Aneurysm-Rainbow Team/Helsinki

Microneurosurgical management of anterior communicating artery aneurysms

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Abstract

Background: Anterior communicating artery complex is the most frequent site of intracranial aneurysms in most reported series. Anterior communicating artery aneurysms are the most complex aneurysms of the anterior circulation due to the angioarchitecture and flow dynamics of the ACoA region, frequent anatomical variations, deep interhemispheric location, and danger of severing the perforators with ensuing neurologic deficits. The authors review the practical microsurgical anatomy, importance of preoperative imaging in surgical planning, and microneurosurgical steps in dissection and clipping of ACoAAs.

Methods: This review, and the whole series on intracranial aneurysms, are mainly based on the personal microneurosurgical experience of the senior author (JH) in 2 Finnish centers (Helsinki and Kuopio), which serve, without patient selection, the catchment area in Southern and Eastern Finland.

Results: These 2 centers have treated more than 10,000 patients with aneurysm since 1951. In the Kuopio Cerebral Aneurysm Database of 3,005 patients with 4,253 aneurysms, 1,145 patients (38%) had altogether 1,179 ACA aneurysms; of them, 898 patients harbored 921 (78%) ACoAAs. In this series, 715 patients (80%) presented with ruptured ACoAAs with the median diameter of 7 mm. Giant ACoAAs were present in 15 (2%), whereas only 3 (0.3%) were classified as fusiform.

Conclusions: Anterior communicating artery aneurysms present frequently with SAH at small size. Furthermore, unruptured ACoAAs may have increased risk of rupture regardless of size, also as an associated aneurysm, and require treatment. The aim in microneurosurgical management of an ACoAA is total occlusion of the aneurysm sac with preservation of flow in all branching and perforating arteries. This demanding task necessitates perfect surgical strategy based on review of the 3D angioarchitecture and abnormalities of the patient’s ACoA complex with its ACoAA and to orientate accordingly during the microsurgical dissection. The surgical trajectory should provide optimal visualization of the ACoA complex without massive brain retraction. Precise dissection in the 3D anatomy of the ACoA complex and perforators requires not only experience and skill but
1. Introduction

Aneurysms of the ACA can be classified into 5 groups: A1As or proximal ACA aneurysms; ACoAAs or aneurysms of the anterior communicating artery, aneurysms of the A2 segment (A2As), aneurysms of the A3 segment (A3As) or classic pericallosal aneurysms; and aneurysms of the A4 and AS segments (AdistAs) or distal ACA aneurysms (Table 1, Fig. 1) [12].

1.1. Anterior communicating artery aneurysms

In many series, the ACoA complex is the most frequent site of intracranial aneurysms [48,54,55,57,66,89,105,126]. In Finland, the MCA bifurcation is more frequent [13,86], in theory, because of genetic features the branching site wall of the cerebral artery tree in Finns. The ACoAAs are, by far, the most frequent ACA aneurysms. They are the most complex aneurysms of the anterior circulation due to the angioarchitecture and flow dynamics of the ACoA region, frequent anatomical variations, deep interhemispheric location, and danger of severing the perforators with ensuing neurologic deficits. The microsurgical challenges with the ICA aneurysms are more related to the proximity and involvement of the skull base structures.

There is often asymmetry of the A1 segments, and other anatomical variations are frequent in the ACoA region. The ACoAAs usually originate from the junction of the dominant A1 and the ACoA. The dome of ACoAA is often in close proximity with 1 or both A2s. The recurrent artery of Heubner (RAH) and perforators arising from the ACoA complex may become occluded during exosurgery or endosurgery with serious consequences [3,76,85,105,126]. Large series of ACoAAs report relatively high management morbidity and mortality [48]. Cognitive dysfunction and electrolyte imbalances are the major complications associated with the rupture of ACoAAs [2,10,15,29,56,58,105,108,126].

Anterior communicating artery aneurysms present frequently with SAH at small size [9,19,39,47,64,69,70]. Unruptured ACoAAs may pose with an increased risk of rupture regardless of size [64], also as an associated aneurysm [30,39,64,65].

The microneurosurgical clipping of ACoAAs requires experienced hands. The aim is total occlusion of the aneurysm while preserving the flow in the branching arteries and perforators. The surgical trajectory should provide optimal visualization of the ACoA complex with minimal frontal brain retraction. Precise dissection in the 3D anatomy of the ACoA complex and perforators requires not only experience and skill but patience to work the dome and base under repeated protection of temporary clips and pilot clips. This is particularly important with the complex, large, and giant aneurysms [60,85,97,126,128].

1.2. Purpose of review

This review, and the whole series on intracranial aneurysms, is intended for the neurosurgeons that are subspecializing in neurovascular surgery. The purpose is to review the practical anatomy, preoperative planning, and avoidance of complications in the microsurgical dissection and clipping of ACoAAs.

1.3. Authors

The microneurosurgical technique in this review is mainly based on the personal experience of the senior author (JH) in 2 Finnish centers (Helsinki and Kuopio), which serve without selection the catchment area in Southern and Eastern Finland. These 2 centers have treated more than 10000 patients with aneurysm since 1951.

The data presented in our series are of articles representing 3005 consecutive patients harbouring 4253 IAs from the Kuopio Cerebral Aneurysm Database (1977-2005). The aim is to present a consecutive, nonselected population-based series of IAs without any selection bias. This database is not reflective of the personal series of the senior author (JH) alone.

2. Occurrence of ACoAAs

In most series, the ACoA complex is the most common site for intracranial aneurysms [48,54,55,57,66,89,105,126]. Tables 2 to 5 present clinical data of the 898 ACoAA patients in a consecutive series of 3005 patients with intracranial aneurysms from 1977 to 2005 in the Kuopio Cerebral Aneurysm Database. Of the 3005 Finnish patients, 1145 patients (38%) had altogether 1179 ACA aneurysms, of which 921 (78%) were at the ACoA complex (Table 2). In contrast, 1456 (49%) patients had 1704 MCA aneurysms, of which 1385 (81%) were at the MCA
bifurcation [13]. Of the 921 ACoAAs in our series, 15 (2%) were giant, whereas only 3 (0.3%) were classified as fusiform (Table 3).

2.1. Ruptured and unruptured ACoAAs

Of the 3005 patients with aneurysm, 2365 (79%) had primary aneurysmal SAHs. The total number of unruptured aneurysms was 1888 in this series. Table 2 presents the proportion of the ACoAAs among the aneurysms on the ACA (A1As; ACoAAs; A2As; A3As; AdistAs) as well as in the whole series. Among the 2365 patients with primary SAH, the ACoAAs were virtually as frequent sites of rupture (n = 715, 30%) as the MbifAs (n = 711, 30%) (correction of the data in [13]). Among the 1888 unruptured aneurysms, however, the MbifAs were, by far, more frequent (n = 674, 36%) [13] than the ACoAAs (n = 206, 11%) (Table 2).

Table 3 presents the characteristics of the ACoAAs with comparison between the ruptured and the unruptured ones. Interestingly, the median diameter of the ruptured ACoAAs was 7 mm in our series, and that of the unruptured ones only 4 mm (Table 3). Consequently, about half of the ruptured ACoAAs were less than 7 mm, which, admittedly reflecting the Finnish background, show that small aneurysms are dangerous and puts the results of the ISUIA study into question [41]. Underrepresentation of ACA aneurysms confounds the ISUIA series.

2.2. Intracerebral hematoma and IVH

Anterior communicating artery aneurysms bleed frequently into the adjacent frontal lobe or the ventricular system. Of the 715 patients with ruptured ACoAA, 33 (5%) had ICH only; 74 (10%), ICH with IVH component; and 137 (19%), IVH only (Tables 3 and 5).

