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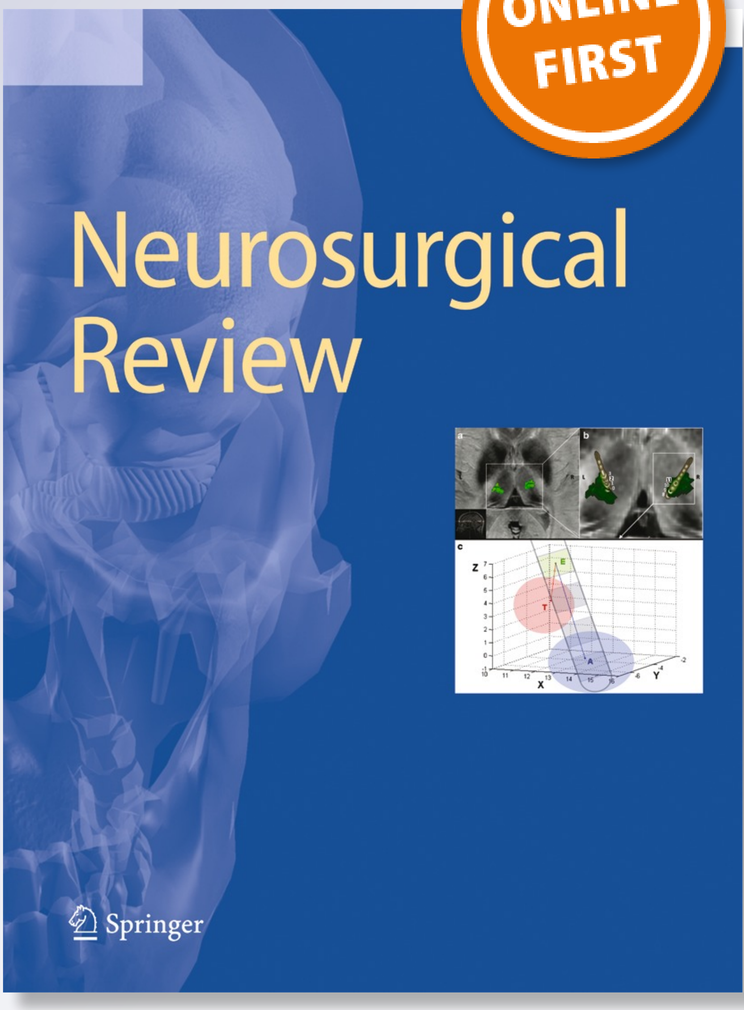

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ORIGINAL ARTICLE

Analysis of superiorly projecting anterior communicating artery aneurysms: anatomy, techniques, and outcome. A proposed classification system

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Abstract Superiorly projecting (SP) anterior communicating artery (AComA) aneurysms are typically described as a homogenous group. Clinically and microsurgically, these aneurysms vary in multiple important characteristics. We propose a microsurgical classification system for these complex aneurysms and review its implications regarding presentation, microsurgical techniques, and outcome. This retrospective analysis reviews patients undergoing clipping of SP AComA aneurysms (2005–2013). The classification system is based on the virtual plane created by the A2 segments and its relationship to the aneurysm. Aneurysm type was assessed by intraoperative images and videos. Type 1 is defined by bisection of the dome by the virtual plane. Type 2 is defined by dome projection posterior to this plane. Sagittal rotation of the plane defines type 3. We analyzed clinical presentation, morphology, angiographic characteristics, operative technique, and outcome relative to the classification types. There were 44 SP AComA aneurysms. 3D angiographic images predicted classification type in 83 %. Type 1 presented more often with SAH (95.5 %, $p=0.0046$). There was no statistically significant difference between the types regarding patient demographics or aneurysm characteristics. In type 2, fenestrated clips were used frequently (87.5 % $p=0.0016$), and there was higher rate of intraoperative rupture (37.5 %). Although there was no statistically significant difference between the types in respect to HH grade upon presentation, patients with type 2 aneurysms experienced higher rates of poor GOS (50 %). The proposed classification system for SP AComA aneurysms has implications regarding surgical planning, micro-dissection, clipping, and outcome. Type 2 aneurysms carry significant surgical risk.

Keywords Anterior communicating artery · Aneurysm · Classification · Microsurgery · Superiorly projecting · Clip

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Introduction

Anterior communicating artery (AComA) aneurysms are the most frequent site of intracranial aneurysms [1–4]. The AComA complex has a unique anatomy that includes multiple anatomic configurations and variants, critical perforators, and a variable relationship to aneurysms in this location [2, 5, 6]. In the endovascular era, the subset of AComA aneurysms treated microsurgically includes lesions that are morphologically complex [2, 5] with incorporation of the proximal A2 segments. These aneurysms often present a unique challenge; therefore, anatomic conceptualization and three-dimensional (3D) appreciation of these lesions are mandatory for efficacious microsurgical intervention.

Several classification systems for AComA aneurysms have been proposed, most of them are based on their approximation to linear projections in a two-dimensional grid: superior, anterior, inferior, and posterior [4, 5, 7–10]. In a 3D system, AComA aneurysms can be viewed as the epicenter of a

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microsurgical anatomic sphere and thusly project into four distinct spatial quadrants. Superiorly projecting (SP) AComA aneurysms account for the majority of AComA aneurysms (19–34 %) [4, 11]. Aneurysms in this region require sophisticated clipping techniques secondary to their projection and affiliation with associated and adjacent major vessels and perforators.

SP AComA aneurysms vary in multiple important characteristics; however, despite repeated citation in the literature as a homogenous group [2, 10], there has yet to be proposed a paradigm of classification of these aneurysms which emphasizes their distinct anatomic variants and type-specific microsurgical techniques. This study proposes a novel microsurgical classification system of SP AComA aneurysms and analyzes its type-specific implications regarding microsurgical dissection strategies, clipping techniques, and clinical outcome.

