Surgical Outcome After Microsurgical Clipping of Internal Carotid Bifurcation Aneurysm. Series of 30 cases

ABSTRACT

Introduction: Internal carotid artery bifurcation aneurysms (ICAbiAs) are uncommon. They have a very low incidence in adults, accounting for only 5% of all intracranial aneurysms, and are even less common amongst aneurysms of the internal carotid artery (ICA). Surgical series regarding exclusively ICAbiAs are very scarce. Methods: We describe 30 ICAbiAs surgically treated patients from June 1995 to January 2020, in a universe of 648 aneurysms operated by the senior author in this paper. Results: At presentation 46% (14/30) of the ICAbiAs were ruptured. Good outcome was found in 73% of the 30 patients (Glasgow Outcome Scale score 5), whereas eight patients (26.6%) died. Conclusion: Aneurysms at this location, large sized, with broad neck, incorporating the origin of the middle cerebral or anterior cerebral arteries, and especially regarding the direct water hammer effect of flow at the carotid summit, often favor surgical treatment, in detriment of endovascular coiling or stenting.

Keywords: Internal carotid bifurcation aneurysm; Brain aneurysm; Vascular neurosurgery

RESUMO

Introdução: Os aneurismas de bifurcação da artéria carótida interna (ICAbiAs) são pouco comuns. Têm uma incidência muito baixa em adultos, representando apenas 5% de todos os aneurismas intracranianos, e são ainda menos comuns entre os aneurismas da artéria carótida interna (ICA). As séries cirúrgicas relativas exclusivamente ao ICAbiAs são muito escassas. Métodos: Descrevemos 30 pacientes ICAbiAs tratados cirurgicamente de junho de 1995 a janeiro de 2020, num universo de 648 aneurismas operados pelo autor sênior deste artigo. Resultados: 46% (14/30) do ICAbiAs foram rompidos na apresentação. 73% dos 30 pacientes tiveram um bom resultado (escala de Glasgow com escore 5), enquanto oito pacientes (26,6%) morreram. Conclusão: Os aneurismas neste local,
INTRODUCTION

Internal carotid artery bifurcation aneurysms (ICAbiAs) are uncommon. They frequently rupture at a younger age compared to other intracranial aneurysms, which correlates with remarkable socioeconomic impact. They have a very low incidence in adults, accounting for only five percent of all intracranial aneurysms. Little is known about its incidence, anatomical characteristics, clinical baseline, and outcomes of the surgical treatment of this kind of aneurysm.

Since the publication of the International Subarachnoid Aneurysm Trial and with the advancement of endovascular technique, the number of aneurysms treated by endovascular coiling has dramatically increased. However, the expansion of endovascular treatment has been driven by short-term safety data, and concerns about incomplete aneurysm obliteration, neck remnants and recurrence still afflict the scientific community. Moreover, ICAbiAs often harbor unfavorable morphologies (wide-necked or fusiform) and/or incorporate perforating branches (mainly the recurrent artery of Heubner), which may limit the usage of endovascular treatment. In recent years, various endovascular techniques emerged as promising tools to occlude the aneurysm and preserve the perforators, including intracranial stents, yet with conflicting results. Due to the so-called “water-hammer” effect, ICAbiAs often experience an unacceptable rate of recanalization after coiling (ranging from 17.5% to 22%).

Therefore, microneurosurgical clipping of ICAbiAs, despite its challenges (deep location and vital perforators surrounding or adherent to the aneurysm dome), is still a possible treatment, since it warrants lower rates of postoperative recanalization and rupture.

