Round table: Giant intracranial aneurysms

Selective microsurgical treatment of giant intracranial aneurysms

Traitement microchirurgical sélectif des anévrismes géants intracrâniens

J.-P. Lejeune a,∗, L. Thines b, F. Proust c, B. Riegel d, M. Koussa e, C. Decoene d

a Department of Neurosurgery, Lille University Hospital, 59000 Lille, France
b Department of Neurosurgery, Besançon University Hospital, 25000 Besançon, France
c Department of Neurosurgery, Strasbourg University Hospital, 67000 Strasbourg, France
d Department of Anesthesiology, Lille University Hospital, 59000 Lille, France
e Department of Cardiac and Vascular Surgery, Lille University Hospital, 59000 Lille, France

A R T I C L E   I N F O

Article history:
Received 8 November 2013
Received in revised form 7 December 2015
Accepted 9 December 2015
Available online 23 February 2016

Keywords:
Giant aneurysms
Complex aneurysms
Microsurgery

A B S T R A C T

Giant intracranial aneurysms are defined as greater than 25 mm in diameter. They share the same surgical challenges and strategies as so-called complex aneurysms, sometimes smaller in size but presenting with similar complex anatomy. The surgical difficulties arise from the size of the sack, the presence of intraluminal thrombus, the thickness of the arterial wall, and the complexity of arterial branching on the neck. Preoperative imaging gathers complementary information from magnetic resonance imaging, computed tomographic angiography, and rotational catheter-based angiography with three-dimensional reconstruction including balloon-test occlusion. The therapeutic decision-making needs a multidisciplinary approach including endovascular, neurosurgical and anesthesiological expertises. The microsurgical treatment needs a step-by-step preoperative planning with anticipation of possible pitfalls and alternative strategies. Classical principles of aneurysm surgery have to be tailored to face the difficulties arising from the size of the sack and from the arterial wall calcifications.

© 2016 Elsevier Masson SAS. All rights reserved.

R É S U M É

Les anévrismes géants sont définis par la taille de leur sac, quand elle est supérieure à 25 mm. La dénomination d’anévrismes complexes est préférable car elle permet d’inclure beaucoup de situations chirurgicales qui partagent les mêmes difficultés techniques et la même stratégie. Ces anévrismes présentent des difficultés chirurgicales particulières liées à la taille du sac, à sa thrombose éventuelle, à l’épaisseur des parois du sac et à la complexité du collet. Ils nécessitent un bilan neuroradiologique complet où l’imagerie en résonance magnétique nucléaire, l’angiographie et l’angiographie conventionnelle avec tests de clamping apportent chacune des informations complémentaires. La décision thérapeutique ne peut être que multidisciplinaire, mettant en commun les ressources de la neuroradiologie interventionnelle, du traitement microchirurgical, et l’évaluation indispensable des anesthésistes-réanimateurs. Le traitement microchirurgical, quand il est retenu, doit être soigneusement planifié en incluant un scénario idéal et des stratégies dégradées. Les principes de dissection classiques du vaisseau porteur, des branches collatérales et du sac doivent s’adapter aux difficultés rencontrées, souvent liées à la taille du sac et aux remaniements de la paroi artérielle.

© 2016 Elsevier Masson SAS. Tous droits réservés.

http://dx.doi.org/10.1016/j.neuchi.2015.12.001
0028-3770/© 2016 Elsevier Masson SAS. All rights reserved.
complex aneurysms \cite{1} should be preferred as many of these aneurysms share the same surgical difficulties and strategies.

Modern refinements in microsurgery like cranial base operative approaches, peroperative angiography, bypass surgery or the use of extra corporeal circulation have increased the indications for microsurgical treatment, but mortality and morbidity are still evaluated between 10 and 30\% \cite{2,3}.

The modern endovascular treatments have reduced the indications for the microsurgical treatment, making difficult for a neurosurgical team to maintain a high level of expertise concerning these rare lesions. Nevertheless, the selective microsurgical treatment of giant aneurysms remains possible in many cases, as reported by Sughrue et al. \cite{4}: selective neck clipping was possible in 64 of 141 aneurysms (45\%).