2.3. Associated aneurysms

Anterior communicating aneurysms are often associated with other aneurysms, as 29% of all 898 ACoAA patients and 19% of those 715 with ruptured ACoAA had at least 1 additional aneurysm (Table 4). The most frequently associated aneurysm was MbifA in 142 (16%) patients. Two or more aneurysms on the ACoA complex are possibly underreported in the literature: 5 sporadic case reports and a series of 6 patients [40,52,53,122]. Yaşargil [126], however,

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**Table 2**

 Patients with ACA aneurysms in a consecutive and population-based series of 3005 patients with 4253 intracranial aneurysms from 1977 to 2005 in the Kuopio Cerebral Aneurysm Database

<table>
<thead>
<tr>
<th>No. of patients</th>
<th>No. of aneurysms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole series</td>
<td>3005</td>
</tr>
<tr>
<td>Patients with primary SAH</td>
<td>2365</td>
</tr>
<tr>
<td>Patients without primary SAH</td>
<td>640</td>
</tr>
<tr>
<td>ACoA aneurysms</td>
<td>1145</td>
</tr>
<tr>
<td>A1As</td>
<td>23 (2%)</td>
</tr>
<tr>
<td>ACoAAs</td>
<td>898 (78%)</td>
</tr>
<tr>
<td>A2As</td>
<td>35 (3%)</td>
</tr>
<tr>
<td>A3As</td>
<td>163 (14%)</td>
</tr>
<tr>
<td>AdistAs</td>
<td>26 (2%)</td>
</tr>
<tr>
<td>Ruptured ACoA aneurysms</td>
<td>855</td>
</tr>
<tr>
<td>A1As</td>
<td>12 (1%)</td>
</tr>
<tr>
<td>ACoAAs</td>
<td>715 (84%)</td>
</tr>
<tr>
<td>A2As</td>
<td>21 (2%)</td>
</tr>
<tr>
<td>A3As</td>
<td>97 (11%)</td>
</tr>
<tr>
<td>AdistAs</td>
<td>10 (1%)</td>
</tr>
<tr>
<td>Fusiform ACoA aneurysms</td>
<td>6</td>
</tr>
<tr>
<td>Fusiform A1A</td>
<td>2</td>
</tr>
<tr>
<td>Fusiform ACoAA</td>
<td>3</td>
</tr>
<tr>
<td>Fusiform A2A</td>
<td>1</td>
</tr>
<tr>
<td>Fusiform A3A</td>
<td>0</td>
</tr>
<tr>
<td>Fusiform AdistA</td>
<td>0</td>
</tr>
</tbody>
</table>

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**Table 3**

 Characteristics of 921 ACoAAs

<table>
<thead>
<tr>
<th>No. of aneurysms</th>
<th>Ruptured</th>
<th>Unruptured</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median aneurysm size (mm)</td>
<td>7 (range, 2–55)</td>
<td>4 (range, 1–48)</td>
<td>7 (range, 1–55)</td>
</tr>
<tr>
<td>Aneurysm size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small (&lt;7 mm)</td>
<td>303 (42%)</td>
<td>142 (69%)</td>
<td>445 (48%)</td>
</tr>
<tr>
<td>Medium (7–14 mm)</td>
<td>365 (51%)</td>
<td>43 (21%)</td>
<td>408 (44%)</td>
</tr>
<tr>
<td>Large (15–24 mm)</td>
<td>37 (5%)</td>
<td>16 (8%)</td>
<td>53 (6%)</td>
</tr>
<tr>
<td>Giant (≥25 mm)</td>
<td>10 (1%)</td>
<td>5 (2%)</td>
<td>15 (2%)</td>
</tr>
<tr>
<td>ICH</td>
<td>107 (15%)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Temporal</td>
<td>2</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Frontal</td>
<td>105</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Parietal</td>
<td>0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>IVH</td>
<td>211 (30%)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Preoperative hydrocephalus</td>
<td>317 (44%)</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Data are given as number of aneurysms.
reported 19 patients (5%) with multiple ACoAAs among his series of 375 patients. In our series, 21 patients (2%) had 2 or more aneurysms on the ACoA complex. There were 2 patients with 3 ACoAAs (Table 4).

3. Microsurgical anatomical considerations of ACoAAs

The microneurosurgical anatomy of the ACA and its branches has been well described earlier by Yaşargil [125] and others [16,26,38,73,74,83,84,111,112]. The ACA is divided to 5 major segments, A1 to A5 [18,38,73,74,112,125,126]. The A1 segment is located between the ICA bifurcation and the ACoA (Fig. 1). The A2 segment extends from the ACoA to the region between the rostrum and the genu of the corpus callosum (Fig. 1). The A3 segment curves around the genu of the corpus callosum and ends at the rostral part of the body of the corpus callosum (Fig. 1). The A4 and A5 segments follow the superior surface of the corpus callosum with a virtual plane of division at the level of the coronary suture [73,74,84] (Fig. 1).

Aneurysms of the ACA can be classified into 5 groups: A1As or proximal ACA aneurysms; aneurysms of the anterior communicating artery (ACoAAs); A2As; A3As or classic pericallosal aneurysms; and AdistAs or distal ACA aneurysms (Table 1, Fig. 1). This classification is practical and important as it emphasizes different microsurgical approaches and challenges in clipping the ACA aneurysms in 5 different locations. A1As were previously published in Surgical Neurology [12]; ACoAAs are the focus of the present review; and A2As, A3As, and AdistAs will be the subjects of subsequent articles, respectively.

3.1. A1 segment of ACA

The ICA bifurcates just below the anterior perforating substance into two major branches, the M1 and the A1. The A1 arises from the ICA in the carotid cistern and, with a medial and somewhat anterior course, enters the cistern of lamina terminalis (Fig. 2). A group of thick arachnoid bands extending from the olfactory triangle to the lateral side of the optic nerve encases the A1 segment at this point. This is important to note when dissection and mobilization of the A1 segment is required. Furthermore, previous SAHs may toughen these arachnoid bands. The course of A1 varies highly according to its length and dominance, with possible loops under the frontal lobe [90,125]. The right A1 and the left A1 join the ACoA complex mostly above the chiasm (70%) and less frequently above the optic nerves (30%) [83].

The 3D orientation of the ACoA complex inside the lamina terminalis cistern and its relation to the anatomical landmarks, such as the chiasm and the adjacent structures of the skull base, vary highly and depends on the diameter, length, and course of the A1s [83].

3.1.1. Hypoplasia and aplasia of A1

The A1 trunk is, in general, thinner than the ipsilateral M1 trunk [125]. Vascular anomalies are frequently seen with A1As [28,34,50,103,120,121,126]. Anomalies of the A1 trunk include hypoplasia, aplasia, duplication, fenestration, and very rarely, infraoptic course of the A1 [73,125]. Suzuki et al [103] reported 24 vascular anomalies with 38 A1As, including hypoplasia of the contralateral A1 in 26%. In the series of 87 circles of Willis studied with silicon cast at autopsy [63], ACoA was missing in 22%, stressing the importance of both A1s. With aplasia of the contralateral A1 trunk, it is of utmost importance to preserve the patency of the single A1 trunk when occluding an aneurysm on it.

3.1.2. Medial lenticulostriate arteries

The branches of the A1 trunk can be divided into 2 groups: the MLAs and the RAH. Medial lenticulostriate arteries are to be differentiated from the LLAs that arise from the M1 trunk and the bifurcational complex of the MCA.

3.2. A2 segment of ACA

The anterior cerebral artery (ACA) branches into two major terminal branches, the A2 and the A3, at the level of the diencephalon. The A2 segment, also known as the pericallosal artery, is responsible for supplying the anterior part of the corpus callosum and the anterior two-thirds of the frontal lobe. The A2 segment arises from the A1 trunk and courses in a posterior direction, surrounding the genu of the corpus callosum. Its course is highly variable and can be quite tortuous, especially in the presence of vascular anomalies.

3.3. A3 segment of ACA

The A3 segment is the most distal segment of the ACA, and it is responsible for supplying the posterior two-thirds of the frontal lobe and the genu of the corpus callosum. The A3 segment arises from the A2 segment and courses in a posterior direction, curving around the genu of the corpus callosum. Its course is highly variable and can be quite tortuous, especially in the presence of vascular anomalies.

