Endovascular treatment of intracranial aneurysms as the first therapeutic option

Traitement endovasculaire de première intention des anévrysmes intracrâniens

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Abstract
Background and purpose. — To prospectively evaluate the results of endovascular treatment (EVT) of intracranial aneurysms when it is considered as first-intention treatment.
Methods. — From April 2004–October 2006, 167 consecutive patients with 202 aneurysms were treated in our institution. Five patients with a ruptured aneurysm with an associated hematoma were excluded. In 162 patients with 197 aneurysms, EVT was considered as first-intention treatment.
Results. — Surgical clipping was performed in 25 aneurysms (25/197 = 12.7%) including 22 aneurysms excluded from EVT and three EVT failures. EVT was thus attempted in 144 patients with 175 aneurysms and successfully performed in 141 patients with 172 aneurysms (172/197 = 87.3%). EVT failure rate was 1.7%. Clinical outcome according to the modified Glasgow Outcome Scale was: Excellent, 81.5%; Good, 7%; Poor or Fair, 3.5%; Death, 8%. Procedural complications occurred in 17 cases (10%). Balloon- or stent-assisted techniques were used in 60 cases (34.9%) and were not associated with higher complication rate. Overall procedural morbidity and mortality rates were 4.2 and 2.1%. Initially, complete occlusion was obtained in 68%, neck remnant in 23%, and incomplete occlusion in 9% of aneurysms. Follow-up (mean 11 months) was obtained in 119 aneurysms and showed major recanalisation — that required re-treatment — in 13 cases (11%) and minor recanalisation in 17 cases (14.3%).
Conclusion. — Our findings suggest that new endovascular techniques allow proposing EVT as first-intention treatment in 87.3% of patients with intracranial aneurysms. This therapeutic strategy is associated with good clinical results. However, anatomical results are not improved and remain the EVT limiting factor.

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Endovascular treatment of intracranial aneurysms as the first therapeutic option

Introduction

Endovascular treatment (EVT) by endosaccular coiling has been accepted as an alternative to surgical clipping for the treatment of unruptured and ruptured intracranial aneurysms [10-12]. Until recently, EVT was mostly applied in patients with small aneurysm (diameter < 12 mm) with a small neck (neck < or = 4 mm or neck/sac ratio < 0.7). In this particular subgroup of patients EVT has the same efficacy as surgical clipping, but it is associated with lower morbidity and mortality rates [10-12]. Therefore, EVT is now considered as the first therapeutic option in such patients in most centres [4,7,10-12,23,25,31]. Indeed, small aneurysms with a small neck have an anatomical configuration that prevents coil protrusion within the parent vessel and are associated with stable long-term anatomical results [11]. However, these results cannot be extrapolated to more than this subgroup of patients and surgical clipping still remains the standard treatment for more complex aneurysms such as wide-necked aneurysms or aneurysms with a branch arising from the sac. Nevertheless, thanks to the recent development of new endovascular techniques and tools, more and more aneurysms are amenable to EVT. New coils, remodelling balloons, and self-expandable stents allow to treat complex aneurysms including wide-necked aneurysms, fusiform aneurysms, and aneurysms with a branch arising from the sac [1,2,15,17-19,22]. These new techniques have thus enlarged EVT indications but the question remains as to whether these techniques justify EVT as first-intention treatment in all aneurysms. To our knowledge, there are only two series that have prospectively evaluated aneurysm treatment results when EVT is considered as the first therapeutic option in all patients [21,26]. Raftopoulos et al. [26] have published a series of 103 patients treated between 1996 and 1999 when none of these new techniques and tools was used. This paper reported a high number of failures and poor outcomes in patients treated by endovascular approach. Six years later, Mejdboui et al. [21] have published a similar series of 230 patients treated between 1998 and 2002 when these techniques were more frequently used. This paper reported good results in most patients and a very low EVT failure rate. Nowadays, balloon- and stent-assisted techniques may routinely be used in a very specialised neurovascular centres. The aim of our study was thus to prospectively evaluate, over a 30-month period in a single centre, the feasibility and results of EVT as first-intention treatment for all patients with intracranial aneurysms.

