Giant and Very Large Intracranial Aneurysms: Surgical Strategies and Special Issues

Sabino Luzzi, Massimo Gallieni, Mattia Del Maestro, Donatella Trovarelli, Alessandro Ricci, and Renato Galzio

Abstract Giant intracranial aneurysms (GIAs) and very large intracranial aneurysms (VLAs) have a poor natural history because of a high incidence of bleeding and strokes. These lesions always represent a great challenge for neurosurgeons and interventional neuroradiologists because of some peculiar intrinsic features such as size, angioarchitecture, wide neck, mass effect, intraluminal thrombosis, atherosclerotic changes, involvement of branches and perforators, and a frequent need to perform revascularization procedures. The results of a cumulative surgical series of 75 VLAs and GIAs are reported. Thirty-three aneurysms were unruptured. Sixty aneurysms underwent direct surgical treatment consisting of 56 direct clippings, 3 trappings w/o revascularization, and 1 wrapping. Fifteen aneurysms were treated by means of extracranial to intracranial (EC-IC) high-flow bypass. An mRS score ranging between 0 and 2 was observed in 54 patients, whereas an mRS of 3 was seen in 5 patients. Four patients had a severe disability (mRS 4–5) and six patients died. Aneurysm's fragmentation, with stacking and seating clips, thrombectomy, and aneurysmorrhaphy were the techniques most frequently employed. Revascularization options involving EC-IC high-flow bypass were used in cases not amenable for direct treatment. Some technical tips and special issues related to the surgical management of these complex lesions are discussed.

Keywords Intracranial aneurysms · Giant intracranial aneurysms · Clipping · By-pass surgery · Revascularization techniques · Subarachnoid hemorrhage

S. Luzzi, M.D. · A. Ricci, M.D.
Department of Neurosurgery, San Salvatore City Hospital, L'Aquila, Italy

M. Gallieni, M.D. (✉) · M. Del Maestro, M.D.
Department of Life, Health and Environmental Sciences (MESVA), University of L'Aquila, L'Aquila, Italy

D. Trovarelli, M.D.
Department of Anesthesiology, San Salvatore City Hospital, L'Aquila, Italy

R. Galzio, M.D.
Department of Neurosurgery, San Salvatore City Hospital, L'Aquila, Italy

Department of Life, Health and Environmental Sciences (MESVA), University of L'Aquila, L'Aquila, Italy

Introduction

Despite the tremendous advances in the understanding of their pathophysiology and surgical management, GIAs (giant intracranial aneurysms) and VLAs (very large intracranial aneurysms) still remain among the most demanding challenges for both the neurosurgeon and the interventional neuroradiologist. In their classical definition, GIAs have at least one diameter larger than 2.5 cm, with an irregular geometric configuration and a broad neck. GIAs often incorporate efferent vessels and have thick arachnoid adhesion to the surrounding structures. A massive intraluminal thrombosis is often present with atherosclerotic changes frequently involving the sac, the neck, and even the parent artery. Although theoretically the flow pulsatility may also produce a progressive enlargement of the smaller aneurysms that may become giant [1], recently GIAs formation and enlargement have proved to be completely different from those of the smaller aneurysms. Indeed, they seem to be related to a massive degeneration of the elastic lamina with a lack of the muscular layer caused by repeated sub-adventitial hemorrhages by vasa vasorum. Therefore, GIAs should be considered as a "*proliferative disease of the vessel wall induced by extravascular activity*" [2]. Regarding the intraluminal thrombosis, it occurs in approximately 60% of cases and is strictly related to the high turbulence of the jet flow. Compared with that of the smaller ones, the natural history of GIAs is extremely dismal because of their higher tendency to bleed and a higher incidence of related strokes, with consequent severe disability and death ultimately. The estimated risk of rupture is six

https://doi.org/10.1007/978-3-319-73739-3_4,

times higher for GIAs, and a mortality rate at 2 years greater than 60% has been reported for those untreated [3, 4]. All these intrinsic features, as well as the mass effect they cause to the neighboring neurovascular structures, make VLAs and GIAs a specific subset of lesions where an aggressive treatment must be considered mandatory, as reported in a large series of publications [5–13]. Although endovascular techniques, especially with the advent of flow-diverters, flow-disruptors, and stents, are increasing their efficacy, microneurosurgery still remains the unique curative option for most of these aneurysms, especially for those with a complex angioarchitecture, involvement of efferent branches, and a massive intraluminal thrombosis. Furthermore, microsurgery is the only treatment option possible in all cases where a revascularization procedure is need.