3.4. A4 segment of ACA

The A4 segment is the most posterior segment of the ACA, and it is responsible for supplying the posterior part of the brain, including the parietal and occipital lobes. The A4 segment arises from the A3 segment and courses in a posterior direction, following the superior surface of the corpus callosum. Its course is highly variable and can be quite tortuous, especially in the presence of vascular anomalies.

Table 4

<table>
<thead>
<tr>
<th>Patients with an ACoAA and possible associated aneurysms</th>
<th>Ruptured</th>
<th>Unruptured</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients with ACoAA</td>
<td>715</td>
<td>183</td>
<td>898</td>
</tr>
<tr>
<td>Patients with a single aneurysm</td>
<td>577 (81%)</td>
<td>63 (34%)</td>
<td>640 (71%)</td>
</tr>
<tr>
<td>Patients with multiple aneurysms</td>
<td>138 (19%)</td>
<td>120 (66%)</td>
<td>258 (29%)</td>
</tr>
<tr>
<td>Associated ACoAA</td>
<td>19</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>Associated aneurysms at other sites</td>
<td>119</td>
<td>118</td>
<td>237</td>
</tr>
</tbody>
</table>

Data are given as numbers of patients.
The number of MLAs varies highly, with a mean of 8 (range, 2-15). Most MLAs arise from the proximal half of the A1 trunk [16,73]. Perforators from the distal part of the A1 trunk are smaller, and they join the arterial plexus of the optic nerve, the chiasm, and the optic tract [16]. Medial lenticulostriate arteries originate mostly from the superior or posterior aspect of the A1 trunk [73,105]. Nearly half of MLAs arise from the proximal half of the A1 trunk [13,14]. The number of MLAs varies highly, with a mean of 12 [73,105]. Medial lenticulostriate arteries supply the septum pellucidum, medial part of the anterior commissure and pallidum, pillars of the fornix, paraolfactory area, anterior limb of the internal capsule, anterior-inferior part of the striatum, and anterior hypothalamus. It is important to know the spectrum of neurologic symptoms that may ensue if MLAs are severed [16,71,73,125]. During dissection toward ACoAs or temporary clip application, these tiny vessels should be painstakingly identified and preserved.

### 3.1.3. Recurrent artery of Heubner

The point of origin of the RAH and its course in relation to the A1 trunk is highly variable. Appreciation of this variability is of utmost importance when dissecting and placing temporary clips on the A1 trunk. In most cases, the artery of Heubner originates from the first few millimeters of the A2 trunk but is first exposed in the surgical view (Fig. 2). With anterior course (34%), Heubner is less often involved with the A1 trunk but is first exposed in the surgical view (Fig. 2). With rare posterior course (3%), the artery and the A1 trunk should be differentiated before application of temporary clip on A1 [26]. The distal part of Heubner travels freely in the subarachnoid space before penetrating the brain at the base of lateral and medial olfactory stria, with a highly variable branching pattern (1-12 branches) [16,26,73,125].

### 3.2. Anterior communicating artery

The ACoA is the fundamental anastomotic part of the circle of Willis. Detailed microneurosurgical anatomy of the ACoA complex and its anatomical variations has been reported by Yasargil [125] and others [4,16,26,45,62,73,83,95,106,111]. The ACoA is expected to be formed by the union of 2 A1 segments of equal diameter within the lamina terminalis cistern. This, however, happens in only 20% of cases with ACoAAs. In most cases, on the other hand, A2s are formed by division of a large A1 segment. Eventually, ACoA can be defined as the entry point of hypoplastic A1 [125].

The 3D position of the ACoA complex inside the lamina terminalis cistern varies in relation to the surgical landmarks during exposure such as the chiasm and skull base. The position depends on the diameter, length, and course of each A1 [73,83,125]. High position of the ACoA was observed in 2 (6%) of 30 brains [95]. The diameter, length, and shape of the ACoA also varies [73,125]. The average diameters of ACoA and A1s were 1.6 and 2.6 mm, respectively, in 50 adult brains [73]. The length of ACoA was between 2 and 3 mm (0.3-7.0 mm). In cross sections, ACoA can be round, triangular, or even flat. The diameter of the A1-A2 junctions was equal in 74%, larger in the right side in 14%, and larger in the left side in 12% [73].

#### 3.2.1. Perforating branches of ACoA

It is difficult to overestimate the importance of the perforators of the ACoA complex region. The microneurosurgical anatomy of the ACoA perforators is complicated. It has been studied in detail [5,4,16,38,62,73,83,95,106,112,119,125], but there is still controversy. The reported number of perforators varies: less than 3 [16], not more than 6 [62], and between 1 and 11 [119]. Türe et al [112] found perforators in all 20 brains studied, between 1 and 6 (an average 2.5), with diameters from 0.15 to 2.1 mm. They subdivided perforators into hypothalamic, subcallosal, and median callosal ones [112]. Serizawa et al [95] found in 30 brains 2 to 8 perforators (an average 4.1) with diameters from 0.1 to 0.8 mm, and their subdivision was hypothalamic, subcallosal, and chiasmatic.

The pattern of origin, laterality, and supply areas of the ACoA perforators vary highly [16,62,73,95,112,119,125]. The perforators may arise from any part of the parent vessel [61], but the most frequent patterns are ipsilaterally to the dominant A1 in case of unequal A1s and from the medial part of ACoA in case of equal A1s [125]. Perforators arise regardless of the type or shape of ACoA, from hypoplastic, multiple, or fenestrated ACoAs, and even from anomalous branches of ACoA [5,61,95,119,125].

The ACoA perforators arise, such as the A1 perforators, from the superior and posterior aspect of the parent artery and rarely from the anterior or inferior surfaces [73]. Vincentelly et al [119] described the angle between postcommunicating A2s and the perforators to be 96° (range, 30°-180°) and, in particular, between 90° and 120°...
in 70% of cases. This is highly important from a surgical point of view because if the clip is applied perpendicular to parent artery (ACoA), then it is possible to preserve most of the perforators [119].

The ACoA perforators supply the infundibulum of pituitary, optic chiasm, superior part of the optic nerve, anterior hypothalamus and lamina terminalis, anterior perforating substance, rostrum and genu of the corpus callosum, anterior commissure, anterior cingulate gyrus, parolfactory gyrus, paraterminal gyrus, septum pellucidum and column of fornix, and some parts of the limbic system [5,16,38,62,73,83,95,112,119,125]. Anastomoses between perforators are frequent, particularly between hypothalamic branches [62,95].

The perforators involving the base of ACoA, in particular, may become severed during dissection, coagulation, or application of standard or tunnel clips [93]. This is particularly valid with wide-based aneurysms and with vascular abnormalities of the ACoA region [62]. Injury to the perforators by surgery or vasospasm may result in a wide range of serious and incapacitating neurologic sequels, including memory deficits, changes of personality, and electrolyte imbalance [95,125].

3.3. A2 segment of ACA

The A2 segment extends from the ACoA complex to the region between the rostrum and the genu of the corpus callosum (Fig. 1). Inside the interhemispheric fissure, importantly, the left A2 was more anterior in 48%, and the right A2, more anterior in 34%, whereas A2s were found side by side only in 18% [73]. This, in part, shows the patterns of fork of ACoA and the orientation of the aneurysm dome.

3.3.1. Branches arising from A2

The A2 segment has 3 main branches: the RAH (see above), the orbitofrontal artery, and the frontopolar artery. Their point of origin and diameter are highly variable [4,49,74]. They should be differentiated by different destinations in preoperative images and during surgery. The orbitofrontal and frontopolar arteries can be identified in more than 95% of patients [114] but not always arising from the A2 trunk.

The orbitofrontal artery arises from the first 5 mm of the A2 trunk, at the junction of the lamina terminalis and callosal cisterns, and has a downward and forward course to reach the gyrus rectus and to cross the olfactory tract [125]. This artery should be differentiated from the RAH during microneurosurgical dissection toward ACoAAs [105].

The frontopolar artery originates after the orbitofrontal artery, with average diameters of 1.3 and 0.9, respectively [74], and travels anteriorly and crosses the subfrontal sulcus [74]. The frontopolar artery is directed more anteriorly than laterally, which helps to distinguish it from the RAH.