Patients and methods

This retrospective IRB approved (13–303, 2013) study is based on prospectively collected data of patients undergoing craniotomy for clipping of SP AComA aneurysms in a single institution between 2005 and 2013. All of our patients are routinely presented to our multidisciplinary neurovascular conference, and team composed of cerebrovascular neurosurgeons, stroke neurologists, and neuro-interventional radiologists. The decision regarding the ultimate optimal treatment paradigm for each specific case is arrived at to achieve complete and definitive anatomical aneurysm occlusion with the lowest associated morbidity and risk. These modality decisions are based upon multiple factors inclusive of the aneurysm size, lobularity, position and overall morphology, inclusive of neck/dome ratio, and incorporation of the take-off of the proximal A2 segments and Heubner's arteries. Additionally, the patient's age, Hunt and Hess grade, and comorbidities are important factors that bear on the final decision as well. All treatment options are always presented to the patient with our recommendations and reasons for the definitive treatment decision. All craniotomies were performed with intraoperative monitoring of somatosensory evoked potentials, electroencephalography, and motor evoked potentials. Standard pterional transsylvian dissection was used in all cases, and temporary arterial occlusion of either one or both A1 segments was routinely employed prior to final dissection and definitive clipping. Indocyanine green (ICG) video angiography was utilized in 37 cases.

Study participants

Patients undergoing craniotomy for microsurgical clipping of SP AComA aneurysms were included. All patients had involvement of the AComA itself. Aneurysms which involved only the A1 or A2 segments of the AComA complex, AComA aneurysms with other than superior projection, blister aneurysms, and dissecting aneurysms in this region were excluded from the cohort. All patients were treated by the senior author (DJC).

Operative reports as well as intraoperative microscopic images and videos were reviewed in all patients in order to determine SP AComA aneurysm type classification. Preoperative CTA, inclusive of source imaging and 3D reconstructions and/or formal cerebral angiography with 3D reconstructions were blindly assessed retrospectively to evaluate the radiographic predictability of SP AComA aneurysmal type. Patient's files were reviewed for demographic data. Neurological evaluation upon presentation was assessed using the Hunt and Hess (HH) grading system. Imaging studies were reviewed to evaluate subarachnoid hemorrhage (using the Fisher grading system) and to assess ventricular system enlargement. CT angiography (CTA) and/or formal angiographic studies were reviewed to assess aneurysmal morphology and the associated anatomy of the AComA complex. Patient's operative reports were reviewed for surgical techniques (use of temporary clips, type of clip(s), number of clips used, and number of clip readjustments), intraoperative aneurysmal rupture, and complicating intraoperative events.

Complications were categorized as operative complications (i.e., return to the operating room due to extra-axial collections), any new focal neurological deficit, and any medical complications (i.e., deep vein thrombosis, diabetic insipidus, sepsis, etc.) All patients underwent CT scanning in the immediate postoperative period to detect postoperative hematomas, hydrocephalus, perforator infarctions, and other complications. All but three patients underwent postoperative cerebral angiography, which was used to assess complete aneurysm occlusion and in selected cases, to diagnoses and treat vasospasm. Aneurysm occlusion was classified as complete (no residual aneurysm), minimal residual aneurysm (<5 %), or incomplete (>5 % of the original aneurysm lumen remaining) based on linear measurements of maximal aneurysm angiographic length as compared to maximal length of any remnant.

Neurological outcomes were assessed using the Glasgow Outcome Scale (GOS) score.

Aneurysmal projection

The focus of this report is specifically AComA aneurysms within the superior projection quadrant. Within this particular 3D zone, the relationship between the proximal A2 segments and the aneurysmal fundus may vary in an axial/coronal plane or orthogonally, in a sagittal plane, based on co-existent and independent movements of these structures. These tandem anatomic variations give rise to the categories we propose (Fig. 1).

Classification system

We have classified SP AComA aneurysms into three categories—Types 1, 2, and 3. This classification is both

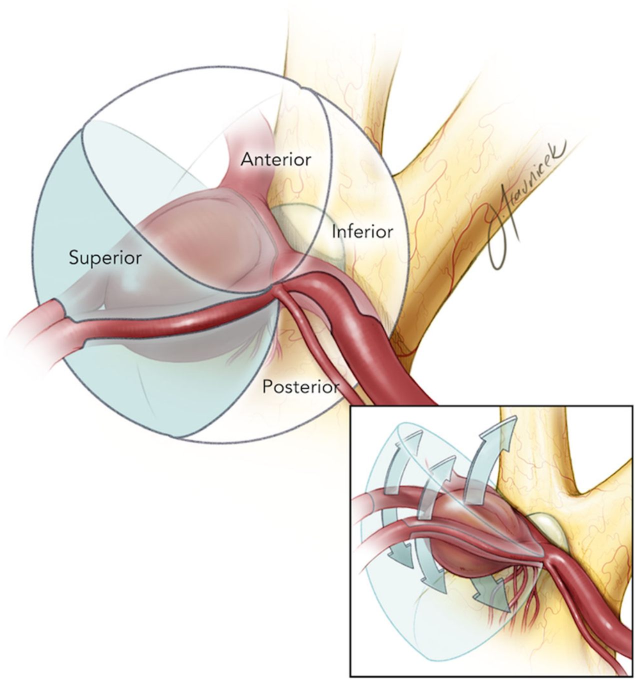

Fig. 1 An AComA aneurysm is seen projecting into the center of the superior spatial quadrant (*blue shaded area*). *Arrows* (lower right image) show possible coordinated or independent anatomic variations of the dome and A2 segments within the superior quadrant

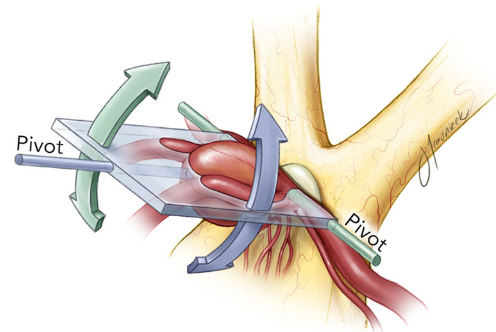

Fig. 2 The virtual two-dimensional plane formed by the proximal A2 segments has two potential axes of pivot within the superior quadrant. The *green* pivot axis describes potential movement from the coronal to axial plane. The *blue* pivot axis places the virtual plane orthogonally in the sagittal axis

anatomic and microsurgical. It is based on the specific angioarchitecture of the anterior aspect of their circle of Willis in each patient. Although frequently predicted by preoperative 3D imaging, classification types are ultimately realized in totality at surgery during final microdissection.