Surgical technique

ICAbiAs are routinely clipped using the standard pterional craniotomy, hence some special anatomical topics and landmarks need to be recognized. In approximately half of the patients, the aneurysm dome is pointed superiorly and may be embedded in frontal cerebral lobe. Starting frontal lobe retraction with the retractor adjacent to the carotid-optic cistern may cause premature rupture of the fundus or the aneurysm may become avulsed from the neck. Therefore, we perform wide splitting of the Sylvian fissure distal to proximal as the initial and important step to release cerebrospinal fluid (CSF) and to expose the internal carotid artery bifurcation, which predominantly eliminates the need for brain retraction. Sylvian fissure splitting exposes the M1 portion of middle cerebral artery (MCA), which is traced to the ICA bifurcation. Before dissecting the aneurysm, we also expose the A1 segment from anterior cerebral artery (ACA) so that we have complete proximal and distal control.

Elective temporary clipping of the internal carotid artery before final dissection of the aneurysm neck and fundus is useful in preventing premature rupture and in improving the visualization of the relationship between the neck and the perforating vessels. It is important to avoid injuring or including the perforators during application of the aneurysm clip. After temporary clipping, the aneurysm is dissected to identify and preserve the perforating branches and the recurrent artery of Heubner. Most of the perforators are located on the posterior aspect of the aneurysm. Dissection of the neck in posteriorly projected aneurysms was especially challenging when the recurrent artery of Heubner was related or adherent to the neck (Figure 1 A-F).

Anesthesia considerations

It is highly advisable using the best anesthesiology practices in neurosurgical treatment of intracranial aneurysms.
Figure 1. (A) After anterior curvilinear incision centered in pterium (inside the black line) we pull the skin and temporal muscle with surgical hooks; (B) Surgical exposal of pterional region, temporal scale suture and temporal line; (C) Surgical view of the dura mater after frontotemporal craniotomy centered in the pterium bone; (D) Opening of the dura mater in shape of a turned down boat sail; (E) FL: Frontal Lobe, TL: Temporal Lobe, SF: Sylvian Fissure, IN: Insula, M2: Second branch of the middle cerebral artery; (F) ON: Optical Nerve, CI: Internal Carotid, A1: First segment of the left anterior cerebral artery, M1: First branch of the middle cerebral artery, M2: Second branch of the middle cerebral artery, the black arrow is pointing at the carotid artery bifurcation. Complete overture of the sylvian fissure in order to expose totally the carotid artery bifurcation.

Standard American Society of Anesthesiologists monitors, and invasive arterial monitoring are necessary during this kind of surgery. Choosing between central venous pressure and pulmonary artery pressure monitoring depends on several factors including patient medical history, size and location of the intracranial aneurysms, use of inotropic agents, and the anesthesiologist's discretion.
Induction of general anesthesia and intubation of the patient should be accomplished in a smooth and controlled manner. Small doses of anxiolytics like midazolam can help to decrease patient anxiety preoperatively, although one should be aware that this can change neurologic evaluation and create suspicion of deteriorating mental status postoperatively, especially in elderly patients.

Pinning the head in a Mayfield surgical frame is associated with a high sympathetic discharge, systemic hypertension, and potential aneurysm rupture. A bolus of opioids, such as sufentanil and fentanyl, and scalp infiltration with a local anesthetic attenuates the hemodynamic changes during head pinning.

The surgical decision to use temporary clipping should prompt the anesthesia team to consider measures for brain protection, because temporary clipping can cause a period of reversible focal cerebral ischemia.

Communication between the surgeon and anesthesiologist about timing of application and release of the temporary clip is one of the most important factors in achieving optimal oxygenation and perfusion of the brain during this critical period.

If temporary clips are used before placement of the permanent aneurysm clip, the anesthesiologist can decrease the cerebral metabolic rate for oxygen by giving a bolus of IV anesthetic while blood pressure is maintained. A moderate decrease in blood pressure can help the surgeon manipulate the artery for placement of the temporary clip. After placement, however, a higher blood pressure is needed to promote collateral perfusion to the ischemic area.

The Intraoperative Hypothermia for Aneurysm Surgery Trial, an actual Cochrane meta-analysis, showed that short-duration intraoperative hypothermia did not improve 3-month neurologic outcome after craniotomy for good-grade patients with aneurysmal subarachnoid hemorrhage. Furthermore, hypothermia may be associated with arrhythmias and cardiac ischemia, decreased platelet activity, prolonged coagulation, and increased infection rate.