The aim of this retrospective study is to report the decision-making process, the surgical strategies, and the special issues related to the management of VLAs and GIAs in a personal series of 75 aneurysms consecutively treated.

Materials and Methods

Between 2000 and 2015, a cohort of 428 patients, harboring 510 intracranial aneurysms, was surgically treated by the senior author (R.G.). Among these, 75 VLAs and GIAs aneurysms in 71 patients were selected and retrospectively analyzed. A further 31 VLAs (n. 19) and GIAs (n. 12), were treated by endovascular techniques. In the surgical series, 41 patients were females and 30 were males, with ages ranging between 14 and 80 years (mean 53 years). Forty-eight patients suffered from hypertension, 34 from diabetes, 16 from hypercholesterolemia, and 14 from obesity. Twenty-seven patients were smokers. In two patients, a familiar history of aneurysms was found. Fifty-six aneurysms (74.67%) were located in the anterior circle, whereas the remaining 19 (25.33%) involved the posterior circulation (Table 1). Thirty-eight aneurysms presented with a subarachnoid hemorrhage (SAH) and 33 were taken into charge to our Department because of incidental findings or symptoms attributable to the mass effect or stroke. Cranial nerve neuropathies were observed in nine patients, three with an internal carotid artery (ICA) posterior wall giant aneurysm (all with a third cranial nerve palsy). The remaining six patients suffered from a third to sixth cranial nerve impairment in various combinations. All the elective patients underwent 3D CT angiography; T1 and T2 weighted MRI, to reveal an eventual intra-aneurysmal thrombus, and six-vessels brain digital subtraction angiography (DSA) with 3D volume rendering. A detailed study of both superficial temporal artery (STA) and occipital artery (OA) was carried out in all cases where a revascularization procedure was planned or presumed. STAs and OAs larger than 3 mm were considered as suitable

Table 1 Description of aneurysms site, clinical onset, and surgical methods of treatment

			Clinical onset		Surgical methods of treatment				
Aneurysms site		No.	SAH	Not SAH	Clipping	Wrapping	Trapping	Trapping + EC-IC	EC-IC
Anterior circulation	Intracavernous ICA	6	0	6	0	0	0	6	0
	Para-clinoidal ICA	5	4	1	4	1	0	0	0
	ICA-ophthalmic	12	6	6	11	0	0	1	0
	ICA siphon	9	5	4	4	0	1	4	0
	ICA bifurcation	5	3	2	5	0	0	0	0
	MCA	13	7	6	11	0	0	2	0
	ACA/ACoA	5	4	1	5	0	0	0	0
	ACA2	1	1	0	1	0	0	0	0
Posterior circulation	PCA (P2-P3)	3	1	2	2	0	1	0	0
	PCA (P1-P2)	1	0	1	0	0	0	0	1
	BA tip	5	4	1	5	0	0	0	0
	BA/SCA	2	2	0	2	0	0	0	0
	BA/AICA	1	1	0	1	0	0	0	0
	AICA (proximal)	1	0	1	0	0	1	0	0
	VBJ	1	1	0	1	0	0	0	0
	VA/PICA	2	1	1	2	0	0	0	0
	Distal PICA	2	2	0	2	0	0	0	0
	VA	1	0	1	0	0	0	1	0
Total		75	42	33	56	1	3	14	1