The therapeutic management of these complex aneurysms needs a multidisciplinary approach. Their rarity and the difficulties of the decision-making would, in our opinion, justify a national dedicated forum accessible for all neurosurgical teams.

1. **Surgical challenges of giant intracranial aneurysms**

1.1. **The size of the sack**

The classical definition concerns a diameter of the sack above 25 mm, but the surgical difficulties appear above 15 mm in diameter. The volume of the sack usually masks the access to afferent and efferent vessels, and prevents the use of conventional strategies of dissection. Proximal and distal parent artery control is often difficult and reduces the security in case of intraoperative rupture.

1.2. **The arterial wall of the sack**

The most important issue is to predict whether the volume of the sack can be collapsed during surgery to facilitate the dissection and clipping.

When no intraluminal thrombus is present, puncture followed by suction may reduce the volume of the sack during surgery. This is frequent in young patients with arterial dysplasia. Most of the time, the size of the sack leads to the thickening of the arterial wall, even when calcifications are not present. Some authors have reported the presence of thin intraluminal thrombus close to the arterial wall which increase its thickness \cite{5}.

When intraluminal thrombosis is present, the initial portion of the sack near the neck often remains permeable, and clipping seems achievable. However, the arterial wall around the neck is often thick, calcified, and makes clipping very difficult and risky. The intraluminal thrombus is dense, organized, and adherent to the arterial wall. It may only be reduced by a wide opening of the sack followed by evacuation of the thrombus, and sometimes endarterectomy of the neck is required to soften it and make it suitable for clipping. These techniques require prolonged temporary clipping of the parent artery with an important risk for cerebral ischemia. This situation is frequently reported during the microsurgical treatment of giant aneurysms: 24\% \cite{4}.

The thickness of the arterial wall of giant aneurysms can vary from 0.2 to 2 mm. The internal elastic lamina and the media are interrupted in the arterial wall beyond the neck. The sack wall is often composed of two layers. The outer layer is purely fibrous, but frequently calcified. The inner layer is thicker and consists of young connective tissue. Between these two layers, there are often cholesterol fatty deposits, which can also be associated with calcifications \cite{5}. This complex histological structure is thick and shows variable stiffness, and is the cause of difficulties in the application of the clips: insufficient closing force of the clips, insufficient deformability of the wall when clipping, slipping of the clip, or tearing of the arterial wall at the junction of two zones of different resistance.

1.3. **Surgical pitfalls related to the neck**

The neck is often inaccessible, hidden by the large volume of the sack. It is often broad, including the efferent branches whose ostium is enlarged with a funnel shape; clipping almost always uses several clips installed in a row to reconstruct the anatomical bifurcation. Along the time, inflammatory processes tighten the efferent vessels to the sack, often along a considerable distance after their point of emergence at the neck. The dissection of the efferent branches is often difficult, even with high magnification of the microscope, exposing to the risk of injury to one of the branches. This dissection is sometimes completely impossible for branches of small diameter, truly embedded in the wall of the sack.

1.4. **Surgical difficulties associated with previous treatments of the aneurysm**

The presence of coils in the aneurysm sack is a formidable additional pitfall. The coils prevent the mobilization of the sack by their resistance. They prevent the remodeling of the neck with the clips because they give rigidity to the arterial wall. The removal of coils out from the sack is extremely difficult because the coils are usually embedded in the arterial wall. It is more advisable if possible to cut off the residual neck close to the coils to completely isolate them and reconstruct the neck. The recanalization has to be carefully evaluated on preoperative cerebral angiography, and needs to be important enough to allow this procedure \cite{6}.

2. **Preoperative neuroradiological evaluation**

A complete radiological assessment is essential to understand the angioarchitecture of the aneurysm and its anatomical relationships and hemodynamics features. It helps to evaluate a large part of the surgical difficulties, to anticipate them and establish a true surgical strategy. All neuroradiological exploration methods should be used because they provide different additional information that should be confronted. Figs. 1 to 10, 13a and 13b referenced below refer to the same clinical case.