Hyperglycemia also has a deleterious effect on recovery from ischemic brain injury. The prophylactic use of calcium antagonists such as nimodipine in patients with subarachnoid hemorrhage (SAH) reduces the risk of brain damage. The efficacy of magnesium in preventing delayed ischemic neurologic deficits in patients with SAH seems to be comparable with nimodipine.

**METHODS**

Thirty patients treated for intracranial aneurysm from June 1995 to January 2020 had the aneurysm arising from the bifurcation of the internal carotid artery, from a universe of 648 aneurysms operated by the senior author during this period in Santa Paula Hospital and Nove de Julho Hospital. These patients were selected for a retrospective analysis of their clinical, radiological, surgical, and post-operative records.

**RESULTS**

The mean age of ICABIAs treated patients was 49.6 years (ranging from 25 to 82 years old), and 26.7% of the patients were aged 30 years or younger. Eighteen patients were female and the other twelve were male (Table 1).

Forty six percent (14/30) of the ICABIAs were ruptured at presentation, with subarachnoid hemorrhage. The Hunt and Hess (HH) grading scale was used to access the neurological status on admission and prior to surgery. Fifty seven percent (57.1%) of 14 patients with subarachnoid hemorrhage were HH grades I and II at presentation, whereas 6 (42.9%) were in grades III and IV (Table 2).

**Table 1. Demographics.**

<table>
<thead>
<tr>
<th>Total</th>
<th>30 patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>49.6 years</td>
</tr>
<tr>
<td>Range</td>
<td>25-82 years</td>
</tr>
<tr>
<td>≤ 30 years</td>
<td>26.7% (8/30)</td>
</tr>
<tr>
<td>Female</td>
<td>60% (18/30)</td>
</tr>
</tbody>
</table>

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Twenty six percent (26.7%) of patients harbored multiple aneurysms, two patients with aneurysms in the anterior and posterior circulation (basilar apex aneurysm) and 6 patients with aneurysms in anterior circulation, mainly ICA communicating segment and MCA aneurysms (Table 3).

Clinical comorbidities were relatively common among our casuistic. Sixty six percent (66.7%) of patients were smokers, whereas 40% harbored systemic arterial hypertension, 20% had high blood cholesterol level, and 13% had type 2 diabetes mellitus (Table 4).

Review of the digital subtraction angiogram by an independent neuroradiologist was feasible in all patients. The size of the aneurysm was below 10 mm in 22 cases (73.3%), 11 to 20 mm in 6 cases (20%) and above 20 mm in two (6.6%). The aneurysm projected superiorly in 20 cases (66.6%), anteriorly in 6 cases (20%), and posteriorly in 4 cases (13.3%) (Table 5). The recurrent artery of Heubner was almost always located on the posterior part of the aneurysm, and without significant adherence to the aneurysm neck.

Angiographic vasospasm occurred in all patients who presented Hunt and Hess grade above or equal to II (8 patients), however only 6 patients developed symptomatic vasospasm, and have had their surgeries postponed (Table 6). All patients with SAH were operated within 72 hours of the last ictus, excluding those with symptomatic vasospasm.

Seventy three percent of the 30 patients accomplished good outcome (Glasgow Outcome Scale – GOS score 5), whereas 8 patients (26.6%) died. Six deaths could be attributed to poor clinical status (Hunt and Hess grades III and IV), with the added complication of septicemia in two patients and delayed cerebral ischemia due to vasospasm in another two. Unfortunately, two other deaths were due to pulmonary embolism, one of them in a patient submitted to elective surgery aiming to clip a giant ICAbiAs, measuring above 30 mm (Table 7).
DISCUSSION

The reported incidence of ICA bifurcation aneurysms varies from two to ten percent of all patients operated for intracranial aneurysms\(^1\). In our series, the incidence was 2.16%, resembling the worldwide previous publications. The incidence of multiple aneurysms ranges from nineteen to twenty percent worldwide\(^{1}\), whereas in our series 26.6% had additional aneurysms, most often at anterior circulation.