potential donors for selected cases where the putative need for a revascularization of a distal middle cerebral artery (MCA) or posterior cerebral artery (PCA) branches might be anticipated. Moreover, in those cases where a high flow bypass was planned, the Allen test was performed in both forearms to evaluate the suitability of the radial artery as conduit. Both saphenous veins and radial arteries were traced with Doppler sonography in these cases. In all cases of aneurysms involving ICA, balloon test occlusion (BTO) was performed. For BTO, occlusion of the ICA was performed as near as possible to the aneurysms by means of a 5 Fr balloon inflated for 10 min in the first step, after which the patient was neurologically evaluated and underwent DSA. In all the cases where the patient passed the first step, an intravenous administration of labetalol (200 mL; 1 mg/mL in 2 min) was given to decrease the mean arterial pressure to a level of 20% of the baseline. The patient was then evaluated for a further 20 min and, after the induction of the relative hypotension, a final angiogram was performed. Additionally, in all the elective cases, a preoperative neurophysiological baseline assessment was performed based upon trans cranial motor-evoked potentials (TES-MEPs), somatosensory-evoked potentials (SSEPs), and brainstem-evoked potential (BAEPs), the latter only for posterior circulation aneurysms. Computerized visual field evaluation and hormonal assessment were decided case by case according to the site of the lesion. All the patients with ruptured aneurysms underwent 3D CT angiography and DSA. In selected hemorrhagic cases, MRI ruled out an intra-aneurysmal partial thrombosis.

Results

Sixty aneurysms were judged suitable for direct surgical treatment. In the remaining 15 aneurysms, a flow replacement of the parent artery or a branch was needed. In the surgical cases, the pterional trans-sylvan was the most used approach for the anterior circulation aneurysms. As a general rule, a wide drilling of the superior aspect of the greater sphenoid wing with or w/o anterior clinoidectomy, as well as a wide opening of the sylvian fissure (extended pterional approach), allowed one to maximize the exposure of the sac and to shallow the surgical field for most of the GIAs. More complex antero-lateral approaches were performed in selected cases. A cranio-orbitary approach, sometimes involving the mobilization of the zygomatic arch (fronto-temporo-orbito-zygomatic FTOZ approach), was performed in selected cases of giant superior or superior-posterior projecting anterior communicating (ACoA) aneurysms and high riding basilar top aneurysms. An intradural, rather than extradural, anterior clinoidectomy was performed when needed, especially in selected cases of ICA-ophthalmic aneurysms. The Sonopet ultrasonic aspirator (Stryker Portage, MI, USA) was frequently employed for this purpose to avoid any thermal injury to the optic nerve. Distal A2-pericallosal aneurysms were approached by an anterior interhemispheric route. P2-P3 PCA aneurysms were treated through a subtemporal transtentorial approach, whereas a case of a giant P1-P2 aneurysm was approached via an extended pterional approach with a trans-sylvan and pre-temporal combined access route. All the high-riding basilar top aneurysms were approached by an FTOZ approach involving a wide opening of the sylvan fissure. A posterior transcavernous clinoidectomy was performed in two cases of low-riding and superior-posterior projecting basilar top aneurysms. A combined supra-infratentorial transtentorial route was employed for mid-basilar trunk aneurysms. In only one case of very large low basilar aneurysm was a pure posterior petrosectomy, involving a retrolabyrinthine exposure, performed. A retrosigmoid approach was rarely used to clip distal very large superior cerebellar artery (SCA), anterior inferior cerebellar artery (AICA), and posterior inferior cerebellar artery (PICA) aneurysms. The postero-lateral far lateral approach proved to be very useful for the treatment of vertebro-basilar junction aneurysms and proximal PICA aneurysm. In a rare case of a distal very large PICA aneurysm, a suboccipital craniotomy was performed. A direct clipping was possible in most cases (56 aneurysms). A stacking and seating technique was used with most GIAs. In 21 aneurysms, an intra-aneurysmal thrombectomy was performed to reconstruct the profile of the parent vessel and definitively clip the aneurysms at the neck. Frequently, for ICA-posterior communicating artery (PCoA) aneurysms, multiple fenestrated clips were used to draw a clip line at the level of the posterior wall of the ICA, at the same time sparing PCoA, anterior choroidal artery (AChA), and perforating branches. Temporary occlusion of the parent artery was necessary in some cases of giant MCA bifurcation or trifurcation aneurysms. Temporary clipping was also applied to dissect and reshape the sac in selected cases of ACoA GIAs. In these circumstances, temporary occlusion more frequently encountered a dominant A1. Seldom was a complete trapping of the ACoA necessary. Temporary clipping was always performed under propofol-induced burst suppression and EEG, SSEPs, and TES-MEPs neurophysiological monitoring. Simple trapping was done in three giant thrombosed ICA aneurysms where patients passed BTO. Wrapping with muscle was the only treatment possible in one aneurysm. Fifteen patients underwent a revascularization procedure. In eight of these, an extracranial to intracranial (EC-IC) high flow by-pass was performed before to trap the aneurysm, whereas high flow EC-IC by-pass was the only treatment performed for all the giant intracavernous aneurysms and a further giant P1-P2 PCA aneurysm (Table 1). Elective patient candidates for a high flow bypass started aspirin (325 mg/day)