The basal branches of A2 arise from the lateral and superior aspect of the first few millimeters of A2 trunk and supply the gyrus rectus, inferior frontal area, anterior perforated substance, dorsal optic chiasm, and suprachiasmatic area. This should be kept in mind during dissection [73].

In addition, there are small central perforating branches originating from the A2 trunk that pass posteriorly to enter the optic chiasm, lamina terminalis, and anterior forebrain below the corpus callosum [74].

3.4. Venous structures

The superficial and deep venous structures of the ACoA region are complex and variable [68,83,125]. Particular care
is necessary during dissection and mobilization of the major arteries and perforators so as not to sever the veins.

3.5. Anatomical variations in the ACoA region

Anatomical variations in the angioarchitecture of the ACoA region and the circle of Willis are frequently associated with ACoAAs. Ogawa et al [67] found abnormalities of any kind in 21.4% of their 206 ACoAA patients, the median artery of the corpus callosum being the most frequent (9.7%). The impact of variations on the flow dynamics and on the microsurgical dissection of the ACoA complex should be appreciated while studying the preoperative images. Finally, one may assume that asymmetries of flow would predispose by increased hemodynamic stress to the formation or rupture of aneurysms.

Anomalies of the A1 trunk include hypoplasia, aplasia, duplication, and fenestration, and very rarely infraoptic course of the A1 [73,125,126]. Hypoplasia of the A1 segment has been connected to higher rate of ACoAAs [51,73,116]. It should be noted that an A1 found hypoplastic at imaging may not appear so through the operating microscope. With aplasia of the contralateral A1 trunk, it is of utmost importance to preserve the patency of the ACoA because both A2s are supplied from a single source. The ACoA was missing in 22% in the series of 87 circles of Willis studied with silicon cast at autopsy by Merkkola et al [63], a variation stressing the patency of both A1s.

Anomalies of the ACoA were observed in 60% of cadaver brains [62,95], including dimple, fenestration, duplication, string, fusion, or plexiform appearance. The median artery of the corpus callosum, bihemispheric, and azygous A2s are among anomalous branches arising from the ACoA [95,105]. The rare third or median ACA goes backward and upward over the corpus callosum [73] (Fig. 3).

3.6. Classification of ACoAAs according to the orientation of dome

We find it microsurgically very important to classify the ACoAAs according to the projection of the dome (Fig. 4). There are 5 major groups: (a) downward or toward the skull base (Fig. 5), (b) forward or frontal (Fig. 6), (c) upward or intertruncal (Fig. 7), (d) backward or occipital (Fig. 8), and (e) complex involvement of the ACoA complex (Fig. 9). The ACoAAs usually originate from the junction of the dominant A1 and A2, and the rare ones arising from the ACoA trunk itself tend to originate from its superior surface [51,62,80,116,126]. The projection of the dome depends on
the course, diameter, length, and shape of the dominant A1 segment. Usually, the dome points away from the A1-ACoA junction, toward the contralateral side (see below). In case of curved or tortuous A1, the dome may point to any other direction [73,80-83].

4. Imaging of ACoAs

Digital subtraction angiography is still the present gold standard in many centers. Multislice helical CTA is the primary modality in our centers for several reasons: noninvasive and quick imaging, comparable sensitivity and specificity to DSA in aneurysms larger than 2 mm [27,44,46,96,109,118,123,124], disclosure of calcifications in the walls of arteries and the aneurysm, and quick reconstruction of 3D images that, for example, show the surgeon’s view of ACoAAs. Some ACoAAs may be difficult to visualize by routine DSA [73], and rotational 3D DSA and 3D CTA are more successful in this region [91]. If CT suggests a ruptured ACoAA but DSA is negative, DSA aided by manual compression of contralateral ICA may be considered [43,105]. Digital subtraction angiography with compression test may also help to assess the collateral flow to the ACoA complex.

For intraoperative navigation, 3D CTA and/or DSA reconstructions should be rotated to illustrate the angioarchitecture of the ACoA complex and its relation to the skull base, projection of the ACoAA dome in relation to the A1s and the A2s, and the site of possible rupture (Figs. 5-9).

Fig. 6. Computed tomographic angiographic images of a forward projecting ACoA (arrows). A: Sagittal view. B: 3D reconstruct superior view. C: 3D reconstruct anterior view (see also Videos ACoAA-2 and 3).

Fig. 7. Computed tomographic angiographic images of intertruncal ACoAA. A: Coronal reconstruction. B: Sagittal reconstruction. C: Three-dimensional reconstruction. Loop of left A1 segment and turning of fork of A2s toward left can be noted (see also Video ACoAA-4).
Vascular aberrations, frequent in this region (see above) [113], should be looked for, and their possible impact on flow conditions in the ACoA complex should be assessed (Fig. 3). In giant and fusiform ACoAAs, MRI with different sequences, along with 3D CTA, helps to distinguish the true wall of the aneurysm and the intraluminal thrombosis.

In the work station, 3D CTA images can be rotated accordingly to evaluate the surgeon’s view to the ACoA complex, which is not standard but varies according to the dome’s projection and relation to the A2s. The fork of the A2s should be adapted to the operative trajectory. The prime concern is to find a view that best helps to preserve the perforators around the base and the dome of the aneurysm. A suitable bony exposure can be performed with virtual tools for the planned surgeon’s view. If the anterior interhemispheric exposure is planned, it is important to review the 3D
images for the presence of large bridging veins at the edge of the sagittal sinus.

5. Microsurgical strategy with ACoAAs

The anatomical and hemodynamic features associated with ACoAAs make them the most complex aneurysms of the anterior circulation. The aim, total occlusion of the aneurysms sac with preservation of flow in all branching and perforating arteries, is very demanding. Before surgery, it is important to review the 3D angioarchitecture and abnorm-

5.1. Neuroanesthesiologic principles

A general review of our neuroanesthesiologic principles has been published previously [79].

5.2. Intracerebral hematoma

In the Kuopio series, the ACoAAs were the second most frequent cause of aneurysmal ICH that required emergency evacuation after the MbIrAs [13]. Of the 715 patients with ruptured ACoAA, 33 (5%) had ICH only, 74 (10%) ICH with IVH component, and 137 (19%) IVH only (Table 5). Pasqualin et al [72] reported ICH with 32% of 402 ruptured ACoAAs, and 79% of ICHs were in the frontal or frontobasal region. Intracerebral hematomas worsen the outcome [35,36], and early surgical evacuation of massive ICH has been advised [7,8,31,35,36,85,107]. In our practice, patients with massive

<table>
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<th>Table 5</th>
<th>Intracerebral hematoma, IVH, and acute hydrocephalus associated with aneurysm rupture on different ACA segments</th>
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<tr>
<td>Ruptured aneurysms</td>
<td>A1As</td>
</tr>
<tr>
<td>ICH only</td>
<td>12</td>
</tr>
<tr>
<td>ICH with IVH component</td>
<td>74 (10%)</td>
</tr>
<tr>
<td>IVH only</td>
<td>2 (17%)</td>
</tr>
<tr>
<td>Preoperative hydrocephalus</td>
<td>5 (42%)</td>
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Fig. 9. A-C: Three dimensional reconstruction CTA images show 3 different examples of complex projection of the ACoAA and involvement of the branches.
ICH are transferred directly to operating room from acute CTA for immediate evacuation and clipping, and processed 3D images become available until early craniotomy. A small cortical incision is made accordingly in the craniotomy, avoiding the Broca’s area. Hematoma is partially evacuated to gain space. This may risk rerupture of the ACoAA, which would be difficult to control through the ICH cavity. In removing the ICH clot, before or after clipping, minor force should be applied so as not to sever perforating arteries.

5.3. Intraventricular hematoma

The close proximity of ACoAAs to the ventricular system predisposes to IVH [88], which appears as an independent risk factor of poor outcome in SAH. However, in a recent study by Rosen et al [87], posterior circulation aneurysms are found to be more frequently associated with IVH than ACoAAs.