There are two inter-related, yet variable spatial-anatomic factors that determine our categorization of SP AComA aneurysms. The first factor relates to the virtual two-dimensional plane that passes through the center of both proximal A2 segments. This virtual plane “moves” based on the anatomic variability of the location of the A2 segments, specifically within the superior quadrant. Thusly, this important virtual plane can shift based on its horizontal virtual pivot at the AComA in a coronal to axial projection and can also pivot orthogonally into a sagittal alignment. The proximal A2 segments are generally straight and linear, and conceptualization of the virtual plane is possible in all cases (Fig. 2).

The second factor is based on the co-existent projection axis and angulation of the aneurysmal dome, again exclusively within this superior projection spatial quadrant. It is the combination of the movements of the A2 segments with their associated virtual plane and the variability of the position of the actual aneurysmal dome that generates our classification types (Figs. 1 and 2). These relationships within the superior quadrant are further illustrated in the Supplemental video.

There are several approaches to SP AComA aneurysms, among them the pterional approach (with or without removal of the orbital bar), the pure sub-frontal approach, and the interhemispheric approach. In our institution, we prefer the pterional approach for these lesions, as it affords the most direct, atraumatic access to these aneurysms with the best visualization of regional anatomy, inclusive of the lamina terminalis, the origins of the A2 segments and the bilateral recurrent arteries of Heubner, and an important orthogonal view of the critical underlying hypothalamic perforating arteries.

We have generally accessed these aneurysms based on an assessment of sidedness of the dominant A1 segment and of laterality of dome projection. Our classification is based on the anatomical relationship between the AComA complex and the aneurysmal dome and stays relevant for each line of sight created by each trajectory toward the AComA complex in all standard microsurgical approaches, inclusive of lateral supraorbital and orbitozygomatic approaches.

Variability of aneurysmal projection in the axial/coronal planes in conjunction with anatomic variability of the virtual plane of the A2 segments gives rise to type 1 and type 2 SP AComA aneurysms. Anatomic alteration of the virtual plane of the A2 segments from axial/coronal to sagittal within this specific three-dimensional superior quadrant yields type 3 SP AComA aneurysms. The subtypes, 3a and 3b, relate to the relative position of the ipsilateral and contralateral proximal A2 segments to the aneurysmal fundus and involve a 180 degree rotation of the virtual A2 plane in the same stationary sagittal axis. Type 3a is realized when the ipsilateral A1 segment (in respect to the side of the approach) is oriented posteriorly, while in type 3b the ipsilateral A1 segment is oriented anteriorly.

Type 1

Type 1 SP AComA aneurysms are essentially centered in the superior projection quadrant and are “bisected” by the plane created by the proximal A2 segments. The resultant anatomy places part of the dome of the aneurysm anterior to the virtual proximal A2 segment plane and part posterior (Fig. 3a–c).

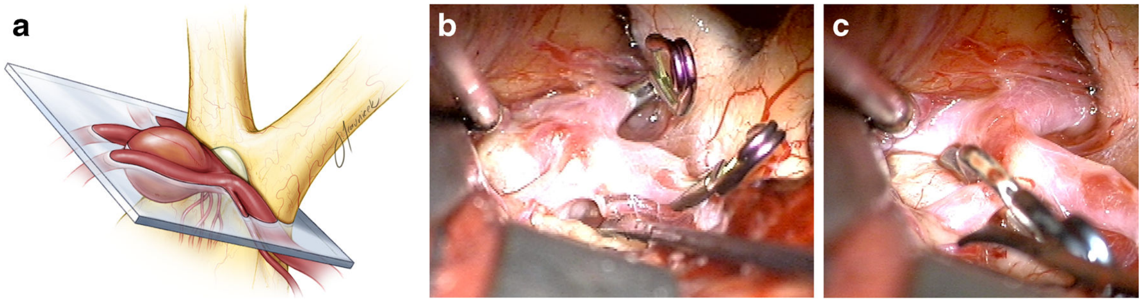

Fig. 3 **a** Type 1 SP AComA aneurysm: the virtual plane formed by the proximal A2 segments "bisects" the aneurysmal dome. The dome obscures the proximal contralateral A2 segment. **b** Right pterional exposure demonstrates a type 1 SP AComA aneurysm. Temporary clips are on both A1 segments. **c** A fenestrated clip encompassing the proximal ipsilateral A2 segment is placed parallel to the AComA and abuts the medial surface of the contralateral A2 segment

Type 2

Type 2 SP AComA aneurysms have domes that are oriented posterior to the virtual proximal A2 segment plane, yet remain completely within the superior projection quadrant. In these cases, the trajectory of the proximal A2 segments is more anterior, and thusly, the plane formed by the A2 segments is tilted off of the horizontal pivot anteriorly. Concurrently, the axis of projection of the aneurysmal fundus shifts posteriorly within the same superior projection quadrant. In these cases, the dome is in direct contact with the critical perforators in the region and is positioned superior to these perforators (Fig. 4a–c).

Type 3

Type 3 SP AComA aneurysms are defined by the anatomic variant of sagittal rotation of the virtual plane formed by the proximal A2 segments. We define it as rotation of more than 45 degrees off of the anatomic coronal plane. This plane is orthogonal to that described in type 1 and type 2. Here, dominance of either of the A1 segments and its associated vector of flow may affect lateral aneurysmal projection in respect to the virtual sagittal A2 plane; however, this relationship does not affect our proposed classification system. We have further classified type 3 SP AComA aneurysms to types 3a and 3b based on the orientation and position of the proximal A2 segments relative to the aneurysmal dome.

Type 3a

The ipsilateral A2 segment is positioned posteriorly, and the contralateral A2 segment is situated anteriorly relative to the aneurysmal dome. This anatomic construct obscures the perforators of the anterior communicating artery complex. The anterior aspect of the AComA is en-face and orthogonal to the surgeon's line of sight (Fig. 5a–c).