Table 2 Overall data about revascularization procedures

Aneurysms site		No.	Surgical methods of treatment		Type of graft		Patent graft at last follow-up	
			Trapping + EC-IC	EC-IC	RAG	SVG	RAG	SVG
Anterior circulation	Intracavernous ICA	6	6	0	4	2	4	1
	ICA-ophthalmic	1	1	0	1	–	1	–
	ICA siphon	4	4	0	3	1	3	0
	MCA	2	2	0	1	1	1	1
Posterior circulation	PCA (P1-P2)	1	0	1	1	–	1	–
	VA	1	1	0	1	–	1	–
Total		15	14	1	11	4	11	2

Table 3 Overall patient outcome

Modified Rankin scale (mRS)	0–1	2	3	4–5	6
Hemorrhagic 38	22 (57.89%)	4 (10.53%)	3 (7.89%)	3 (7.89%)	6 (15.79%)
Not hemorrhagic 33	25 (75.75%)	3 (9.09%)	2 (6.06%)	1 (3.03%)	2 (6.06%)
Total patients 71	47 (66.20%)	7 (9.86%)	5 (7.05%)	4 (5.63%)	8 (11.27%)

the day before surgery at least, and continued for 6 months after surgery. A radial artery graft (RAG) was the conduit in 11 patients and the saphenous vein (SVG) in 4 cases. The overall rate of the graft patency was 86% (Table 2). Both during direct clipping and during revascularization procedures, the combination of intraoperative indocyanine green videoangiography (ICG), microdoppler ultrasound (MDU), and neurophysiological monitoring were paramount to check constantly the complete exclusion of the aneurysm, the adequacy of the flow into the parent artery, branches, perforators, and by-passes, as well as to recognize promptly any warning sign of ischemia in a real time modality. In five cases, a combined simultaneous endovascular and surgical treatment was performed. In no cases was a deep hypothermia adenosine-induced circulatory arrest considered necessary in the present series.

A good overall outcome (mRS 0–2) was achieved in 54 patients, 26 of whom suffered from an SAH. The best outcome was obtained in all the anterior circulation aneurysms and in eight aneurysms involving the posterior circle. A moderate disability (mRS 3) was seen in five patients, three of whom were hemorrhagic. Severe disability (mRS 4–5) was the final outcome in four patients and six patients died (Table 3).

Discussion

VLAs and GIAs are challenging lesions where an aggressive treatment must be consider mandatory because of their poor natural history and bad prognosis [3]. The complex decision-making process related to these aneurysms should always take into account factors such as patient age and co-morbidities, neurological status, Hunt–Hess and Fisher grades, aneurysm site and angioarchitecture, eventual intra-aneurysmal thrombosis, previous endovascular treatments, adequacy of cross-flow, caliber of PCoAs, BTO results, and the need for revascularization procedures. In the acute phase, endovascular treatment was reserved for older patients (age > 70 years) in severe neurological condition at admission (Hunt–Hess 4–5; Fisher 4). Except for these cases, an endovascular option was almost never considered for ruptured GIAs. The advent of pipeline embolization devices (PED) in the last few years has instead made a "first-line" endovascular approach more rational in selected elective cases of giant non-thrombosed aneurysms involving the intracavernous and paraclinoid ICA. Mid-basilar trunk large and fusiform non-thrombosed aneurysms were also considered as good candidates for flow diversion, as well as selected cases of basilar top aneurysms. Nevertheless, the DSA finding of a slow and turbulent flow into the aneurysm, with the consequent high likelihood of early thrombosis, was always considered a *conditio sine qua non* for flow diversion. Conversely, one of the most important exclusion criteria for the endovascular treatment was the presence of an intra-aneurysmal thrombus because of the related mass effect and the high incidence of strokes caused by distal embolization of atherosclerotic material. The literature reports a series of severe complications related to both balloon-assisted coiling and PED for GIAs [14]. The intrinsic features of a very complex angioarchitecture of these lesions, which frequently involves the need for a thrombectomy and a possible distal flow replacement, make microneurosurgery still the best treatment option today for most ruptured and unruptured