In the Kuopio series, 30% presented with IVH, and 44% had acute preoperative hydrocephalus.

5.4. Acute hydrocephalus

In case of acute hydrocephalus, 44% in the Kuopio series (Table 3), we often start immediate ventricular drainage to reduce ICP and to lower the risk of brain damage, in most cases, after acute securing of the ruptured aneurysm. We also open the lamina terminalis for additional CSF removal before clipping. This allows removal of blood clots from the third ventricle.

5.5. Approach and craniotomy

Exposure in ACoAA surgery depends on multiple factors: rupture status, size, and projection of the dome of the aneurysm; length, course, and dominance of the A1 trunks; orientation of the A2 fork; height of the ACoA complex from the skull base; neurovascular variations; presence of associated aneurysms; presence and extent of atherosclerosis in adjacent arteries and in the aneurysm base, detected by preoperative imaging if possible; presence of associated ICH and/or IVH; preexisting neurologic deficits; and previous surgeries. The approach selected depends on personal experience.

In our practice, the lateral supraorbital approach [32] is used in almost all ACoAAs (see below). An important exception is the downward projecting ACoAAs in which the pterional approach may provide more lateral access to the aneurysm. If the ACoA complex is located high in the interhemispheric fissure, preventing clipping through these 2 approaches, the interhemispheric approach should be considered [42].

The orbitozygomatic approach and its modifications may reduce retraction of the frontal lobe during microneurosurgery of ACoAAs [25,85,94,131]. The orbital contents, however, may reduce the space achieved by additional bone removal, a feature not apparent in formalin-fixed cadaver studies. In addition to injury to the frontal nerve, rarely pulsatile exophthalmus and diplopia may occur [85].

5.5.1. Lateral supraorbital approach

The LSO craniotomy as a direct and short approach is preferred by the senior author (JH) to the classic pterional approach [97,125-127]. The LSO craniotomy, described in detail elsewhere [33], is demonstrated on video in our article on M1A of the MCA in Surgical Neurology [14] (Table 6).

Briefly, the head fixed to the head frame is (a) elevated clearly above the cardiac level; (b) rotated toward the opposite side according to projection of the ACoA dome; (c) tilted somewhat laterally for optimal visualization of the A2 fork, to bring the ACoA into the tip of pyramid of surgical trajectory, and to visualize the ACoA complex and the ACoAA base; and (d) minimally extended. It is our practice to adjust the position of the fixed head and body during the operation as needed [33]. We prefer to use a Sugita head frame with 4-point fixation. Besides providing good retraction force by its fishhooks, it allows the surgeon to rotate it during surgery. If this feature is not available, the table can be rotated as needed [33].

After minimal shaving, an oblique frontotemporal skin incision is made behind the hair line (see also the video M1A-1 in [14]). The incision is short and stops 2 to 3 cm above the zygomatic arch. The incision is partially opened by frontal spring hooks. The temporal muscle is split vertically by a short incision, and 1 spring hook is placed in the incision to retract the muscle toward the zygomatic arch. The 1-layer skin-muscle flap is retracted frontally by spring hooks until the superior orbital rim and the anterior zygomatic arch are exposed. The extent of craniotomy depends on the surgeon’s experience, projection of the ACoAA, and presence of ICH. Usually, a small LSO craniotomy is all that is necessary (the keyhole principle). A single burr hole is placed just under the temporal line in the bone, the superior insertion of the temporal muscle. The bone flap of 3 × 3 cm is detached mostly by the side-cutting drill, and the basal part can be drilled before lifting. In case of ICH or backward projected ACoAA, the lateral sphenoid ridge is drilled to create a more lateral view to the ACoA complex.
The dura is incised curvilinearly with the base sphenoidally. Dural edges are elevated by multiple stitches, extended over craniotomy dressings. From this point on, all surgery is performed under the operating microscope, including the skin closure.

5.5.2. Anterior interhemispheric approach

The anterior interhemispheric approach may be preferred for ACoAAs on high-located ACoA complex. We prefer the unilateral approach over the bilateral one as less invasive and quicker but usually sufficient to expose the ACoA complex. The general positioning principles of the LSO craniotomy apply here (see above). The head, elevated about 20° above the heart level, is in neutral position the nose pointing exactly upwards. There is absolutely no rotation or tilt. The optimal positioning provides an almost perpendicular trajectory to the ACoA complex [42,130]. If intraoperative catheter angiography is planned, the head frame and pins should be placed accordingly.

After minimal shaving, an oblique skin incision with its base frontally is made just behind the hair line, over the midline, extending more to the side of the planned bone flap, usually the right side. Right-handed neurosurgeons may find right-sided approaches more convenient. Location and extent of skin incision depend on the hair line, dimensions of the frontal bony sinuses, orientation of the ACoA, and presence of large ICH. Strong flap retraction with hooks usually allows anterior enough exposure of the frontal bone, making bicoronal incision unnecessary. A 1-layer skin flap is reflected frontally with spring hooks. We prefer a 3- to 4-cm-diameter bone flap. Very small flaps may not provide enough working room between the bridging veins. The size of the flap depends on the surgeon’s experience and the presence of large ICH. Often, a single burr hole over the superior sagittal sinus at the posterior margin of craniotomy is enough. Through this hole, the bone is carefully and unhurriedly detached from the dura, avoiding tear to the roof of the sagittal sinus. Alternatively, 2 burr holes are placed in the midline, and 1, laterally in a triangular fashion to ease detachment of the dura, particularly in the elderly. The bone flap is removed using a side-cutting drill. The flap is placed slightly over the midline, to allow better retraction of the falx and to enlarge the opening if necessary.

Dura is opened under operating microscope as a C-shaped flap with its base toward the midline. The incision is started laterally and extended anteriorly and posteriorly toward the midline, avoiding opening of the edge of the superior sagittal sinus. Large bridging veins usually attach to the dural sinus, some centimeters laterally from the midline. Preoperative 3D images should be carefully studied to identify the pattern of veins in the area of exposure. It is hurried and careless opening of the dura that severs bridging veins. The exposure is carefully covered during surgery, and during closure, it is packed and isolated with fat (rather than muscle) and covered with a pericranial flap. High speed drill is used to smooth the edges and to enlarge the opening if necessary.

CSF drainage

In most unruptured ACoAAs, dissection toward the aneurysm is first aimed subfrontally to open the cistern of lamina terminalis and then the suprasellar cistern to gradually let CSF. In all ruptured ACoAAs and in some
unruptured ones, the dissection is further directed to open the lamina terminalis for additional CSF removal. The important exception is the downward projected ACoAA in which case the Liliequist membrane is opened to remove additional CSF (see below). Intraoperative ventricular puncture can be adopted, rarely by us.

6. Dissection and clipping of ACoAAs

6.1. Lateral supraorbital approach

6.1.1. General principles

In our practice, the intradural approach toward ACoAAs usually starts with dissection of the arachnoid bands under the frontal lobe to reach the lamina terminalis cistern. To minimize the risk of premature bleeding, we prefer to dissect arachnoid bands sharply by microscissors. Then, we open the carotid cistern and the optic cistern, followed by the most proximal part of the sylvian fissure to enhance mobilization of the frontal lobe and to remove tension on the sylvian veins. The exception is the downward projecting ACoAA, however, with high risk of premature rupture, in which case, we first open the optic and carotid cisterns and the Liliequist membrane to let CSF.

The ICA bifurcation and the origin of the ipsilateral A1 trunk are visualized. The distal one third of the ipsilateral A1 segment, RAH, and ACoA in the lamina terminalis cistern is identified. After identification of the ipsilateral anatomy, dissection continues toward the contralateral A1 and the RAH to prepare proper places for temporary clip(s). Depending on the course and length of the A1s and orientation of the ACoA complex, the contralateral A1 may be exposed first in some cases. Optimally, both A1s, proximal part of the A2s and their branches, and the ACoA trunk together with the aneurysm base are identified. However, the presence of thick blood cloths or arachnoid thickening from previous SAH or operations may prevent this.