Type 3b

The ipsilateral A2 segment is positioned anteriorly, and the contralateral A2 segment is positioned posteriorly relative to the aneurysmal dome. In this variant, an orthogonal and en-face view of the posterior aspect of the AComA is established for the surgeon; thusly, there is a direct view of the regional perforators (Fig. 6a–c).

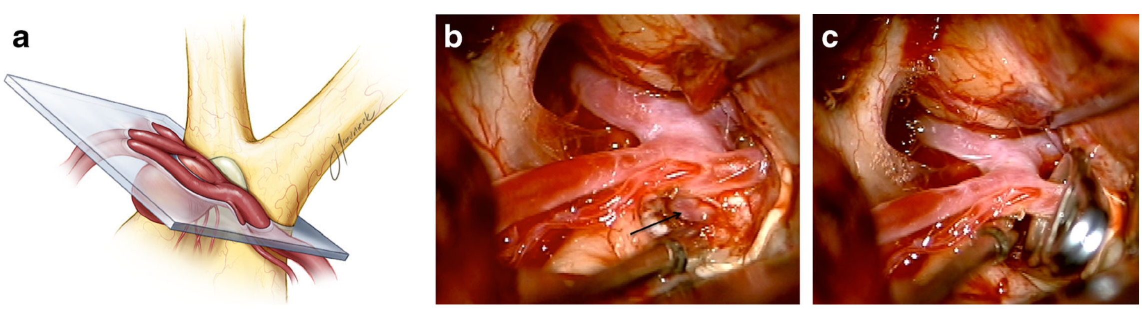

Fig. 4 **a** Type 2 SP AComA aneurysm: movement of the virtual plane anteriorly toward the axial plane and shift of the aneurysmal dome posteriorly toward the coronal plane is seen. The dome is completely posterior to the virtual A2 plane and closely associated with AComA perforators. There is clear visualization of the anterior aspect of both proximal A2 segments. **b** Left pterional exposure demonstrates a type 2 SP AComA aneurysm. Both A2 segments (*arrows*) are visualized. The aneurysmal dome (*arrow*) is visualized medial to the gyrus rectus resection. **c** A fenestrated clip is placed encompassing the proximal left A2 segment. The distal clip blades lie posterior to the contralateral A2 segment. The clip assumes an axial orientation

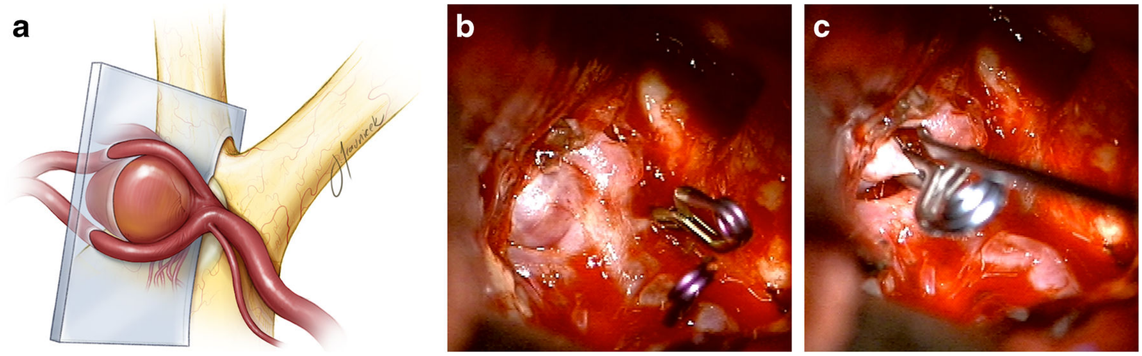

Fig. 5 **a** Type 3a SP AComA aneurysm: the virtual plane assumes a sagittal orientation and the ipsilateral proximal A2 segment is posterior to the aneurysmal dome. The contralateral proximal A2 is anterior to the dome. The anterior side of the AComA is orthogonal and en face to the approach trajectory. The perforators are obscured. **b** Right pterional exposure demonstrates a ruptured type 3a SP AComA aneurysm. Temporary clips are in place on both A1 segments. The ipsilateral A2 segment is positioned posterior to the aneurysmal dome. **c** The aneurysm is definitively clipped with a straight clip. A dissector demonstrates the contralateral A2 segment

Statistical methods

For each continuous factor, the association between the type of SP AComA aneurysm and that specific factor was examined using the Kruskal-Wallis test. Upon finding a significant difference, pairwise comparisons were carried out using the Mann–Whitney test. For each categorical factor, the association between the type of SP AComA aneurysm and that specific factor was examined using the Fisher's Exact test. Upon finding a significant difference, pairwise comparisons were carried out using the Fisher's exact test. For all pairwise comparisons, a Bonferroni adjustment was used, such that $p<0.017$ (0.05/3) was considered significant. The association between HH Grade and measures of GOS at follow-up was each examined using the Fisher's exact test.

Results

The senior author (DJC) has microsurgically clipped 389 AComA aneurysms in the period 1986–2013. Eighty-two AComA aneurysms were clipped between 2005 and 2013, and 44 (53.7 %) of these AComA aneurysms were SP AComA aneurysms. All of these cases were assessed by a multidisciplinary group (endovascular and microsurgical) who deemed these aneurysms were best treated by open clipping. Determinants included aneurysmal morphology, association with A2 vessels, neck size, age, presence of multiple aneurysms, and presence or absence of medical comorbidities. Among them, 29 patients (65.9 %) were female patients. The median age of the cohort was 54 (47–62) years. The median aneurysm size was 4.5 mm (3.5–6 mm), and the median neck size was 3 mm (2.5–4 mm). The median dome/neck ratio was