The gender predominance varies with the aneurysm site. A series of 1104 cases of ICA aneurysms, from the cooperative study chaired by Locksley et al.\(^{12}\), showed the highest female predominance (1:7.3) in patients with intracavernous aneurysm, and the lowest (1:1.6) in patients with ICAbiAs. In our series 60% were female, with a female predominance of 1:1.5, comparable to Locksley et al. enormous series\(^{12}\).

Lehecka et al.\(^{13}\) published a splendid paper regarding microneurosurgical management of ICAbiAs. They evaluated more than 11,000 patients with aneurysms and only 4% had ICAbiAs, in agreement with our incidence and the one worldwide. They found multiple aneurysms in 43% of patients, while we found in 26.7%. ICAbiAs represented 18% of all intracranial aneurysms ruptured before the age of 30 years.

Elective temporary clipping of the ICA prior to the final dissection of the neck and placement of the aneurysm clip is a useful strategy, which makes dissection of the aneurysm much safer and easier, while allowing better identification of the perforators before final placement of the clip. It should also be considered that emergency temporary clipping may be needed in the event of intraoperative aneurysm rupture, therefore the preemptive use of elective temporary clipping decreases the risk of perforator injury\(^{14}\).

The authors have showed (de Araujo et al.\(^{14}\)) that elective temporary clipping of anterior communicating aneurysms did not impact the outcome, although it prevents intraoperative anterior circulation aneurysmal rupture. However, in this series, due to the small number of patients and to technical nuances of the senior author who routinely avoids using temporary clipping in ICAbiAs (Figures 2 A-D, showing images before and after clipping), further conclusions regarding elective temporary clipping versus outcome are impossible.

Mortality rate in some of the older series was high, ranging up to 30%, but the introduction of microneurosurgery techniques has reduced the rates to 0-12%\(^{1}\). The most important factor affecting outcome is the clinical grade of the patient prior to surgery. Our overall mortality was 26.6% (8 patients), quite high to microsurgery era, despite the fact those six patients had poor clinical status prior to surgery (Hunt and Hess grades III and IV) and one patient had a giant aneurysm and died due to pulmonary embolism.

Another noteworthy technical nuance, which is recommended by the scientific community since the masterpiece publications of Yaşargil et al.\(^{5}\) and performed routinely by the senior author, is the wide opening of the sylvian fissure from distal to proximal, to identify the MCA and approach the ICA bifurcation (Figure 3 A-E).

Nowadays, intraoperative micro-Doppler sonography or intraoperative fluorescence angiography (Indocyanine green angiography) ensures patency of perforating vessels, mainly the recurrent artery of Heubner, which originates from the anterior cerebral artery corner and runs posteromedially to the fundus of the aneurysm. It is also important to consider the medial lenticulostriate arteries, which are from the A1 segment of the anterior cerebral artery, the lateral lenticulostrate arteries, from the M1 portion of the middle cerebral artery, the hypothalamic branches of the posterior communicating artery, the branches of the anterior choroidal artery during the surgery of bifurcation aneurysms, as they are, together with the artery of Heubner, intimately involved with the back of the aneurysm neck.

Our approach of pterional craniotomy with the wide splitting of the Sylvian fissure allows a proximal and distal control that would not be achieved with a contralateral approach. In cases of bilateral ICA aneurysms, the contralateral clipping can be an opportunity to decrease operation time, length of hospitalization, risk of procedural complications and costs to both hospital and patient\(^{15,16}\). The contralateral approach to the internal carotid artery termination is distinguished by an initial pterional craniotomy with low fronto-orbital extension for adequate contralateral exposure, by the exposure of the optic chiasm and fenestration of the lamina terminalis, then the opening of the contralateral falciform fold for contralateral optic nerve mobilization, lateral retraction of the same nerve for exposure of the medial aspect of the proximal contralateral carotid, and then exposure of the ICA termination\(^{16}\). The exposure of the contralateral ICA termination in the supracarotid space can either be accomplished by following the course of the carotid distally or by following the course of the contralateral A1 segment of the ACA proximally, which then permits the dissection of the contralateral M1 segment of the MCA and contralateral frontal lobe.