Patients and methods

Therapeutic protocol

Since April 2004, daily interventional neuroradiology is available in our institution and a multidisciplinary therapeutic protocol has been established for the management of patients with ruptured and unruptured intracranial aneurysms. For all patients, EVT is considered as the first therapeutic option by the multidisciplinary team if it is judged feasible by the senior neurointerventionalist (BL) except for ruptured aneurysms associated with a compressive haema-
toma that require emergency surgical treatment. Our hospital’s ethical committee approved this protocol and this study.

Population

Between April 2004 and October 2006, 167 consecutive patients with 202 aneurysms were treated in our hospital according to this protocol. Five patients, who presented with a ruptured aneurysm with an associated compressive haematoma, were excluded from the present study and treated by surgical clipping.

The present study consisted of 162 patients with 197 aneurysms. There were 107 women (66%) and 55 men (34%) with an age ranging from 18 to 90 years (Fig. 1). Clinical presentation is summarised in Fig. 2. Because the treatment decision was essentially based on aneurysm morphology and because patients with multiple aneurysms underwent multiple endovascular and/or surgical treatments, each aneurysm was considered to be a single case (197 in all). Surgical clipping was performed in 23 patients with 25 aneurysms for different reasons that are detailed in Table 1.

The endovascular cohort consisted of 144 patients harbouring 175 aneurysms. For an easier understanding, we have separated aneurysms in three groups: group I consisted of symptomatic aneurysms (subarachnoid hemorrhage (SAH), mass effect, transient ischemic attacks (TIA)); group II consisted of asymptomatic and unruptured aneurysms; group III consisted of aneurysms that had to be re-treated.

All patients underwent conventional angiography of both carotid arteries and vertebral arteries.

Aneurysm morphology

The maximal aneurysmal sac diameter was defined as small (< 12 mm), large (12-25 mm), or giant (> 25 mm). The aneurysm neck width was defined as small (\( \leq 4 \) mm or neck/sac < 0.7) or wide (> 4 mm or neck/sac > 0.7).

Endovascular procedure

In all patients, EVT was performed under general anesthesia and systemic heparinisation. The adequacy of systemic anticoagulation was monitored by frequent measurements of the activated clotting time (ACT). A baseline ACT was obtained prior to the bolus infusion of heparin (30 to 50 IU/kg body weight), and hourly thereafter. The bolus infusion of heparin was followed by a continuous drip (1000 to 1500 IU/h), with the purpose of doubling the baseline ACT. At the end of the procedure, systemic heparinisation was maintained for 24 h in most patients. All procedures were performed by the same interventional neuroradiologist (BL).

In case of wide-necked aneurysms, aneurysms with a branch arising from the sac, and fusiform aneurysms, the balloon-assisted technique [17,18,22] with a HyperForm/HyperGlide balloon (Micro Therapeutics, Irvine, CA) or the stent-assisted technique [1,15,19] with a Leo stent (Balt, Montmorency, France) were used. For intracranial stenting of an unruptured aneurysm, medical premedication was

<table>
<thead>
<tr>
<th>Table 1 Surgical clipping in 25 intracranial aneurysms</th>
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<tbody>
<tr>
<td>Reason for clipping</td>
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<tr>
<td>Aneurysms judged unsuitable for EVT</td>
</tr>
<tr>
<td>Wide-necked MCA aneurysm</td>
</tr>
<tr>
<td>Aneurysm size &lt; 2 mm</td>
</tr>
<tr>
<td>Giant, partially thrombosed MCA aneurysm</td>
</tr>
<tr>
<td>Wide-necked AcomA aneurysm</td>
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<tr>
<td>Wide-necked PcomA aneurysm</td>
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<tr>
<td>Failure of EVT</td>
</tr>
<tr>
<td>Wide-necked AcomA aneurysm</td>
</tr>
<tr>
<td>Distal PICA aneurysm</td>
</tr>
<tr>
<td>Significant recanalisation despite two EVT</td>
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<tr>
<td>Mass effect on the pituitary gland</td>
</tr>
<tr>
<td>Contraindication to contrast iodine (kidney dysfunction)</td>
</tr>
<tr>
<td>Giant PcomA aneurysm with failure of test occlusion</td>
</tr>
<tr>
<td>Significant internal carotid artery stenosis</td>
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</table>

EVT: endovascular treatment (traitement endovasculaire); MCA: middle cerebral artery; AcomA: anterior communicating artery; PcomA: posterior communicating artery; PICA: posterior cerebellar artery (artère cérébelleuse postéro-inférieure); ACI: artère carotide interne.
initiated 3 days prior to the procedure with 160 mg of aspirin and 75 mg of clopidogrel per day. If the stent was used in patients with a ruptured aneurysm, medical premedication was initiated on the day of the procedure with 320 mg of aspirin and 225 mg of clopidogrel. All patients treated with a stent were maintained on clopidogrel (75 mg per day) for a month and aspirin (160 mg per day) for 12 months.