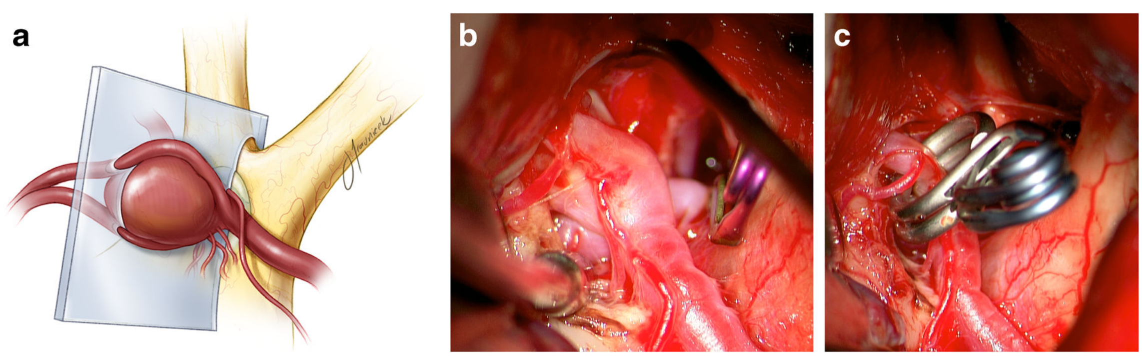

Fig. 6 **a** Type 3b SP AComA aneurysm: the virtual A2 plane assumes a sagittal orientation (rotated 180 degrees from that seen in type 3a). The ipsilateral proximal A2 segment is anterior to the aneurysm dome. The contralateral proximal A2 segment is posterior to the dome. The posterior side of the AComA and the perforator origins are easily visualized and en face to the approach trajectory. **b** Right pterional exposure demonstrates a type 3b SP AComA aneurysm. A temporary clip is in place on the contralateral A1 segment. The ipsilateral A2 segment is located anterior to the aneurysmal dome and both the recurrent artery of Huebner and AComA perforators are well visualized. **c** The aneurysm is clipped with two parallel tandem fenestrated clips

1.5 (1.3–2). Thirty-three (75 %) patients presented with subarachnoid hemorrhage. Eight patients (18.2 %) presented in HH grades of 4–5.

Fifteen (34.1 %) patients required more than one clip. Fenestrated clips were used in 26 patients (59.1 %). Three patients experienced major intraoperative rupture. There were three cases of significant aneurysm residua that required retreatment (two cases were re-clipped and one was treated with endovascular coil embolization) and ten cases with minimal (<5 %) residual aneurysm.

Twenty-nine patients (65.9 %) experienced immediate favorable outcome (GOS 4, 5). The 30-day mortality rate was 6.8 %. Twenty-two (50 %) SP AComA aneurysms were classified as type 1; eight (18.2 %) aneurysms were classified as type 2; nine (20.5 %) aneurysms were classified as type 3a; and five (11.4 %) aneurysms were classified as type 3b. SP AComA aneurysm type was predicted in 83 % of patients based on blinded review of preoperative CTA source images, 3D CTA reconstructions, and formal 3D reconstructed angiographic images.

Anatomy

We analyzed A1 dominance and its implication on the configuration of the AComA complex. There were 12/14 (85.7 %) dominant A1 segments in type 3, while 23/30 (76.7 %) were observed in the type 1 and type 2 groups. Moreover, 10/12 (83.3 %) of type 3 aneurysms with a dominant A1 segment assumed a configuration where the ipsilateral A2 segment was oriented posteriorly.

Clinical presentation and aneurysmal characteristics in respect to SP AComA aneurysm type

There were no demographic differences in respect to the different SP AComA aneurysmal types. There was a distinct difference in the rate of rupture at presentation ($p=0.0046$). Type 1 SP AComA aneurysms presented with aneurysmal rupture and SAH at a rate of 95.5 %, type 2 SP AComA aneurysms presented at a rate of 50.0 %, and type 3 presented with SAH at a rate of 57.1 %. Pairwise comparisons found that these rates were higher in type 1 then either type 2 or type 3 ($p=0.0112$ and 0.0083, respectively). There was no difference between type 2 and type 3, although there was a difference in Fisher grade (median for type 1=4.0, type 2=3.0, type 3=3.0, $p=0.037$); pairwise comparisons were unable to determine which groups differed from the others. There was no difference in respect to clinical neurological presentation (Hunt and Hess grade) between the groups. We note the difference in the rate of patients presenting with intraventricular hemorrhage (type 1=77.3 %, type 2=37.5 %, type 3=35.7 %, $p=0.028$). However, pairwise comparisons were unable to determine statistical significance. There was no difference between the types in respect to intracerebral hemorrhage or hydrocephalus upon presentation. Additionally, there was no difference in respect to aneurysm morphology, aneurysm size, and neck size or dome/neck ratio between the types (Tables 1 and 2).

Table 1 Superiorly projecting anterior communicating artery aneurysm (types 1, 2, and 3)—Clinical presentation, aneurysm characteristics, clipping technique, and outcome

Type	1	2	3	*p* value
Number of SP AcomA aneurysms (%)	22 (50)	8 (18.2)	14 (31.8.)	NA
Median age	55.5 (41–80)	58.5 (35–76)	49.5 (43–41)	0.42
Rupture (%)	21 (95.5)	4 (50)	8 (57.1)	0.0046
HH grade				0.39
0 (%)	2 (9.1)	2 (25)	5 (35.7)	
1–3 (%)	15 (68.2)	5 (62.5)	7 (50)	
4–5 (%)	5 (22.7)	1 (12.5)	2 (14.3)	
Median size of aneurysm in mm (range)	4.0 (2.5–11.0)	4.5 (3.0–7.0)	4.8 (2.0–11.0)	0.98
Median size of aneurysm neck in mm (range)	3.0 (1.7–7.0)	3.0 (2.0–5.0)	3.0 (1.5–5.0)	0.83
Median dome/neck	1.5 (1.0–2.5)	1.3 (1.0–3.5)	1.5 (1.0–2.7)	0.89
Multiple clips used (%)	9 (40.9)	2 (25.0)	4 (28.6)	0.69
Fenestrated clips used (%)	16 (72.7)	7 (87.5)	3 (21.4)	0.0016
Clip readjusted (%)	9 (40.9)	4 (50)	5 (35.7)	0.84
Intraoperative rupture (%)	6 (27.3)	3 (37.5)	3 (21.4)	0.82
Vasospasm (%)	12 (54.6)	2 (25)	3 (21.4)	0.12
Number of deaths within 30 days (%)	0	2 (25)	1 (7.1)	0.06
Stroke per CT (%)	9 (40.9)	3 (42.9)	6 (42.9)	>0.99
Postoperative GOS 1–3 (%)	8 (36.4)	4 (50)	3 (21.4)	0.44