2.1. **Magnetic Resonance Imaging**

MRI is used to analyze the anatomical relationship of the aneurysmal sac in axial, coronal and sagittal sections (Figs. 1–3). Gradient echo sequences identify the degree of thrombosis of the sack and traces of a previous bleeding. FLAIR sequences emphasize the perilesional edema. The magnetic resonance angiography analyzes the relationship of the efferent branches with the aneurysmal sack, but it is much less precise than conventional angiography.

2.2. **CT Scanner and CT Angiography**

CT scan is particularly useful for the detection of calcifications in the wall of the sack, at the neck, and possibly along the efferent branches: this information is essential to predict the difficulties of the clip positioning during surgery (Figs. 4–6). 3D reconstructions are useful to understand the relationship between the efferent branches and the sack. However, the computer reconstruction process often ignores small diameter efferent branches.

2.3. **Cerebral angiography**

Rotational catheter-based angiography with three-dimensional reconstruction remains the most effective examination for the
accurate determination of angioarchitecture of the neck, the analysis of the efferent branches, including small diameter branches sometimes of capital functional importance (Figs. 7a, b, 8, 9). Three-dimensional reconstructions indicate the anatomical relationships, allow accurate measurements that predetermine the size of the clips that will be used. The three-dimensional reconstruction can also be reoriented along the axis of the surgical approach, which allows the surgeon to anticipate pitfalls during surgery (Fig. 9). For partially thrombosed aneurysms, the size of injected sack is below the actual size, which significantly alters the relationship of efferent branches with the sack.
3. The therapeutic decision

3.1. Multidisciplinary evaluation

A multidisciplinary therapeutic decision-making is mandatory in these complex situations where the expertise of every member of the team enlights the analysis of the case to achieve the best therapeutic result. In our institution, interventional neuroradiologists, neurosurgeons, vascular neurologists, anesthesiologists are concerned, and also cardiovascular surgeons and anesthesiologists if surgery using extracorporeal circulation is considered. A complete cardiovascular evaluation is essential.

Microsurgical treatment is only decided when endovascular treatment cannot be proposed:

- treatment of very large sack with mass effect that will remain unchanged by the volume of coils after a selective endovascular treatment;
- treatment of a very large thrombosed sack for which endovascular procedural complications are more frequent, as well as the risk of serious recanalization [7];
- insufficient hemodynamic supply during balloon-test occlusion when nonselective endovascular treatment is considered;
- in our experience, the microsurgical treatment was reserved to giant aneurysms of the anterior circulation. The surgical risk for posterior circulation giant aneurysms is higher and endovascular treatment was preferred. Modern endovascular devices like flow diverters stents recently raised new therapeutic possibilities.

Fig. 6. Three-dimensional reconstruction of CT angiography showing the permeable portion of the sack and relationship with the distal middle cerebral artery branches. Reconstruction tridimensionnelle de l’angiographie : portion perméable du sac anévrismal et rapports des branches de division de l’artère cérébrale moyenne.

Angiography can also assess the potential supply from other cerebral arteries when a balloon-test occlusion is performed during the procedure.

The angiographic evaluation should always include a selective angiogram of the external carotid artery to evaluate the feasibility of extracranial to intracranial bypass.

Fig. 7. a and b. Conventional angiography showing the permeable portion of the aneurysm and its relationship with distal middle cerebral artery branches Artériographie digitalisée sous-traitée : portion perméable de l’anévrisme, rapports du sac avec les branches de division distales de l’artère cérébrale moyenne.

Fig. 8. Three-dimensional reconstruction of conventional angiography showing the size of the neck and the origin of distal middle cerebral artery branches. Reconstruction tridimensionnelle de l’angiographie : taille du collet, rapports des branches de division distales de l’artère cérébrale moyenne.
4.1. Installation and equipment

The surgical procedure is always long and the accuracy of the patient’s installation is particularly important. The installation must take into account any associated procedure (cervical segment of carotid artery control, radial arterial graft or a saphenous vein graft harvesting, for example).