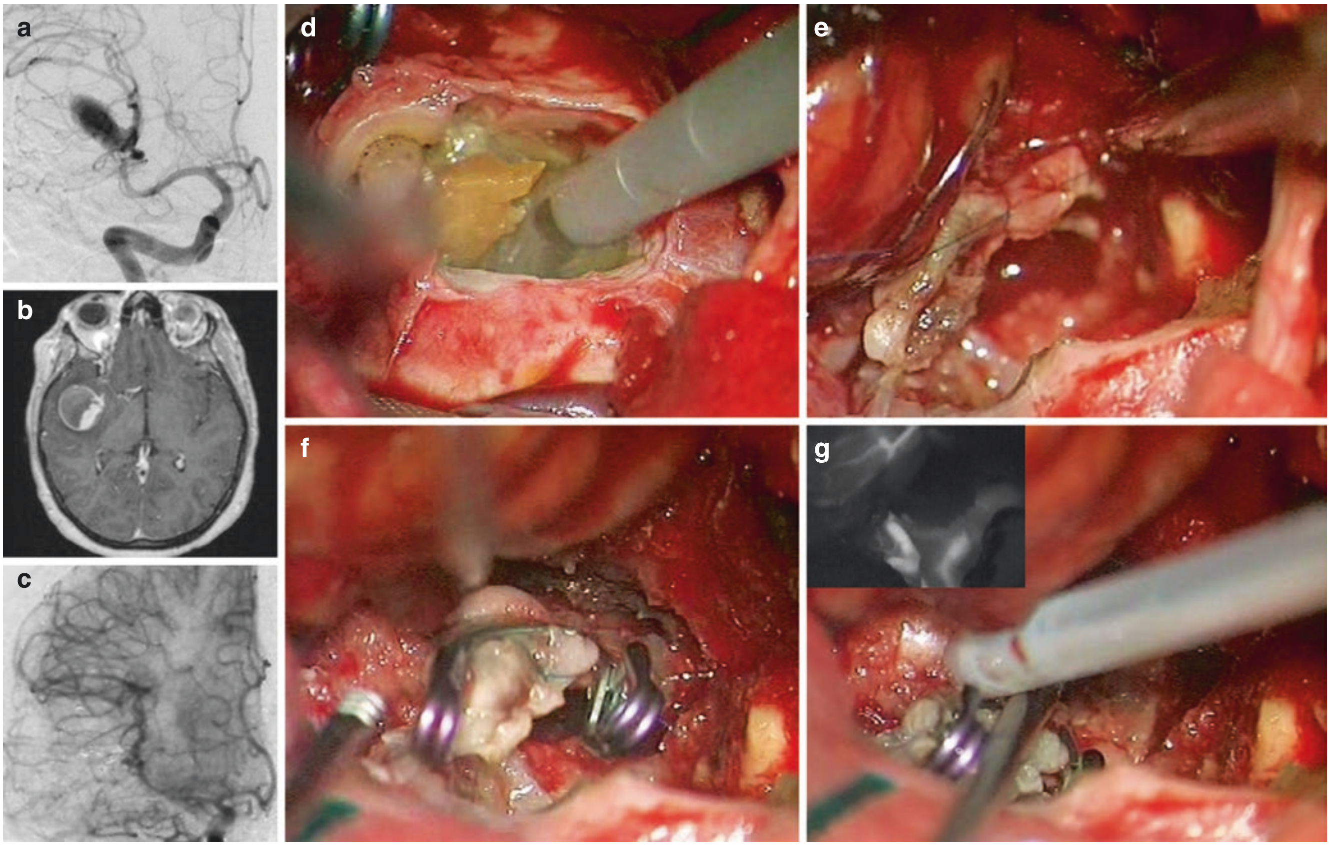

Fig. 1 Pre-operative DSA showing a very large partially thrombosed aneurysm of the right MCA (**a**). T1-weighted MRI showing intra-aneurysmal thrombus (**b**). Aneurysmal thrombectomy with ultrasonic aspirator (**d**). Aneurysmorraphy (**e**) with tandem clipping reinforcement (**f**). MDU and ICG flow check of the parent artery and branches (**g**). Post-operative DSA showing the complete exclusion of the aneurysm (**c**)