Table 2 Superiorly projecting anterior communicating artery aneurysm (types 3a and 3b): clinical presentation, aneurysm characteristics, clipping technique and outcome

Type	3a	3b
Number of aneurysms (%)	9 (20.4)	5 (11.4)
Number of ruptured cases (%)	5 (55.6)	3 (60)
Median size of aneurysm in mm (range)	6 (4–7)	3.5 (3–4.5)
Median dome/neck ratio (range)	1.7 (1.3–2.2)	1.5 (1–1.7)
Number of cases using multiple clips (%)	3 (22)	2 (40)
Number of cases using fenestrated clips (%)	0 (0)	3 (60)
Number of clip readjustments (%)	3 (33.3)	2 (40)
Intraoperative rupture (%)	3 (33.3)	0
Cases with vasospasm (%)	3 (33.3)	0
Ischemic changes per CT (%)	6 (66.7)	0
Cases with poor outcome (GOS 1–3) (%)	2 (22.2)	1 (20)

Intraoperative technique

We used fenestrated clips more frequently in type 1 and type 2, as compared to type 3 SP AComA aneurysms (72.7 and 87.5 % vs. 21.4 %, $p=0.0016$; type 1 vs. type 3, $p=0.0054$; type 2 vs. type 3, $p=0.0062$). Specifically, in type 3a, we did not use fenestrated clips in any of the cases. Although there was no significant statistical difference in respect to intraoperative rupture, the overall rupture rate was higher in type 2 SP AComA aneurysms (37.5 % vs. 27.3 and 21.4 %). There was no difference between the groups in respect to intraoperative temporary clip use, clip readjustment, or tandem clipping.

Operative results and outcome

In an analysis of our entire cohort, we found a statistically significant association between HH grade upon presentation and GOS. In the subgroup analysis for types, there was no statistical difference in respect to the overall preoperative neurological baseline condition (unruptured, HH grade 1–3 or HH grade 4–5) between the groups ($p=0.3933$). Patients with type 2 SP AComA aneurysms, however, had a distinctly higher rate of poor postoperative outcome (GOS 1–3) as compared to type 3 and type 1 (50 % vs. 21.4 and 36.4 %, respectively). This difference, however, did not achieve statistical significance. There was no difference between the groups in respect to aneurysmal occlusion rate. Interestingly, there was no incidence of incomplete aneurysmal occlusion in type 3 aneurysms. There was no difference between the groups in respect to the rate of postoperative ischemic changes per CT scan within the perforator territories (40.9 % vs. 42.9 and 42.9 %), however, in the subgroups of type 3 SP AComA aneurysms, there was no incidence of ischemic changes at all in type 3b while the rate of ischemic changes in type 3a was 66.7 %.

There were no differences between the groups in the rate of vasospasm postoperatively and in all other complication categories.

Discussion

In the final analysis, one of the most important tools in the armamentarium of the microvascular neurosurgeon is the ability to conceptualize and understand structures in three-dimensional space. This ability is critical in the appreciation and microdissection of the AComA complex and associated AComA aneurysms. This applies most specifically to SP AComA aneurysms where the aneurysmal dome is intimately associated with the A2 segments and is often times obscured and adjacent to critical perforating arteries. These SP AComA lesions remain challenging in the endovascular era as many of them still remain within the microsurgical arena based on their complex morphology and association with surrounding vasculature [2, 12]. SP AComA aneurysms require a meticulous dissection technique based on a precise spatial understanding of the local anatomy [5, 7]. In order to achieve this 3D understanding, and to plan and successfully accomplish clipping of these aneurysms, we advocate the use of the proposed classification system.

There are several classification systems for AComA aneurysms described in the literature [2, 4, 7, 9, 10, 13]. Most of these reports classify these aneurysms in a linear, sagittal two-dimensional anatomical fashion, as either projecting superiorly, posteriorly, anteriorly, or inferiorly. Proust et al. have analyzed endovascular and microsurgical treatment modalities of these aneurysms. They have classified them in respect to their angiographic relationship to the axis of the pericallosal arteries as either anteriorly or posteriorly projecting [9]. AComA aneurysms have also been described and characterized according to the involvement of the parent arteries of the AComA complex and its bifurcation as “A1/A2” or “ACom” aneurysms [12].

We have conceptualized that the microsurgical AComA complex anatomic sphere may be divided into four distinct spatial 3D quadrants—anterior, posterior, inferior, and superior. There is variability of projection of both the aneurysm and its surrounding vasculature within each quadrant (see Supplemental video). The superior quadrant of the AComA sphere is a common location of AComA aneurysms [4, 11]. In our series of AComA aneurysms, SP AComA aneurysms were similarly the majority of the cohort (53.7 %). We believe that SP AComA aneurysms should be viewed and analyzed as a separate and distinct category of AComA aneurysms. Anatomic considerations, challenges in dissection, and clipping techniques distinguish this category of AComA aneurysms from all other anterior circulation aneurysms.

Our proposed classification system for SP AComA aneurysms is anatomic and microsurgical; thusly, the microsurgeon can formulate an effective dissection and clipping strategy which is type specific. Its implications regarding microdissection and clipping are based on standard pterional or modified lateral subfrontal approaches. We propose a straightforward and unifying classification system based on an invisible, virtual two-dimensional plane that is defined by the proximal A2 segments, which relates spatially to the aneurysmal dome.