Intraoperative aneurysmal rupture can be dramatic and requires:

- preoperative careful inventory of surgical equipment with the nurses team;
- preoperative information to the anesthesiologists concerning surgical strategy and possible intraoperative complications.

Careful analysis of angiography often predicts the type of the needed clips in terms of size and shape of the jaws. It is common in the surgical treatment of these aneurysms to need less commonly used clips as long clips, fenestrated clips, booster clips: they should be prepared in sufficient quantity.

Surgical technical difficulties often require the help of an experienced assistant to perform “four hands” surgery.

The indocyanine green videoangiography available on modern microscopes is, in our opinion, necessary for the surgical procedure. It allows immediate perioperative control of the patency of arterial branches, especially of small diameter perforating arteries. We have no experience of intraoperative conventional angiography offered by modern hybrid operating rooms. It can undoubtedly provide additional therapeutic options such as the combination of a temporary endovascular balloon occlusion next to the collar to facilitate the dissection of the aneurysm.

4.2. Surgical approach

In most cases, the surgical approach is the pterional approach described by Yasargil et al. [8]. It provides a good access to the anterior circulation aneurysms.

The “conventional” skin incision must be adapted to preserve the superficial temporal artery and its branches, as they may be required during the procedure if an extracranial to intracranial bypass is necessary. The Doppler allows to spot the artery under the skin before the incision to avoid arterial injury and maintain a sufficient length of usable graft.

The bone flap should be large, wide enough on both sides of pterion to gain exposure and adequate work space. The potential length of the intervention and the volume of the aneurysmal sack makes it even more necessary than usual to minimize brain retraction. Pterional drilling close to the cranial base is required, some authors prefer the removal of the zygomatico-orbital arch [9].

The opening of the sylvian fissure should be broad and should preserve the superficial sylvian veins on the temporal edge of the fissure. It sets the landmark of the middle cerebral artery and helps the cerebrospinal fluid depletion, giving access to the suprasellar cisterns. The opening of the sylvian fissure is mandatory to obtain the brain relaxation needed to treat the aneurysm. Some authors associate lumbar drainage, or a transparenchymal puncture of the frontal horn of the lateral ventricle.

4.3. Principles of aneurysm dissection applied to giant aneurysms

The neurosurgeon should keep in mind the general rules of aneurysm dissection: understand the location of the aneurysm on the parent vessel, dissect the efferent arterial branches, prepare the aneurysmal neck for clip application [10]. The prevention and the potential control of premature rupture of the aneurysm should always be anticipated.

Classically, the three successive steps of the surgical treatment of the aneurysm are the dissection of the parent vessel, the dissection of the aneurysm walls, and finally the preparation of the neck for the application of the clip. Each of these steps is achieved with greater technical difficulties during giant aneurysm surgery.

Fig. 9. Surgical approach oriented three-dimensional reconstruction of conventional angiography. Reconstruction tridimensionnelle de l’angiographie réorientée selon l’axe de la voie d’abord chirurgicale.
4.3.1. The dissection of the parent vessel

The control of the parent vessel brings the proximal control of the aneurysm and a much better chance of dealing with premature rupture. The volume of the sack of giant aneurysms almost always hides the parent vessel from the surgeon’s view. For proximal intracranial carotid artery aneurysms, the dissection and the control of the cervical segment of the carotid artery is necessary. For more distal anterior circulation aneurysms, the parent artery can often be exposed upstream of the aneurysm, but usually at a longer distance from the neck, which cannot be exposed properly. A temporary clipping of the parent vessel is therefore more risky, potentially compromising the permeability of branches located between the neck and the site of clamping, unfortunately a frequent location for perforating arteries.