6.1.2. Resection of gyrus rectus

A small resection on the gyrus rectus usually helps to visualize the ipsilateral A1-A2 junction and reduces frontal lobe retraction [117]. After mobilization of the frontal lobe, the gyrus rectus is identified medial to the ipsilateral olfactory tract. During this step, retractors are not used if possible. Pia is opened with microscissors or sharp bipolar forceps, and gyrus tissue is carefully removed by suction, usually less than 1 cm in length and few millimeters in depth [37]. Preservation of pia and arachnoid planes in the interhemispheric fissure side, like a window, protects the aneurysm, the RAH, and other branches of the A2; this membrane can be opened in later stages. An optimal resection will allow to see the A1-A2 junction and proximal part of the A2, including the origin of the frontopolar artery. Resection may have to be expanded in backward directed ACoAAs, and with large and giant ones. A Sugita-type retractor applied carefully at the resection site may facilitate the view to the ACoA complex.

6.1.3. Dissection under temporary clipping of arteries

Early stages of dissection is carried without temporary clips for a better view. Frequent and proper use of temporary clips allows safe and sharp dissection of the ACoA complex. The sites of temporary clips are dissected and prepared with bipolar forceps with plump tips or microdissector. A suitable site on the A1 trunk is often the distal third in both sides. Usually, a short curved clip is applied to the contralateral A1, and a short straight one, to the ipsilateral A1. The RAH should be identified and not involved in the clip blades. To obtain optimal relaxation of the dome, the both A1s, even hypoplastic-looking ones, should be occluded. In general, retrograde flow from the A2s allows more time to dissection the softened aneurysm. To prevent ischemic injury, temporary occlusion of the A1s should be as short as possible [1,92], each period less than 5 minutes. Temporary clips on the A2s are used only in complex, large, and giant aneurysms. Temporary occlusion of the A1s and A2s helps dissection, manipulation, and bipolar coagulation of the aneurysm. It is practical to gently press the temporary clip down by a small cottonoid to protect it from dissecting instruments. The base of ACoAA, usually involving the junction of the dominant A1 and the A2, is the most critical part of dissection. Careless dissection may lead to rupture at the base. If the tear extends to the A2, it is difficult to repair, and occlusion of the A2 may result. When the main part of the base is dissected, usually, a short straight Sugita clip as a pilot clip is applied over the dome, and temporary clips are removed with a distal to proximal order. When removed, the temporary clip should be first opened carefully in place to test if any unwarranted bleeding occurs. Removal in rush can be followed by heavy bleeding and great difficulties in placing the clip back. While removing the temporary clips, even the slightest resistance should be noted as possible involvement of a small branch in the clip or its applier.

6.1.4. Clipping of ACoAA neck

A proper selection of clips with different shapes and lengths, and applicators, suitting the imaging anatomy of the ACoAA, should be ready for use. A limited selection of final clips is needed when temporary clipping of arteries and bipolar shaping of the aneurysm dome are used. If reshaping is not considered, the blade of a single occluding clip should be 1.5 times longer than the width of the base. Frequent short-term application of temporary clips during clip placement and replacement is routine in our practice. We prefer inserting first a pilot clip over the ACoAA dome, preferring Sugita clips for their wide opening distance and plump tips. In ACoAAs, stepwise clipping of the aneurysm dome toward the base with more dissection facilitates complete occlusion, in particular, of the complex ones. Usually, the aneurysm dome is coagulated and reshaped before final clipping. The direction, shape, and length of final clip(s) should be assessed carefully so as not to sever any branches or perforators. If the first clip slides exposing some of the neck, another clip may be introduced proximal to
the previous one for final closure (“double clipping”) (Video ACoAA-4). In case of calcified base, it may be necessary to leave a part of base open (Video ACoAA-6). After final clipping, the sac should be opened. Adequate dissection, proper size of clips, and careful checking that blade tips do not involve the adjacent branches and perforators is very important. To prevent kinking and unexpected occlusions, the flow should be checked once more after removal of the retractors, and papaverin should be applied.

6.1.5. ACoAA rupture before clipping
ACoAAs may rupture during any step of approach and dissection. The risk of premature rupture is highest for the subgroup of forward projecting ACoAAs with their dome directed toward midline, followed by the intertruncal ACoAAs and the downward projecting ACoAAs, respectively (see above). The rupture site is usually at the dome rather than the base. Control should be first attempted via suction, and compressing the bleeding site with cottonoids. Sudden and short hypotension by cardiac arrest, induced by intravenous adenosine [79], can be used to facilitate quick dissection and application of a pilot clip in case of uncontrolled bleeding. A pilot clip may be inserted to a ruptured secondary pouch if visible. Otherwise, temporary clips are inserted on both A1s, even on 1 or both A2s, to allow further dissection of the base and final clipping. Small, thin-walled ACoAAs may rupture at their neck during dissection. In this case, under temporary clipping of the arteries, reconstruction of the base by involving a part of ACoA in the clip should be attempted. We do not recommend trapping as there is risk of occlusion of ACoA perforators.

6.1.6. Very small ACoAAs
In very small (2-3 mm) ACoAAs, clipping is difficult because the wall is fragile. Temporary clipping of both A1s reduces intraluminal pressure and softens the dome. With minimal reduction of the arterial lumen, a thin portion of the healthy arterial wall is taken inside the clip for safe closure of the neck. If the first clip slides, exposing some of the neck, double clipping may be applied (see above) (Video ACoAA-4).

6.1.7. Intraoperative verification of clipping
We routinely use micro-Doppler to check the flow in the A1s and A2s after clipping, but surprise occlusions would still be seen in postoperative angiography. Noninvasive ICG infrared angiography [77,78] is very promising in our hands. It helps the orientation during dissection and visualizes wall thickness and plaques, perforating arteries, and incomplete neck occlusion. Indocyanine green angiography will reduce the need for invasive angiography for intraoperative clipping control. Catheter angiography under digital C-frame guidance with tract memory is still needed for intraoperative assessment of flow in giant and complex aneurysms.

6.1.8. Resection of ACoAA dome
When appropriate, not risking perforators, the aneurysm dome can be resected for the final check of closure and for research purposes [21,22,110]. This policy teaches one to dissect aneurysm domes more completely and thereby avoiding closure of branching arteries (see above).

6.2. Anterior interhemispheric approach
The anterior interhemispheric approach was described by Laugheed [59] and Ito [42] for microneurosurgical clipping of ACoAAs. This approach is routinely used by some authors, particularly if the base of ACoAA is more than 13 mm above the skull base [37]. The main advantages are minimal retraction, preservation of the olfactory tract, and no need for gyrus rectus resection [37,42,59,130]. In our practice, the anterior interhemispheric approach is used in forward and backward projecting ACoAAs on a high-positioned ACoA complex (Fig. 10). Adhesions after previous anterolateral or subfrontal approaches may be another indication.

In CTA reconstructions, the distance of the aneurysm and the corpus callosum from the site of craniotomy should be measured. The key is careful positioning of the head and the angle of surgical microscope to create an optimal, almost perpendicular, route toward the lesion, usually on the right side. During and after opening the dura, extreme care should be taken to preserve the draining veins. After entering the interhemispheric fissure, dissection is directed along the falx.
toward the anterior margin of the genu of corpus callosum. Arachnoidal adhesions attached to the falx are dissected sharply. After reaching the inferior border of the falx, the dissection plane between the cingulate gyri should be identified and followed. Once the callosal cistern is entered, both pericallosal arteries should be identified as they may be coursing on either side of the midline. The corpus callosum can be identified by its white color and transversely running, parallel fibers. The pericallosal arteries are identified and followed carefully in the deep and narrow proximal interhemispheric fissure around the genu of corpus callosum. Surgical route is usually between the A2s to come directly to the ACoA complex. Going between the A2s, branching and perforating arteries can be preserved as they are usually directed laterally or posteriorly. After the ACoA complex is reached, depending on the projection of the dome, the base of aneurysm and the dominant A1 is identified and prepared for with temporary clipping. Both sides of the aneurysm are prepared by microdissector, and a pilot clip is placed on the base of aneurysm. Aneurysm sac can be opened by microscissors, and the fundus can be coagulated. However, limited space restricts manipulation of the aneurysm (see Video ACoAA-8).