All patients were treated by selective embolisation with Guglielmi Detachable Coils (Target Therapeutics, Fremont, CA), or Microplex coils (MicroVention, Aliso Vieja, CA), or Orbit coils (Cordis, Miami Lakes, FL), or Matrix coils (Target Therapeutics, Fremont, CA). Technique of endosaccular coiling procedure has already been published in the literature [6,28,34]. After endovascular treatment, patients were transferred to the intensive care unit, and fluid balance, neurological status, blood pressure were carefully monitored.

Immediate outcome

Patients were evaluated by angiography to document aneurysm obliteration. Angiographic results were classified as: complete occlusion (no contrast filling the aneurysmal sac), neck remnant (residual contrast filling the aneurysmal neck), and incomplete occlusion (residual contrast filling the aneurysmal body). A senior neurosurgeon and neurointerventionalist (FL, MB, BL) recorded the clinical course, including worsening of symptoms and death. Clinical outcome was graded according to a modified Glasgow outcome scale (GOS) [13] as follows: excellent (neurologically intact); good (mild hemiparesis, cranial nerve palsy, or other deficit that does not interfere with daily functioning or work); fair (significant hemiparesis, aphasia, confusion, or other deficit that interferes with daily activities or prevents a return to work); and poor (coma or severe neurological deficit rendering the patient dependent on family or nursing staff).

Patient follow-up

Imaging follow-up included magnetic resonance angiography (MRA) at six and 12 months after treatment and a conventional angiography at 12 months. MRA exams assessed intracranial vessels by using time of flight (34/5.4, flip angle = 50°, field of view = 25, acquisition volume = 55 mm and matrix = 200 × 512) and Gadolinium-enhanced (6.8/2.3, flip angle = 50°, field of view = 25, acquisition volume = 55 mm and matrix = 15 × 512) angiography. Follow-up conventional and MR angiograms were compared to immediate post-embolisation angiograms and were then assigned to one of three categories:

- further thrombosis, when the amount of contrast agent filling the aneurysm decreased;
- unchanged, when a similar degree of aneurysm occlusion in multiple projections was found;
- recanalisation, when an increase of the amount of contrast filling in the aneurysm was observed.

When a recanalisation — that was judged to require a re-treatment — was observed on the 6-month MRA, a conventional angiography was performed. Conventional angiographies, MRA were reviewed for all patients by two senior neuroradiologists together (BL, DB).

Clinical examination by a senior neurosurgeon or neuroradiologist (BL, FL, MB) was obtained at three and 12 months after treatment.

Results

Aneurysm groups

Group I consisted of 80 aneurysms (80 patients) that presented either with SAH (N = 74), mass effect (N = 5), or TIA (N = 1). Group II included 94 unruptured aneurysms (72 patients) and group III included 13 aneurysms (13 patients) that had to be re-treated (see anatomical outcome) because of a significant recanalisation from a previously ruptured (N = 10) or unruptured (N = 3) coiled aneurysm.

Aneurysm morphology and location in the endovascular cohort

Aneurysms location and morphology are described in Tables 2,3 respectively.

Aneurysms were located in the anterior circulation in 83.5% of cases and in the posterior circulation in 16.5% of cases. Seventy-eight aneurysms were small with a small neck (44.5%), 71 were small with a wide neck (40.5%), 15 were large (8.5%), and 11 were giant aneurysms (6.5%). Of these 175 aneurysms, six were fusiform.