4.3.2. The dissection of the aneurysm walls

A parenchymal resection is sometimes necessary to obtain an adequate exposure of the aneurysm, especially giant middle cerebral artery aneurysms which require anterior temporal lobe resection. The anterior face of the sack, facing the surgeon, is often easy to expose. The side walls are less accessible, the posterior wall and the top of the sack are often inaccessible. It is recommended to avoid the dissection of the fragile areas of the sack. The fragile areas of giant aneurysms are not only located at the top of the sack. The walls themselves may be at risk of premature rupture because they have very unequal thickness areas. In addition, they may be injured during the dissection of the efferent branches from the neck, as they are often tightly attached to the walls of the sack.

4.3.3. The preparation of the neck

The neck is almost always hidden by the volume of the sack. However, the dissection should be continued as far as possible before considering the reduction of the volume of the sack. The reduction of the sack’s volume will need the sack opening, and will create a dangerous situation with unstable hemodynamic status which must be as short as possible.

4.3.4. Reducing the volume of the sack

4.3.4.1. If the sack is not thrombosed. If the sack is not thrombosed, it may often be partly deformed by a gentle pressure with soft instruments. The dissection can often be continued further to expose the parent artery and the efferent branches. When it becomes necessary to reduce the volume of the sack, the following techniques can be used:

- a temporary clipping of the parent vessel, if it is exposed, which allows the collapse of the sack after its puncture, in order to complete the dissection of the neck and its clipping. The complete temporary clipping including the parent vessel and the efferent branches is much more difficult as usually one of the efferent branches at least is not accessible. Most of the time, the temporary clipping remains partial and makes the end of the dissection risky;
- a continuous suction of the aneurysmal sac, making a small incision in the aneurysmal sack as far as possible from the neck, in which the aspirator is introduced to collapse the sack [11].

These two techniques create a very unstable hemodynamic situation for the brain downstream the aneurysm, with a major ischemic risk. Their duration should not exceed a few minutes with a good anesthesiologic preparation. It can be longer in time if the extracorporeal circulation under hypothermia is used, but this technique adds its own risks of complications as anticoagulation is necessary.

The final dissection of the neck in these two situations is difficult. The sack walls have become flaccid, highly mobile, and their risk of injury is more important, especially when dissecting adhesions of efferent branches. It is advisable to initially place a clip imperfectly above the surgical neck, in order to leave as soon as possible the unstable hemodynamic status. The clipping can then be optimised at the surgical neck in better conditions and without haste, after the release of temporary clipping.

4.3.4.2. If the sack is thrombosed. If the sack is thrombosed, it cannot be depressed during dissection and the approach to the neck is quickly compromised. Vascular walls are thicker and often rigid or calcified. A wide opening of the sack is necessary, if possible far from the permeable portion of the aneurysm. This incision, usually horizontal and parallel to the axis of the collar, must leave enough arterial wall above the neck to allow its reconstruction later by several clips. It should be started on the side of the aneurysm facing the surgeon and should be continued step-by-step around the whole sack. It allows a thrombectomy of the distal segment of the sack, using traditional dissecting instruments or ultrasonic aspirator. This thrombectomy should be as complete as possible, it will restore a good exposure of the lower portion of the residual sac and neck. The dissection space is then restored and thrombectomy can continue toward the neck. The thrombus is often highly adherent to the wall which may be thin in some area. The dissection should be very careful to avoid creating a tear that would prevent the neck reconstruction. The continued thrombectomy then reaches the residual permeable portion of the sack and it is then necessary to perform a temporary clipping which is usually complete, including the parent vessel and the efferent branches. Attention must be paid not to abandon fragments of thrombus next to the collar, and the neck should be “flushed” by opening alternately the temporary clips to reduce the risk of secondary thrombosis. Sometimes, additional endarterectomy is necessary to get rid of a calcified area that prevents the closure of the clips.