VLAs and GIAs. Angiographic and clinical results of the present series confirm that a direct treatment of the aneurysm is advisable whenever possible, whereas more complex revascularization procedures, stand-alone or associated with proximal ligation or trapping of the aneurysm, should be reserved for limited cases not amenable to direct clipping and burdened with mass effect. Technically, giant thrombosed aneurysms always require a deliberate opening of the sac, an intra-aneurysmal thrombectomy, and a subsequent aneurysmorrhaphy that is more often performed under proximal temporary clipping of the parent artery (Fig. 1). Seldom, and generally for distal ICA aneurysms in patients with a valuable contralateral cross-flow, a trapping of the parent artery is required during aneurysmorrhaphy. Even in burst suppression, SSEPs and BAEPs monitoring add paramount information to distinguish between those tolerated and those not tolerated by stop flow conditions. An important surgical tip during thrombectomy is always to check for a complete freeing of the proximal and distal parent artery ostium from the thrombus to dramatically decrease the risk of distal embolization of atherosclerotic material. A generous washing of the parent artery with heparin solution is recommended before aneurysmorrhaphy and before temporary clips release. Running suture with prolene or ethilon is generally used for aneurysmorrhaphy and, in most of conditions, a tandem clipping with angulated clips is performed to reinforce the site of the suture line. A constant intraoperatively check of the flow is elegantly obtained in these cases thanks to ICG and MDU. The stacking and seating technique with multiple clips is frequently employed to clip these aneurysms, both thrombosed and non-thrombosed. Fenestrated clips are useful to spare branching vessels, especially in posterior wall giant ICA aneurysms. Fenestrated clips are also frequently employed as boost clips to reinforce the clip blades closure of standard clips. The latter technical tip applies mainly to those cases characterized by the presence of severe atherosclerotic changes involving the aneurysm neck and the parent artery.

The literature suggests that surgical or endovascular proximal Hunterian occlusion of the parent artery harboring a large to giant aneurysm should be avoided because of a high incidence of stroke, even in those non-thrombosed aneurysms where the patient passed BTO [11, 15–22].

Regarding the revascularization procedures (Fig. 2), the rationale for a bypass for GIAs may include the need for flow replacement of the parent artery or one or more branches in