Feasibility of EVT

EVT was judged feasible (BL) in 144 patients with 175 intracranial aneurysms and was successfully performed in 141 patients with 172 aneurysms (87.3% of all treated aneurysms, 172/197 aneurysms). Overall success rate of EVT is thus 98.3% (172/175 aneurysms). In three patients, EVT failed (EVT failure rate of 1.7%) and surgical clipping these patients were treated by (Table 1). Two patients had a wide-necked anterior communicating artery aneurysm and we could not ideally protect both A2 segment arising from the neck. In one patient with a distal posterior inferior cerebellar artery (PICA) aneurysm, the PICA had an extracranial origin with multiple loops that prevented safe cathe-
Endovascular procedure

Different endovascular techniques were used to treat aneurysms and they are summarized in Table 4. Among 172 aneurysms successfully treated by embolisation, EVT consisted of endosaccular coiling without the use of adjunctive technique in 106 aneurysms (61.6%). The balloon-assisted technique was used in 37 aneurysms (21.5%) that presented with an unfavourable anatomical configuration such as wide-necked aneurysms (neck > 4 mm or neck/sac ratio > 0.7) or aneurysms with a branch arising from the sac. The stent-assisted technique, with subsequent coiling of the sac, was used in 17 aneurysms (9.9%) with a very wide neck or in case of fusiform aneurysms. In six very wide-necked aneurysms (3.5%) with a very small sac (< 3 mm), only stent deployment was performed in order to promote progressive intraaneurysmal thrombosis. Finally, parent artery occlusion was considered and performed in six cases (3.5%) including five unruptured giant aneurysms and one ruptured, distal, and fusiform PICA aneurysm.

Clinical outcome

Clinical outcome is summarised in Tables 5 and 6.

The modified GOS in 141 patients with 172 aneurysms treated by endovascular approach was as follows: excellent in 81.5% of patients, good in 7%, fair or poor in 3.5 and 8% of patients died. According to our classification in group I/group II, an excellent or a good outcome was observed in 83.4-95.8% of patients, and a poor or a fair outcome was observed in 5.3-1.4%, respectively. Nine patients died in group I (11.3%) and two in group II (2.8%).

EVT complications

Complications are summarised in Table 7.

Procedure-related complications occurred in 17/172 cases (10%) and are detailed in Table 7. These complications were observed during EVT of ten symptomatic patients (SAH in nine patients, mass effect in one patient) and seven asymptomatic patients. Complications included seven thromboembolic events, four intraprocedural aneurysm perforations, two coil protrusions, two retroperitoneal hematomas, one intraprocedural vessel dissection, and one post-procedural aneurysm rupture. These complications were associated with permanent neurological deficit in six patients and death in three patients. A 74-year-old man with multiple femoral stents and bypasses, presented with progressive hemiparesis caused by a 70 mm recurrence from a previously clipped aneurysm. EVT by selective coiling of the recurrent and

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**Table 3** Aneurysms anatomical configuration in 175 aneurysms selected for EVT

<table>
<thead>
<tr>
<th>Anatomical configuration</th>
<th>Number (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S/S: small aneurysm (&lt; 12 mm) with a small neck (&lt; 4 mm or neck/sac &lt; 0.7)</td>
<td>78 (44.5)</td>
</tr>
<tr>
<td>S/W: small aneurysm with a wide neck (&gt; 4 mm or neck/sac &gt; 0.7)</td>
<td>71 (40.5)</td>
</tr>
<tr>
<td>L: large aneurysm (12-25 mm)</td>
<td>15 (8.5)</td>
</tr>
<tr>
<td>G: giant aneurysm (&gt; 25 mm)</td>
<td>11 (6.5)</td>
</tr>
</tbody>
</table>

**Table 4** Technique used in 172 aneurysms successfully treated by endovascular approach

<table>
<thead>
<tr>
<th>Endovascular procedure</th>
<th>Number (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coiling</td>
<td>106 (61.6)</td>
</tr>
<tr>
<td>Balloon-assisted coil</td>
<td>37 (21.5)</td>
</tr>
<tr>
<td>Stent-assisted coil</td>
<td>17 (9.9)</td>
</tr>
<tr>
<td>Stent alone</td>
<td>6 (3.5)</td>
</tr>
<tr>
<td>Parent artery occlusion</td>
<td>6 (3.5)</td>
</tr>
</tbody>
</table>