4.3.5. The exclusion of the neck

The exclusion of the neck of giant aneurysms is rarely achieved with a single clip as usual for small aneurysms. The clipping has also the following significant difficulties in handling multiple clips in a limited surgical space:

- the neck is often wide and may require the use of long clips. The surgeon must keep in mind that the closing force along the jaws of the clip decreases regularly from the hinge to the end of the clip [5];
- the arterial wall is thick and sometimes several clips placed in series may be necessary for the complete closure of the neck (a and b);
- fenestrated clips are often useful for the treatment of proximal carotid aneurysms (a and b);
- the complex morphology of the neck may require the use of a series of clips to allow a true “remodeling” of the arterial bifurcation, especially for giant middle cerebral artery aneurysms (a and b);
- the microsuture of the neck is technically very difficult in a confined space and introduces an additional ischemic risk by the complete temporary clipping it requires a bloodless operative field. It uses a thin suture (8, 9 or 10/0). It is often hampered by the poor quality of the arterial wall that is either very thick and atheromatous or otherwise very thin and tearing at other places. This is in our opinion a rescue solution when the surgeon is facing a premature rupture very close to the neck, in conditions that do not leave enough wall to apply a clip at the neck (a and b).
Fig. 10. a and b. Giant carotid aneurysm treated with multiple clips.
Utilisation de plusieurs clips en série au collet pour le traitement d’un anévrisme carotidien géant.

Fig. 11. a and b. Giant carotid-ophtalmic aneurysm treated with multiple fenestrated clips.
Utilisation de clips fenêtrés multiples pour le traitement d’un anévrisme carotido-ophtalmique géant.

Fig. 12. a and b. Intraoperative view of neck reconstruction and post operative angiogram of a giant right middle cerebral artery aneurysm (same patient as Fig. 1 through 9).
Vue peropératoire de la reconstruction vasculaire et contrôle angiographique postopératoire d’un anévrisme géant thrombosé de l’artère cérébrale moyenne droite (même patient que les Fig. 1 à 9).

5. The use of extracorporeal circulation (ECC)

The concept is attractive because it offers the neurosurgeon the possibility of an optimal control of arterial flow to decrease the tension of the aneurysmal sack, and gives him more time to rebuild the neck or reimplant a branch of a major division with the protection of deep hypothermia, which is used during the procedure. Our colleagues’ cardiovascular surgeons are experienced in this technique can now use a femoral arterial and venous cannulation, thus avoiding a thoracotomy. However, this is a complicated procedure which requires the close collaboration of two surgical teams. It adds specific complications [3,12] which are proportional...
to its duration, and particularly the risk of a thrombosis of the reconstructed vessel when normal coagulation is restored at the end of the procedure. This therapeutic option should only be considered when no other endovascular or microsurgical option is available.

To the eyes of the neurosurgeon, the anatomical situation is normal, the brain remains relaxed by the depletion of cerebrospinal fluid. The vascular anatomy is slightly changed because the color of arterial and venous vessels becomes uniform and the pulsatility of arterial vessels disappears. Hemodynamic conditions provide a greater comfort for dissection: they easily allow to depress a large aneurysm sac to dissect the walls and the parent vessel. They also allow the large opening of the sack while remaining in complete control of the situation by reducing the circulatory flow. Thrombectomy and endarterectomy of a calcified neck can then be achieved in good technical conditions (Fig. 14).

6. Conclusion

The giant intracranial aneurysms represent a very difficult microsurgical challenge. Even in experienced hands for vascular microsurgery, the complexity of their anatomy, the alterations of the arterial wall and the intraluminal thrombosis are real pitfalls.

The analysis of the therapeutic results encourages great modesty. On the other hand, the natural history of giant intracranial aneurysms is life threatening, with a known risk of rupture of 40 to 50% at 5 years in the absence of treatment. The indication for a microsurgical treatment absolutely needs in our opinion a careful analysis of each case by a multidisciplinary team, combining and comparing all modern imaging modalities in order to anticipate as completely as possible the surgical difficulties. This evaluation should lead to build a true surgical “plan”, and also to elaborate alternative strategies in case of intraoperative difficulties. It is never dishonorable to abandon the surgical procedure when facing insurmountable difficulties or unacceptable functional risk. Finally, the rarity and complexity of these observations, the specificities of some major surgical procedures encourage to share the cases in a national dedicated forum.

Disclosure of interest

The authors declare that they have no competing interest.

References