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Though consistently exposable in cadaveric specimens, it can be highly impacted by individual anatomy and the clinical setting, and patients presenting SAH, brain swelling, hydrocephalus, and inflamed arachnoid adhesions, may be deemed unsuitable for the procedure\textsuperscript{9}. The procedure can be effective and safe, its feasibility depending on the anatomic parameters and vascular segment of the aneurysm\textsuperscript{9,15}. Meanwhile, the pivotal proximal and distal control provided by exposing the M1 portion of MCA and the A1 segment from ACA with the wide split of the sylvian fissure on the ipsilateral side safeguards against the risks in case of hemorrhages. The pterional approach is comfortable to neurosurgeons, with access to the basal cisterns, to the anterior communicating artery (and its perforating vessels to the septal region and chiasm), and to common locations in cases of multiple ipsilateral aneurysms\textsuperscript{17}.

At last, it is worth mentioning that minimally invasive techniques, such as transpalpebral and minipterional approaches, are new alternatives to aneurysm treatment. While endovascular treatment might face challenges regarding the anatomical configuration of bifurcation aneurysms\textsuperscript{18}, minimally invasive treatments deliver surgical treatment with a lesser degree of trauma\textsuperscript{19}, such as the dissection trauma that the temporal lobe, insula, draining veins and middle cerebral artery undergo in the wide splitting of the sylvian fissure, and the trauma leading to temporalis muscle atrophy with the pterional craniotomy\textsuperscript{20}. A notable example is the transpalpebral, supratarsal, and transorbital roof minicraniotomy approach to MCA aneurysms (Mandel et al.\textsuperscript{19}) in which a standard procedure was developed for a comparable working area and a favorable angle of attack in comparison to a pterional craniotomy.

Figure 2. (A) Cerebral digital subtraction angiography (CDSA) showing a large Internal Carotid Artery bifurcation Aneurysm (ICAbiAs) superiorly projected, incorporating the origin of Anterior Cerebral Artery (ACA); (B) 3D reconstruction of cerebral angiogram, small ICAbiAs anteriorly displaced, with broad neck; (C) Cerebral angiotomography, large ICAbiAs, incorporating the origin of ACA and Middle Cerebral Artery (MCA), with broad neck; (D) CDSA showing precise location of clip after microsurgical repair of a large ICAbiAs displaced in figure 2A.
CONCLUSION

Despite its low incidence, ICA biAs are an important topic in vascular neurosurgery. Large and posteriorly projected aneurysms pose special surgical challenges. Temperance in microsurgical field and respect to technical nuances, such as distal to proximal wide opening of the sylvian fissure and preservation of perforating vessels (mainly the recurrent artery of Heubner), accomplish favorable outcome.

Even though endovascular coiling and stenting are well-established techniques, we believe that surgical treatment still has a role in this field, especially for aneurysms at this location, large sized, with broad neck, incorporating the origin of the middle cerebral or anterior cerebral arteries, and considering the direct water hammer effect of flow at the carotid summit.

Figure 3. (A) Cerebral digital subtraction angiography (CDSA) showing a small Internal Carotid Artery bifurcation Aneurysm (ICA biAs) superiorly projected; (B) 3D cerebral angiogram, small ICA biAs associated with choroideo segment aneurysm; (C) Cerebral angio 3D reconstruction, showing clearly the aneurysm; (D) Surgical view showing the ICA biAs aneurysm before clipping; (E) Surgical view showing the ICA biAs aneurysm after clipping.
REFERENCES


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