**Table 5** Group I: clinical outcome in 80 symptomatic patients treated for 80 aneurysms by endovascular approach

<table>
<thead>
<tr>
<th>Modified GOS</th>
<th>Hunt and Hess Grade I, II</th>
<th>Hunt and Hess Grade III</th>
<th>Hunt and Hess Grade IV, V</th>
<th>Mass effect, TIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>43</td>
<td>2</td>
<td>7</td>
<td>56/78 (71.8%)</td>
</tr>
<tr>
<td>Good</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>9/78 (11.5%)</td>
</tr>
<tr>
<td>Fair</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2/78 (2.6%)</td>
</tr>
<tr>
<td>Poor</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2/78 (2.6%)</td>
</tr>
<tr>
<td>Death</td>
<td>3</td>
<td>0</td>
<td>5</td>
<td>9/78 (11.5%)</td>
</tr>
<tr>
<td>Total (78 patients)</td>
<td>50/78 (64.1%)</td>
<td>2/78 (2.6%)</td>
<td>20/78 (25.6%)</td>
<td>6/78 (7.7%)</td>
</tr>
</tbody>
</table>

GOS: Glasgow outcome scale; TIA: transient ischemic attacks.
mostly thrombosed sac was performed and the patient woke up with a similar neurological exam. The patient, who was under clopidogrel for years, developed a retroperitoneal haematoma that led to cardiac dysfunction and death 12 hours after EVT. One 44-year-old woman, with multiple sclerosis, presented with three unruptured middle cerebral artery (MCA) aneurysms. All aneurysms were treated by EVT in separate sessions. The balloon-assisted technique was used for the last two aneurysms. These two aneurysms were facing each other and located on the M1 segment of the right MCA. One of these aneurysms presented with a branch arising from the sac and a neck remnant was obtained at the end of EVT. Then the second aneurysm was treated with a remodelling balloon that was inflated several times in front of the neck remnant of the previously coiled aneurysm. After EVT of the last aneurysm, the patient recovered from anaesthesia with a normal neurological exam. Fourteen hours later, she experienced a right sylvian SAH. Angiographic control showed an increased size of the neck remnant of the previously coiled aneurysm. The patient remained in deep coma for 2 weeks and because of the family’s demand, all supportive treatments were stopped and the patient eventually died. Finally, one 53-year-old asymptomatic patient experienced an anterior cerebral artery (ACA) dissection during EVT of a wide-necked anterior communicating artery aneurysm. During embolisation, a coil migration occurred and a retriever (In Time, Target Therapeutics, Fremont, CA) was used to catch the coil. During withdrawal of the retriever, a part of it broke and remained blocked within the ACA. The patient was put on abciximab and another retriever was used to catch the first one. During these manipulations, the patient developed a SAH from an ACA dissection and died several hours later.

In the remaining eight patients, procedure-related complications had no neurological consequence. Overall procedure-related morbidity and mortality of EVT were thus 4.2% (6/141 patients) and 2.1% (3/141 patients), respectively.

### Anatomical outcome

Immediately after EVT of 172 aneurysms, the angiographic occlusion of the sac was judged as follows: complete in 117 cases (68%), neck remnant in 40 cases (23%), and incomplete in 15 cases (9%).

Imaging follow-up (mean, 11 months) was obtained for 119 aneurysms: 95 aneurysms were followed-up at
12 months and 23 at 6 months. Significant recanalisation was observed in 13/119 aneurysms (11%) including ten ruptured and three unruptured aneurysms. Of these 13 aneurysms, eight were small with a wide neck (four treated with the balloon-assisted technique), three were small with a small neck, one was large, and one was a giant aneurysm. These aneurysms were re-treated by embolisation (N = 10) or surgical clipping (N = 3). The treatment choice was based on the anatomical configuration of the aneurysm recanalisation. EVT was also considered as the first-intention re-treatment if it was judged feasible by the senior neuroradiologist (BL). Embolisation resulted in five complete occlusions, four neck remnants, one incomplete occlusion whereas surgical clipping resulted in three complete occlusions. No complication occurred during these re-treatments.

Minor recanalisation was observed in 17/119 aneurysms (14.3%) and these patients are currently followed-up without re-treatment. Further thrombosis was observed in 8/119 aneurysms (6.7%). These aneurysms were unruptured and/or treated with the stent-assisted technique in six cases. Finally, 81/119 aneurysms (68%) showed stable anatomical results.

Discussion

This study shows that EVT as first-line treatment is feasible with good clinical results in 87.3% of patients with intracranial aneurysms. Although this therapeutic strategy frequently requires the use of balloon- or stent-assisted techniques, it was not associated with higher complication rate. The recent development of these new endovascular techniques and tools allow thus to treat more and more aneurysms by endovascular approach with satisfying clinical results. However, these technological advances do not improve the major limitation of EVT that is anatomical results stability.