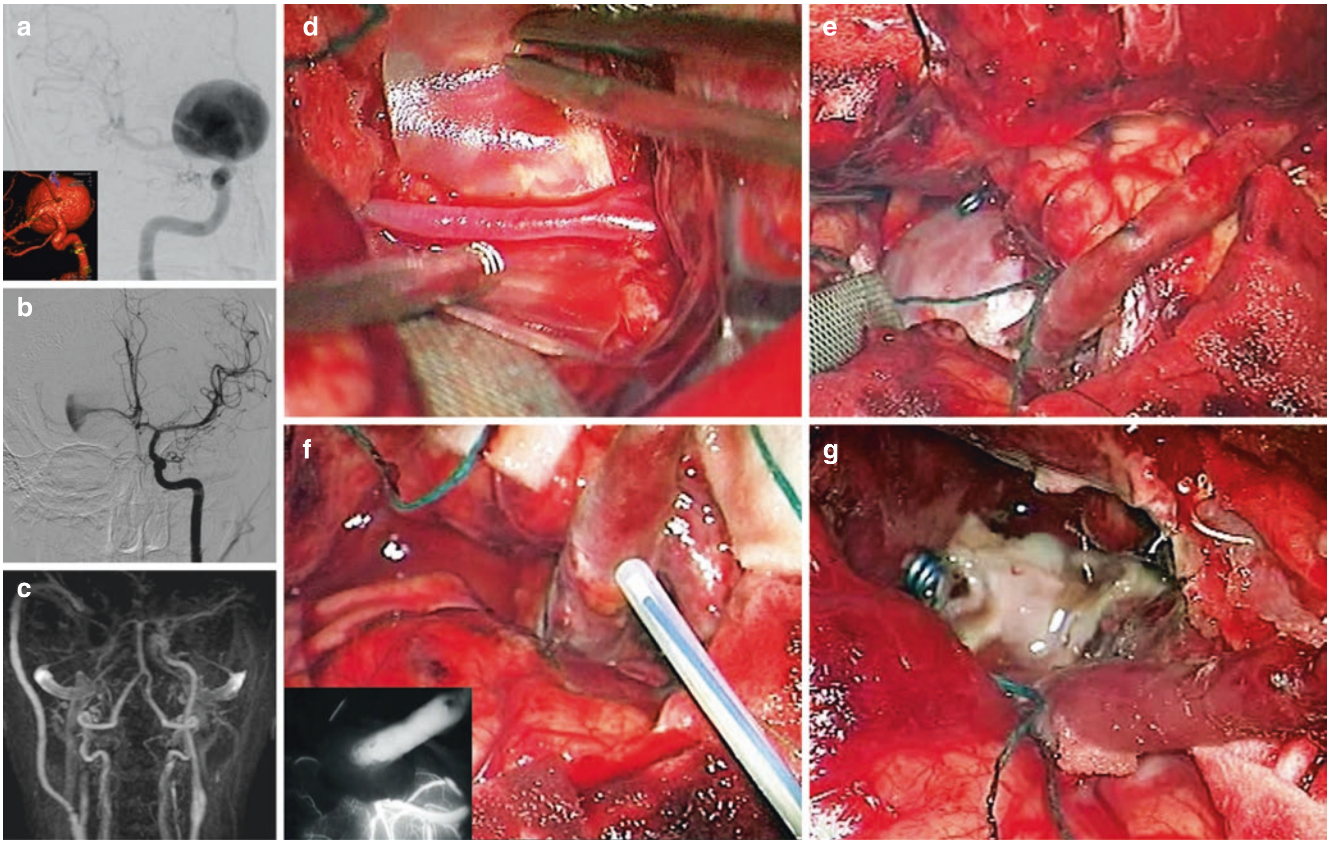

Fig. 2 Pre-operative DSA with 3D volume rendering showing a giant partially thrombosed aneurysm of the right iuxta-clinoidal ICA with huge mass effect (**a**). BTO showing an unsatisfactory cross-flow. The patient also failed BTO clinically (**b**). Initial step of EC-IC involving the superior frontal branch of post-bifurcation MCA (**d**). Saphenous vein graft EC-IC bypass (**e**). Intra-operative MDU and ICG flow check showing the patency of the bypass (**f**). Final clipping of the aneurysm achieved after thrombectomy (**g**). Post-operative MRI angiography at 6th month follow-up showing the complete exclusion of the aneurysm and the patency of the high flow bypass (**c**)

those cases where they cannot be preserved, but also the prevention of a post-operative stroke in selected cases requiring a prolonged temporary parent vessel occlusion (temporary bypass), especially in patients with a reduced cerebrovascular reserve. In the personal series, the authors preferred to proceed to bypass whenever in doubt because of the detection of TES-MEPs or SSEPs modifications not exceeding the threshold considered predictive of ischemia, or in rare cases of contradictory findings between TES-MEPs and SSEPs. RAG high-flow bypass is the most frequently performed to replace ICA and proximal MCA. RAG seems to be associated with a lower incidence of long-term graft occlusion [9], being therefore considered as the best conduit for high-flow bypasses, as also confirmed by the present data. Revascularization procedures aimed at replacing distal ACA or PICA involve side-to-side in situ bypasses. A further bypass option, especially in rare cases of large fusiform M1 MCA aneurysms, is the interposition-graft bypass, where the radial artery or STA should be preferentially used.

Microneurosurgery is still, to date, the best treatment option for most very large and giant complex intracranial aneurysms. The surgical treatment of these lesions always requires detailed and careful preoperative planning and specific surgical skills, including extensive experience in the management of direct clipping of intracranial aneurysms and dexterity with micro suturing techniques. The preoperative planning of these aneurysms should also take into account the selection of the most suitable approach among a large number of skull base approaches in which the neurovascular surgeon must have great confidence. Neuronavigation, intraoperative neurophysiological monitoring, ICG videoangiography, and MDU are essential and unavoidable tools in the surgical armory needed to treat these extremely complex and challenging lesions.

Conflict of Interest Statement The authors declare that they have no conflict of interest.