7. Downward projecting ACoAAs

The dome is projecting toward the skull base, and it is often attached to the optic chiasm and or the skull base (Figs. 5 and 11). The main concern is to minimize retraction of the frontal lobe, not to avulse the attached tip of the aneurysm.

7.1. Planning

The approach is from the side of the dominant A1. The contralateral A1 is usually easily visualized during early dissection, and the orientation of the A2 fork is not a determining factor. The LSO craniotomy is routinely used in our practice, but the pterional craniotomy may be considered in case of associated aneurysms. In rare cases, the downward dome is also projecting to the contralateral side, and the contralateral approach may allow a better view to an unruptured aneurysm. The presence of associated aneurysms is another reason for selecting the nondominant A1 side approach.

7.2. Head position

The head is minimally flexed, rotated 30° to 40° toward the contralateral side, with a moderate lateral tilt. Flexion of the head views the medial part of the anterior fossa and rotation facilitates lateral dissection toward the aneurysm.

7.3. Dissection toward downward ACoAA

The proximal part of the sylvian fissure is opened, and the carotid cistern is dissected to release CSF. Dissection of the Liliequist membrane may facilitate CSF release and brain relaxation (Video ACoAA-1). Ventriculostomy may be adopted if the brain is swollen by SAH with no room to reach the lamina terminalis. Frontobasal dissection of arachnoid bands is directed over the ipsilateral optic nerve toward contralateral side. The ipsilateral A1 is identified at the ICA bifurcation and its course is followed medially. Any retraction of the frontal lobe should be avoided. Resection of the gyrus rectus will bring the ACoA complex and the base of the aneurysm in view almost without frontal retraction. Extension of the gyrus rectus resection depends of the height of the ACoA complex, as measured in 3D CTA. After clear visualization of the aneurysm, the lamina terminalis can be fenestrated to get more space for the dissection of the posterior part of the aneurysm base.

7.4. Temporary clipping

After the distal parts of the both A1s and the RAH are identified, proper sites for temporary clips are carefully prepared. Usually, a small curved one is placed on the contralateral A1, and a short straight one, on the ipsilateral A1 (see above Section 6.1.3).

7.5. Final clipping

A short Sugita clip (pilot clip) is inserted around the base of the aneurysm. After checking the clip position, the temporary clips are removed: first, the contralateral one, and then the ipsilateral one. The fundus and the tip of the aneurysm are dissected from the optic chiasm (Fig. 11), the optic nerve, or the skull base (Video ACoAA-1). In cases of acute SAH, the dome usually empties after pilot clip application or during dissection of the fundus. The aneurysm is coagulated and reshaped by plump bipolar forceps, more safely under temporary clips or the pilot clip. If the tip is strongly attached to the optic system, the dome is cut and the attached part is left in place. There are no perforators in the

Fig. 11. Intraoperative photograph of a downward projecting ACoAA viewed through a right lateral supraorbital approach. After identification of right A1 frontobasal dissection is continued toward contralateral side, and left A1 and A2 segments are exposed. Please note the attachment of the dome to the optic chiasm (black arrows). White arrow demonstrates a secondary bleb projecting upward (intertruncal). M1, proximal middle cerebral artery; ON, optic nerve (see Section 7 and Video ACoAA-1).
vicinity of these aneurysms, which allows thorough coagulation of the dome. Temporary clips are replaced, and after removal of the pilot clip, the base is further coagulated (Video ACoAA-1). After final reshaping, the shortest possible final clip is applied, and temporary clips are removed. These steps must be repeated until the optimal occlusion of the aneurysm is achieved. In downward ACoAAs, the risk of involving adjacent branches in the clip blades is less than in other ACoAAs. In any case, narrowing of the parent artery by clipping should be avoided so as not to disturb blood flow in the A1-A2 junction.

8. Forward projecting anterior communicating aneurysms

The aneurysm is in front of the A2s, the dome projecting forward (frontally), and the A2s are not involved in the aneurysm base (Figs. 6 and 12). Occasionally, the forward dome or the whole A2 fork is turned to the side of the nondominant A1, which makes the clipping more difficult.

8.1. Planning

The approach is usually from the side of the dominant A1 through the LSO craniotomy in our practice.

8.2. Head position

The head is minimally extended, rotated some 30° toward the contralateral side (somewhat less than with downward ACoAAs), with a moderate lateral tilt.

8.3. Dissection toward forward ACoAA

Carotid and optic cisterns are dissected to release CSF (Videos ACoAA-2 and 3). To obtain optimal view to the ACoA complex, the proximal part of the sylvian fissure may be opened (Video ACoAA-2). The frontobasal dissection is directed toward the lamina terminalis cistern, and the lamina terminalis is opened to let CSF (Fig. 12). If the aneurysm and the ACoA complex are not optimally visualized, a small resection of the gyrus rectus is performed (Videos ACoAA-2 and 3). Distal parts of the ipsilateral A1 and the contralateral A1 are dissected carefully and prepared for temporary clips. The ACoA complex and the base of the aneurysm are carefully dissected. Usually, the ipsilateral A2 is seen through the gyrus rectus resection and the base can be dissected from it (Video ACoAA-2).

8.4. Temporary clipping

Under temporary clipping, the base is dissected further. A pilot clip is inserted and applied slowly around the base which usually uncovers the contralateral A2 (see Section 6.1.3).

8.5. Final clipping

The temporary clips are removed, and the position of the pilot clip is carefully checked. The aneurysm dome is further dissected and shrunken by bipolar coagulation. Temporary clips may be reapplied on the A1s, and the pilot clip is removed. After final coagulation and reshaping of the base, the shortest possible final clip is placed, keeping the contralateral A2 out of its blades.

8.6. Forward and medially projecting ACoAA

When the A2 fork with the dome is turned to the side of the nondominant A1, the contralateral A1 and the origin of the contralateral A2 become hidden. The final dissection of the base can be performed with a temporary clip applied on the ipsilateral A1 only, and a pilot clip is applied. After careful dissection of the softened dome, it should be possible to check the base. After complete visualization of the contralateral A1, the temporary clips are applied on both A1s, and the aneurysm is coagulated, reshaped, and clipped as above.

9. Upward projecting or intertruncal ACoAAs

The aneurysm is between the A2s, the dome is projecting in the same direction as the A2s, and the base involves 1 or both A2s (Fig. 7).

9.1. Planning

The approach is from the side of the dominant A1, usually through the LSO craniotomy. In case of high position of the ACoA complex, the peritonal approach or, at least, in unruptured cases, the anterior interhemispheric approach is considered (see Section 6.3).

9.2. Head position

The head is 30° rotated to the opposite side with a moderate lateral tilt but no extension. The aim is to open the
A2 fork in the surgeon’s view and to create an optimal view to the base of the aneurysm. Lateral tilt helps to have the contralateral A1 in view.

9.3. Dissection toward the aneurysm

After opening the carotid and optic cisterns, the lamina terminalis cistern and the lamina terminalis are opened, which is rather safe due to the direction of the dome (Video ACoAA-4). The distal ipsilateral A1 is identified. A small resection of the gyrus rectus is usually performed for a better view on the ipsilateral A1-A2 junction and the base of the aneurysm. The ACoA, the origin of the contralateral A2, and the distal part of the contralateral A1 should be identified and dissected. Before applying the temporary clips on the A1s, the base should be dissected as much as possible.

9.4. Temporary clipping

Temporary clipping of the both A1s softens the aneurysm so that it is possible to further dissect the base and fundus from the ipsilateral A2 (Video ACoAA-4). The angle of the base and the A2 is critical because too much distortion here may cause a rupture that is difficult to handle. It is usually easier to dissect the base from the contralateral A2. Both sides of the base are checked with microdissector with an approximate size of clip blade. The pilot clip is usually a straight Sugita clip, which is inserted and slowly closed around the base. If the aneurysm is still tense, the clip should be reapplied deeper or replaced by a longer clip. In case of large aneurysms, it is difficult to see the origin of the contralateral A2 during pilot clipping.