EVT as first-intention treatment: impact of new endovascular techniques

To our knowledge, there are only two series that have prospectively evaluated aneurysm treatment results when EVT is considered as the first therapeutic option in all patients [21,26]. Raftopoulos et al. [26] were the first to conduct such study, between 1996-1999, in 103 patients harbouring intracranial aneurysms. Their study showed that EVT was associated with a significant number of treatment failures and poor outcomes. No adjunctive endovascular technique was used to treat aneurysms in this series. More recently, Mejdoubi et al. [21] reported much better results in a similar study that has included 230 patients treated between 1998 and 2002. This study showed that EVT was feasible with good results in 82% of all ruptured aneurysms treated over a 5-year period in a single centre. Moreover, their EVT failure rate was very low (3.3%) and that confirmed their good selection criteria for EVT. In their study, the balloon- and the stent-assisted techniques were performed in 11.9% of all procedures and this might partially explain the significant difference with the series of Raftopoulos et al. [26]. Indeed, over the last decade, new endovascular techniques and tools (three-dimensional coils, remodelling balloons, stents) have been developed to increase EVT indications. Several authors have shown the safety and efficacy of these techniques [1,2,15,17-19,22] for complex aneurysms treatment so that most intracranial aneurysms are now technically treatable by endovascular approach. This latter consideration is especially important for EVT of MCA aneurysms. Only few authors, including our group [9,20,33], have shown that the availability of adjunctive techniques has made more MCA aneurysms treatable by endovascular approach with good results. In the present study, MCA aneurysms represented 23.5% of all embolised aneurysms that is much higher than the rate reported in the ISAT or ISUIA studies [10,12]. Unsurprisingly, the percentage of aneurysms treated by endovascular approach should therefore increase over time in specialised neurovascular centres. All these findings were confirmed in our study that has included patients between 2004 and 2006. Indeed, when EVT was judged feasible with satisfying results and was thus proposed as first-intention treatment, it could successfully be performed in 98.3% of all selected aneurysms. Our EVT failure rate is thus very low (1.7%) and this highlights our rigorous selection criteria for EVT. Moreover, a retrospective analysis of these three cases was performed and nothing was suggestive of an expected EVT failure. Thus, we believe that this failure rate is very satisfying and may be considered as a slight limitation of the endovascular technique. Overall, 87.3% of all aneurysms that were seen in our institution during a 30-month period were successfully treated by endovascular approach. The impact of new endovascular techniques and tools is thus very significant over the coiling/clipping ratio and it should even increase in the future because of the permanent development of new endovascular devices.

Endovascular procedure

In our series, balloon- or stent-assisted techniques were used in 34.9% of all endovascular procedures. This rate of adjunctive techniques use is higher to those reported in most large published series [4,7,10,12,31] and may be explained by the high percentage (40.5%) of wide-necked aneurysms treated in our series. However, the high rate of balloon-assisted embolisation is not different (21.5 versus 25%) from recently unpublished data from Mejdoubi et al. [21]. There is an obvious recruitment bias in our study that is related to the therapeutic protocol that has been established during 30 months in our institution and that is also related to the referral of complex cases that were refused for treatment in other centres.

Another reason for the frequent use of the balloon-assisted technique is more personal and related to the senior neurointerventionalist training that partially took place in the department of J. Moret (Paris, France) who first has described the technique [22]. Furthermore, we have previously shown that the use of new remodelling balloon allows for a safer treatment of wide-necked bifurcation aneurysms or aneurysms with a branch arising from the sac [17,18]. The remodelling technique facilitates coil placement across the aneurysm neck and may be very useful when an aneurysm perforation occurs in order to quickly
stop the bleeding. Therefore, this technique is routinely used in our department whenever it may help EVT.

The stent-assisted technique was performed alone (six aneurysms, 3.5%) or with subsequent coiling of the sac (17 aneurysms, 9.9%) when EVT with or without a remodelling balloon was judged unfeasible. The Leo stent (Balt, Montmorency, France) was used in all cases because it may be repositioned whenever necessary. This technique proved to be effective and safe for EVT of complex aneurysms [1, 15, 19] so that it is now part of the therapeutic armamentarium of complex cerebral aneurysms.