References

1. Barth A, de Tribolet N. Growth of small saccular aneurysms to giant aneurysms: presentation of three cases. Surg Neurol. 1994;41(4):277–80.
2. Krings T, Piske RL, Lasjaunias PL. Intracranial arterial aneurysm vasculopathies: targeting the outer vessel wall. Neuroradiology. 2005;47(12):931–7.
3. Barrow DL, Alleyne C. Natural history of giant intracranial aneurysms and indications for intervention. Clin Neurosurg. 1995;42:214–44.
4. International Study of Unruptured Intracranial Aneurysms Investigators. Unruptured intracranial aneurysms—risk of rupture and risks of surgical intervention. N Engl J Med. 1998;339(24):1725–33.
5. Drake CG. Giant intracranial aneurysms: experience with surgical treatment in 174 patients. Clin Neurosurg. 1979;26:12–95.
6. Hosobuchi Y. Direct surgical treatment of giant intracranial aneurysms. J Neurosurg. 1979;51(6):743–56.
7. Lawton MT, Spetzler RF. Surgical management of giant intracranial aneurysms: experience with 171 patients. Clin Neurosurg. 1995;42:245–66.
8. Lawton MT, Spetzler RF. Surgical strategies for giant intracranial aneurysms. Neurosurg Clin N Am. 1998;9(4):725–42.
9. Sekhar LN, Tariq F, Mai JC, Kim LJ, Ghodke B, Hallam DK, Bulsara KR. Unyielding progress: treatment paradigms for giant aneurysms. Clin Neurosurg. 2012;59:6–21.
10. Sousa A, Sousa Filho J, Dellaretti Filho M. Treatment of giant intracranial aneurysms: a review based on experience from 286 cases. Arq Bras Neurocir. 2015;34(4):295–303.
11. Spetzler RF, Schuster H, Roski RA. Elective extracranial-intracranial arterial bypass in the treatment of inoperable giant aneurysms of the internal carotid artery. J Neurosurg. 1980;53(1):22–7.
12. Sundt TM, Piepgras DG. Surgical approach to giant intracranial aneurysms. Operative experience with 80 cases. J Neurosurg. 1979;51(6):731–42.
13. Symon L, Vajda J. Surgical experiences with giant intracranial aneurysms. J Neurosurg. 1984;61(6):1009–28.
14. Jahromi BS, Mocco J, Bang JA, Gologorsky Y, Siddiqui AH, Horowitz MB, Hopkins LN, Levy EI. Clinical and angiographic outcome after endovascular management of giant intracranial aneurysms. Neurosurgery. 2008;63(4):662–74.
15. Diaz FG, Ausman JI, Pearce JE. Ischemic complications after combined internal carotid artery occlusion and extracranial-intracranial anastomosis. Neurosurgery. 1982;10(5):563–70.
16. Hacein-Bey L, Connolly ES, Duong H, Vang MC, Lazar RM, Marshall RS, Young WL, Solomon RA, Pile-Spellman J. Treatment of inoperable carotid aneurysms with endovascular carotid occlusion after extracranial-intracranial bypass surgery. Neurosurgery. 1997;41(6):1225–31.
17. Heros RC. Thromboembolic complications after combined internal carotid ligation and extra- to-intracranial bypass. Surg Neurol. 1984;21(1):75–9.
18. Heros RC, Nelson PB, Ojemann RG, Crowell RM, DeBrun G. Large and giant paraclinoid aneurysms: surgical techniques, complications, and results. Neurosurgery. 1983;12(2):153–63.
19. Ibrahim TF, Jahromi BR, Miettinen J, Raj R, Andrade-Barazarte H, Goehre F, Kivisaari R, Lehto H, Hernesniemi J. Long-term causes of death and excess mortality after carotid artery ligation. World Neurosurg. 2016;90:116–22.
20. Niiro M, Shimozuru T, Nakamura K, Kadota K, Kuratsu J. Long-term follow-up study of patients with cavernous sinus aneurysm treated by proximal occlusion. Neurol Med Chir. 2000;40(2):88–96.
21. Polevaya NV, Kalani MYS, Steinberg GK, Tse VCK. The transition from hunterian ligation to intracranial aneurysm clips: a historical perspective. Neurosurg Focus. 2006;20(6):E3.
22. Steinberg GK, Drake CG, Peerless SJ. Deliberate basilar or vertebral artery occlusion in the treatment of intracranial aneurysms. Immediate results and long-term outcome in 201 patients. J Neurosurg. 1993;79(2):161–73.