9.5. Final clipping

The temporary clips are removed, and the position of the pilot clip is carefully checked. The aneurysm dome is further dissected and shrunken by bipolar coagulation. Reshaping the dome may help to have the both A2s in view. If the aneurysm wall is thick, extreme care should be taken as it cannot be reshaped by coagulation, and a strong base resists perfect clipping. If the base of the aneurysm is not completely clipped, manipulation and bipolar coagulation of the aneurysm may risk rupture and cumbersome bleeding. In this case, temporary clips are replaced on both A1s and after complete dissection of the base, proper permanent clip is applied. After final coagulation and reshaping of the base, the shortest possible final clip is placed as above, keeping the contralateral A2 out of its blades.

10. Backward projecting ACoAAs

The aneurysm is behind the A2s, the dome projected backward (occipitally), and the base does not involve the A2s (Fig. 8), in contrast to the intertruncal case above. Importantly, now ACoA perforators are frequently involved in the base or attached to the dome.

Occasionally, the backward dome or the whole A2 fork is turned to the side of the nondominant A1, which makes the clipping more difficult (see below) (Fig. 8).

10.1. Planning

Usually, the LSO approach is optimal. To have a good view to the base and the perforators (see above), the side of more anterior A2 in sagittal 3D CTA may be preferred for the approach. In case of large ICH, its side is preferred to prevent bilateral gyrus rectus injury. Associated aneurysms or high location of the ACoA complex may affect the choice. High location of backward ACoAA may indicate the anterior interhemispheric approach [37] (Video ACoAA-8), requiring the distance from vertex to the aneurysm base to be measured.

10.2. Head position

The head is extended 10° and rotated 30° toward the contralateral side with a pronounced lateral tilt. This position opens the angle of the A1-A2 junction behind the ACoA complex and gives a better view to the base of the backward aneurysm.

10.3. Dissection toward the aneurysm

The carotid and optic cisterns are opened, then the optic and lamina terminalis cisterns. The ipsilateral A1 and then the contralateral A1 are dissected and prepared for temporary clipping (Video ACoAA-5). A gyrus rectus resection with posterior extension is performed, and the A1-A2 junctions, the base of the backward aneurysm, and the A2s are visualized. After application of a Sugita retractor with small tip in the cavity of gyrus rectus resection, tedious dissection of the base of the aneurysm and the ACoA complex is started. Dissection of the contralateral A2 behind the aneurysm may be difficult and risks premature rupture. The aneurysm base is involved to various degrees with ACoA perforators.

10.4. Temporary clipping

Temporary clipping of the both A1s softens the aneurysm so that it is possible to further dissect the base. The use of temporary clips on the A2s should be limited to complex and giant aneurysms. The pilot clip should be applied carefully so as not to sever perforators.

10.5. Final clipping

Under protection of the pilot clip, the base is painstakingly dissected from perforators. Coagulation and reshaping of the backward ACoAA should be minimized so as not to sever the perforators. Aggressive dissection of perforators may cause their rupture. After optimal dissection of the base and the perforators under temporary and pilot clipping, the shortest possible final clip, usually a curved one, is applied. The angle of application should be assessed carefully so as not to damage the perforators by clip blades. In case of a
11. Complex ACoAAs

Complex ACoAAs are usually large dysmorphic aneurysms that are characterized by (a) a dome that projects to more than 1 direction and by (b) involvement of arteries and perforators of the ACoA complex (Fig. 9). It is difficult to obtain an adequate view to adjacent arteries, particularly to the contralateral A1 and A2. Furthermore, clipping may be complicated by calcifications in the base and wall of the aneurysm (Video ACoAA-6).

When the A2 fork with the dome is turned medially, the contralateral A1 and the origin of the contralateral A2 become hidden (Video ACoAA-5). The final dissection of the base can be performed with a temporary clip applied on the ipsilateral A1 only, and a pilot clip is applied. After careful dissection of the softened dome, it should be possible to check the base. After complete visualization of the contralateral A1, the temporary clips are applied on both A1s, and the aneurysm is coagulated, reshaped, and clipped as above.

The dome is behind the ACoA complex, and the A2 fork is turned toward the nondominant A1. Extension of the gyrus rectus resection more posteriorly may give a better view to the ACoA complex. After primary dissection of the A1s and the ACoA complex, temporary clips are applied on both A1s, and the base of the aneurysm is carefully dissected between the A2s. It is very difficult to get the perforators in view as they are hidden by the dome. A pilot clip is applied, the fundus is dissected, and the position of the pilot clip is checked. To avoid injury to perforators, coagulation and reshaping should not be applied. A curved final clip is usually optimal, not leaving a remnant behind the surgical field (Video ACoAA-5).

12. Associated aneurysms

The ACoAAs are often associated with other aneurysms. In the Kuopio series, 29% of all ACoAA patients and 19% of those with a ruptured ACoAA had at least 1 additional aneurysm (Table 4). Our strategy is to clip all aneurysms that can be exposed through the same craniotomy. Usually, it is advisable to treat the ruptured aneurysm first, and if this succeeds without particular difficulties, additional aneurysms can be treated in the same session. We do not prefer to clip associated ruptured aneurysms if the brain is swollen due to acute SAH.

12.1. Multiple ACoAAs

Multiple ACoAAs were seen in 21 patients (2.3%). Multiple ACoAAs usually have different projections, so the positioning and dissection toward the ACoA complex should be tailored according to these directions (Video ACoAA-7).

12.2. “Minianeurysms”

Anterior communicating artery aneurysms may also accompany with mini blebs not seen in preoperative imaging and of poorly known natural history. Depending on the patient’s age and sclerosis of parent arteries, we may reduce them by bipolar coagulation under temporary clipping of the parent artery.

13. Giant ACoAAs

Giant ACoAAs are rare [100,104], 2% in the Kuopio series. In rare instances, the mass causes visual or hypothalamic symptoms, behavioral changes, or hydrocephalus. Giant and large ACoAAs are difficult to treat. The often calcified base involves the whole ACoA complex, including perforators. Comprehensive preoperative imaging by CTA, DSA, and MRI is mandatory. Three-dimensional CTA reconstructions may disclose calcifications at the base and show the orientation of the aneurysm with respect to the bony landmarks. Digital subtraction angiography with unilateral carotid occlusion tests may provide important information on the angioarchitecture and flow dynamics of the ACoA complex. We recommend intraoperative catheter angiography to disclose surprise occlusions.

We generally prefer a modified LSO approach [32] for giant ACoAAs. Positioning and craniotomy should allow useful visualization of the A1s and the A2s bilaterally, which is extremely important during temporary clipping. The identification of the A1s is followed by a generous resection of the gyrus rectus to achieve a view to the whole ACoA complex and the aneurysm. Anterior communicating artery aneurysms with intraluminal thrombosis can be opened after application of temporary clips for evacuation of thrombus by ultrasonic aspirator.
lumen is irrigated copiously by saline. The dome is usually reduced by bipolar coagulation to allow final dissection of the neck anatomy before deciding how to perform the final clipping. Particular care should be taken so as not to sever ACoA perforators by bipolar coagulation. In case of thin-walled aneurysms with no thrombosis, the collapsed aneurysm sac can be opened and shrunken by bipolar coagulation.

The base of giant ACoAAs requires clip reconstruction [99,100,101,104]. We do not prefer ring clips as they are often impractical within the complex ACoA anatomy. The problem is in the insufficiency and inexactness of the design of the blades close to the ring. Giant ACoAAs can usually be successfully clipped after multiple stages of clip replacement and coagulation reshaping.

Advanced revascularization techniques, including EC-IC bypass with vein graft to A2s, side-to-side A2 or A3 bypasses [60], or trapping with distal revascularization [85], may be used in selected cases.

14. Fusiform ACoAAs

Fusiform ACoAAs are extremely rare with only 3 cases (0.3%) in the Kuopio database.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.surneu.2008.01.056.

References