Preoperative imaging

Analysis of preoperative vascular imaging is an essential component to preoperative planning in aneurysm microsurgery. Operative planning based on CTA has been previously described [2–4], although information regarding branches incorporated to the aneurysmal fundus are lacking in this modality [14]. We have found 3D reconstructed CTA imaging to be a reliable modality to assess our proposed SP AComA aneurysm classification system prior to craniotomy. In our overall cohort of 44 SP AComA aneurysms, the classification type of 83 % of these aneurysms was correctly predicted by blinded neurosurgical postoperative review of CTA source images combined with analysis of CTA 3D reconstructions. The demonstration of the skull base combined with bilateral demonstration of the proximal A2 segments and the AComA complex in its totality enhances the accuracy of SP AComA aneurysm type prediction. Conventional 3D angiographic reconstructions allow for accurate assessment of the aneurysm morphology as well as accurate demonstration of the relationship between the aneurysm and the AComA, but usually only the ipsilateral A1 and A2 segments are demonstrated. Conventional 3D angiographic reconstructions without the association of the bony skull base and without concurrent demonstration of the contralateral vessels become less efficacious than CTA for preoperative determination of SP AComA aneurysm type. CTA and angiographic reconstructions do not completely approximate the anatomy realized under the operating microscope at surgery. Thusly, our preoperative prediction of SP AComA aneurysm type is not yet 100 % accurate. With advances in software and potential utilization of heads-up displays, we anticipate continued improvement in preoperative and pre-dissection prognostication of SP AComA aneurysm type, where subjective analysis of images becomes more quantified and reliable.

Type 1

Type 1 SP AComA aneurysms are usually centered in the superior spatial quadrant and are in essence "bisected" by the virtual plane created by the proximal A2 segments. In our cohort, these aneurysms represent the largest group among all SP AComA aneurysms (50 %). Patients harboring type 1 aneurysms predominantly presented with ruptured aneurysms and subarachnoid hemorrhage. In type 1 SP AComA aneurysms, the AComA is usually well visualized and the perforators are obscured. There are significant aspects of the aneurysmal fundus located both anterior and posterior to the virtual plane formed by the A2 segments. The contralateral A1/A2 junction, the proximal contralateral A2 segment, and the origin of the contralateral recurrent artery of Heubner are usually obscured by the aneurysmal fundus. After the application of temporary clips, depression of the fundus allows the surgeon to appreciate the position of the contralateral A2 segment, and if necessary, to dissect a plane between the medial aspect of the contralateral A2 segment and the adjacent, lateral aspect of the aneurysmal dome. As has been well documented, gyrus rectus resection is necessary in most SP AComA aneurysms [2, 10, 13]. This resection allows for appreciation of the most posterior aspect of the aneurysm dome and adjacent perforators and frequently facilitates visualization of the posterior and medial aspect of the contralateral A2 segment after elevation of the posterior aspect of the dome. Inadvertent dissection medial to a gyrus rectus resection or blind dissection posterior to the ipsilateral A2 segment may carry the risk of a difficult and complicating intraoperative rupture.

Fenestrated clips are generally very effective for SP AComA aneurysms [2, 7, 10, 15]. In our cohort of type 1 SP AComA aneurysms, (72.7 % of this type was treated with fenestrated clips) fenestrated clips are placed parallel to the AComA with clip blade tips that are usually abutting the adventitia of the medial wall of the contralateral A2 segment. In selected cases, the use of two tandem parallel fenestrated clips is necessary for complete clipping and reconstruction of the AComA complex. We have found ICG video angiography to be problematic for difficult type 1 SP AComA aneurysms, due to the potential inability to completely visualize the aspect of the aneurysmal dome posterior to the posterior clip blade (two cases of incomplete occlusion were observed in this cohort). Postoperative angiography or state-of-the-art intraoperative angiography in a hybrid suite is mandatory in these cases to assess complete aneurysmal clipping.

Type 2

Type 2 SP AComA aneurysms pose a distinct challenge technically and were associated with considerably poorer postoperative GOS in our study. Type 2 aneurysms are completely posterior to the virtual plane formed by the proximal A2 segments and are not seen in the initial phases of dissection of the AComA complex. There is typically relatively clear and early visualization of the contralateral proximal A2 segment, the contralateral A1/A2 junction, and the contralateral recurrent artery of Heubner.

These aneurysms are in the posterior aspect of the superior spatial quadrant. Type 2 SP AComA aneurysms are distinct from pure posteriorly projecting AComA aneurysms in respect to both their vector of projection and their location relative to the perforators. In pure posterior projecting AComA aneurysms, the dome is inferior to and encased by the perforators [7]. In type 2 SP AComA aneurysms, the dome remains superior to these perforators. This close proximity to the perforators may be the reason for the poor clinical outcome observed in patients with type 2 SP AComA aneurysms in our study, as has been similarly described for posteriorly projecting AComA aneurysms [4, 9]. Generally, a generous gyrus rectus resection is also required in type 2 SP AComA aneurysms that allows for visualization of the posterior aspect of the aneurysmal dome and subsequent appreciation and dissection of adjacent perforators. As in type 1 SP AComA aneurysms, here it is absolutely essential for the surgeon to appreciate that dissection posterior to the ipsilateral A2 segment carries risk of intraoperative rupture, as portions of the dome occupy this spatial zone. This dissection must be performed with great caution, usually with temporary clips in place.

Fenestrated clips are critical tool in the effective clipping of these aneurysms (used in 87.5 % of our type 2 patients) and allow for safe anatomic reconstruction of the AComA complex. Prior to the application of a fenestrated clip, there must be complete visualization and preservation of all perforators. Typically, in type 2 SP AComA aneurysms, the anterior blade of the fenestrated clip is placed posterior to the contralateral proximal A2 segment. Appropriate and accurate rotation of the clip must be performed just prior to clip closure to assure freedom of perforators adjacent and posterior to the aneurysm dome and to insure complete inclusion of the aneurysmal neck within the clip blades. In type 2 SP AComA aneurysms, the final position of the clip assumes an axial orientation (Fig. 4c) while in pure posteriorly projecting AComA aneurysms (outside of the superior quadrant), the final position of the clip generally assumes a coronal orientation.

There is clearly a learning curve associated with the technical use and appropriate application of fenestrated clips. We advocate repeated practice in the cadaver lab under the operating microscope. ICG angiography and the careful use of microvascular Doppler are important adjuncts when using fenestrated clips

Intraoperative aneurysmal rupture is known to be associated with poor outcome [16, 17]. In our series, patients with type 2 SP AComA experienced a high rate of intraoperative rupture. This is most probably due to line of sight and visualization difficulties inherent in the anatomic configuration of this type. Additionally, patients with type 2 SP AComA aneurysms were noted to be associated with the greatest risk of poor outcome and the highest mortality rate. Their deep location and obscuration by the gyrus rectus and the A2 segments and their close association with AComA perforators create a microsurgical challenge. The surgeon must be aware of the possibility of aneurysm remnants after clipping and a meticulous post-clipping inspection is absolutely essential. These lesions are generally rare and demand the highest level of spatial-anatomic understanding and subsequent sequential dissection and clipping. Selected cases of type 2 SP AComA aneurysms, particularly patients in poor clinical condition with sub arachnoid hemorrhage, may be considered for sub-total coiling followed by delayed stent placement or other endovascular modalities.

