve. Endovascular parent artery occlusion with/without bypass protection beyond the vasospasm phase can be recommended for all cases with higher anticipated direct treatment risks as compared to the risks of early spontaneous rerupture before indirect treatment.

COMPETING INTERESTS

No author has any personal or institutional competing interests in drugs, materials, or devices described in this submission.

FUNDING

There were no grants pertinent to the paper.

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APPENDICES

Figure legends

Figure 1. Frequency of location of 64 C6 aneurysms (schematic anterolateral view):

1- ophthalmic artery aneurysms 56.3%; 2- superior hypophyseal aneurysms 21.9%; 3- posterior carotid wall aneurysms 14.1%; 4- carotid cave aneurysms (normally projecting medially; in this schematic figure lateral to ICA for better visualization) 4.7%; 5- transitional aneurysms 3.1%;

ICA=internal carotid artery, Opht A=ophthalmic artery, Ant Chor A=anterior choroidal artery, PCom=posterior communicating artery

Figure 2. Illustrative cases: a,b) Giant ophthalmic aneurysm objected to clipping b) final follow-up angiography documenting total aneurysm occlusion and patent parent arteries c,d) Small sized, narrow necked ophthalmic aneurysm (A) at a non-branching site, objected to embolization due to favorable aneurysm morphology and significant internal co-morbidities of the patient. d) Final follow-up angiography documenting total aneurysm occlusion and patent ophthalmic artery.