Complications

In this prospective series over 30 months, 87.3% of all aneurysms were successfully treated by endovascular approach including a high percentage of wide-necked aneurysms (40.5%). In order to safely treat these difficult aneurysms, remodelling balloons and stents were frequently used. Despite the use of such adjunctive techniques, the procedural complication rate (10%) was not higher than those reported in large series of aneurysms treated mostly by conventional coiling [4, 5, 7, 10–12, 20, 23, 31, 32]. There is a current debate in the literature whether or not these new techniques increase EVT complication rate. Several authors have reported an increased complication rate [7, 24] while others reported no significant increased complication rate with the use of balloons and stents [4, 18, 22, 30]. This difference might be explained by authors experience with these new techniques. Indeed, balloon- and stent-assisted techniques require a long learning curve and are mostly operators’ dependant. Our study does confirm these findings as it shows that complication rate of EVT are not increased when balloons and stents are routinely used.

Overall procedural morbidity and mortality rates were 4.2% (6 of 141 patients) and 2.1% (3 of 141 patients) respectively. If one considers that these rates might be calculated according to the number of treated aneurysms (172 aneurysms) rather than the number of patients (141 patients), these procedural complication rates are even lower. A procedural morbidity or mortality [8, 27, 29] that a re-treatment will be necessary in 10% of embolised aneurysms — including mostly ruptured lesions — and that EVT should therefore be considered as a staged treatment for a certain percentage of patients. Fortunately re-treatment by endovascular approach is associated with low complication rate of approximately 3% of severe morbidity or mortality [8, 27, 29]. Furthermore, this complication rate is not correlated to the aneurysm size and thus not higher among large and giant aneurysms. These latest aneurysms are often surgically challenging and clinical results are sometimes far from ideal [14]. Therefore, EVT of large and giant aneurysms must be considered as a reasonable therapeutic alternative even if it may sometimes require multiple sessions. Nevertheless, aneurysm recanalisation sometimes presents with complex anatomical configuration that may be more suitable for surgical clipping. Therefore, surgical clipping is considered by our neurovascular team as an alternative option in every case of aneurysm recanalisation that requires a re-treatment. Moreover, if a second significant recanalisation from a small aneurysm occurs despite two endovascular sessions (Table 1), surgical clipping is preferred for re-treatment.
Current EVT limitations

Our study partially confirms what could be expected from the development of new endovascular techniques and tools. On a technical point of view, most intracranial aneurysms are now treatable by endovascular approach and EVT is no more limited to small aneurysms with a small neck. It also appears obvious that these techniques require a learning curve and this may explain contradictory information within the literature about their associated complication rate. On a clinical point of view, EVT as first-line treatment seems a reasonable strategy that is associated with good clinical results. However, these new developments fail to circumvent the major limitation of EVT that remains the anatomical results stability.

Another limitation concerns EVT of small wide-necked aneurysms located on the AcomA, and on the MCA bifurcation. Most of our procedural complications occurred during EVT with or without adjunctive techniques of such cases. Even if these aneurysms are treatable by embolisation with good clinical results in most cases, they still represent a technical challenge for neurointerventionalists. Moreover, these aneurysms are associated with a higher rate of recanalisation because of the neck width and the water-hammer effect [16]. Therefore, if these aneurysms are not considered technically challenging by the surgical team, they might remain standard indications for clipping rather than embolisation.

Finally, intracranial stenting seems very promising, as it is associated with better anatomical results and stability. However, the stent-assisted technique has also limitations including the need for a potentially dangerous premedication and the unknown long-term outcome of such foreign bodies within cerebral vessels. In our department, this technique is therefore reserved for intracranial aneurysms that are not treatable by standard techniques including surgical clipping and/or embolisation with or without remodelling balloons.

Conclusion

This study suggests that a policy of EVT as first-intention treatment for patients with intracranial aneurysms is associated with a high success rate and good clinical results in 87.3% of cases. Although this therapeutic strategy frequently requires the use of balloon- or stent-assisted techniques, it does not increase overall procedural morbidity and mortality. However, this strategy is still limited by immediate and long-term anatomical results that are of major concern for aneurysms treatment. Technical improvements and/or innovations will be necessary to ideally establish in the future EVT as the first-intention treatment for all patients with both ruptured and unruptured intracranial aneurysms.

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