Type 1 and type 2 SP AComA aneurysms can be associated with post clipping residua (6.8 % in our series) due to difficulty with full visualization of the most posterior aspect of the aneurysmal fundus and association of this part of the aneurysm dome with the hypothalamic perforators. A meticulous post-clipping inspection—routinely performed in all microsurgical clippings—becomes even more important in these lesions and should be considered as a critically important part of the sequential microsurgical procedure

Type 3

Type 3 SP AComA aneurysms represent a major anatomic variation and alteration of AComA anatomy as compared to types 1 and 2. Here, the axis of the vertical pivot takes the virtual plane created by the proximal A2 segments out of the coronal perspective and a sagittal position is assumed. There is an en face view of the proximal A2 segments and the ipsilateral side of the aneurysmal dome. This anatomic sagittal alignment of the proximal A2 segments has been previously described and can be associated with a dominant A1 segment [7, 12]. Similarly, in our cohort, 85.7 % of type 3 SP AComA aneurysms were associated with a significant dominant A1 segment.

The direct en face view of type 3a SP AComA aneurysms and their relationship to the A2 segments does not typically necessitate the use of fenestrated clips. We found that in type 3b SP AComA aneurysms the application of the ipsilateral A2 segment to the anterior aspect of the dome and application of perforators to the aneurysm base necessitated the use of fenestrated clips in 60 % of the group. Although the A2 segments are more easily visualized in all type 3 SP AComA aneurysms, the contralateral extent of the dome is at times more difficult to appreciate, particularly in cases of a dominant A1 segment where the aneurysm is projecting directly away from the surgeon's line of vision along the vector of A1 segment flow. Type 3b SP AComA aneurysms afford a more direct and clear view of the perforators in respect to all other types; especially when compared to type 2 and type 3a, where the perforators can be totally obscured. Although not significant, we observed an interesting trend—there was a high rate (66.7 %) of postoperative ischemic changes, within the perforator distribution zones in type 3a and no ischemic events at all in Type 3b SP AComA aneurysms. This relates to visibility, dissection, and subsequent preservation of critical regional perforators.

Based on our classification system, a type 3a SP AComA aneurysm visualized from the right becomes a type 3b when approached from the left, as the ipsilateral A2 segment changes its anterior/posterior position based on sidedness. We do not however advocate a change in side of craniotomy based on type of aneurysm assessed on 3D pre operative imaging. Dominance of A1 filling and dome projection remains our most important determinants of side of approach. Appreciation of the differences in the anatomic configuration between types 3a and 3b SP AComA aneurysms may allow the surgeon an advanced appreciation of perforator location and potential need for fenestrated clips.

It is our experience that fenestrated clips are useful for all sized aneurysms in the superior projection quadrant, especially small aneurysms that are adherent to the proximal A2 segments and those that are "buried" in the space between these two arteries. Proper clip selection and application can reduce the frequency of complicating intraoperative rupture and allow for anatomic reconstruction of the anterior communicating artery complex, with visualized preservation of the origin and proximal aspect of the recurrent artery of Heubner

It is important to realize that the proposed categorization system is not absolute. Within each of our types, the virtual proximal A2 plane can rotate on its vertical pivot up to 45 degrees before the classification type changes. Thusly, there is an infinite set of anatomic variations within each type of SP AComA aneurysms. The over-arching concepts and techniques for each type do however remain constant and serve as important adjuncts to classic and established methodologies of microsurgical realization and dissection.

Additionally, the introduction of newer and more sophisticated endovascular technologies, inclusive of state of the art stenting devices, will undoubtedly change the future treatment paradigms for these complex lesions, particularly in high grade subarachnoid hemorrhage, where sub-total coiling may be an appropriate temporizing treatment prior to definitive stenting. It is our belief that the three-dimensional appreciation of these aneurysms delineated by our classification system will not only be a future conceptual and visual adjunct for open microsurgical clipping but also an important tool for treatment within the endovascular arena as well.

Study limitations

The limitations of this study are those inherent to retrospective studies. Moreover, our study is composed of a relatively small number of patients and thusly needs to be validated with ongoing data collection, long-term follow-up, and analysis of patients harboring SP AComA aneurysms. Prospectively, comparisons of postoperative neuropsychological testing profiles of patients in our different categories may add important data to potentially substantiate and elucidate our findings.

Conclusions

Superiorly projecting AComA aneurysms are a frequently encountered and technically challenging subset of all AComA aneurysms. Efficacious surgical treatment of SP AComA aneurysms requires meticulous and thorough preoperative planning and conceptualization and a complete spatial understanding of anatomically variable vascular structures in the region. Familiarity and a high level of experience with these lesions are both critically important factors that can lead to excellent neurological outcomes. Although the experienced aneurysm microsurgeon develops a personalized, almost intuitive approach to the AComA region and understanding of local anatomy, our classification system helps crystallize important differences in this specific SP AComA aneurysmal zone. The new classification system proposed is an adjunct to preoperative planning and can be realized in a large percentage of patients by review of preoperative imaging. Thusly, the surgeon can formulate an appropriate and efficacious dissection and clipping strategy that is type specific. Total facility and familiarity with fenestrated clips and tandem clipping techniques are mandatory, and these remain critically important tools for the microsurgical treatment of SP AComA aneurysms. Type 2 SP AComA aneurysms are associated with poor outcome after microsurgical clipping.

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Comments

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This article described the proposal of the new classification system for superior projecting (SP) anterior communicating artery (AcomA) aneurysms which is based on the virtual plane created by the A2 segments and its relationship to the aneurysm dome. The virtual plane can shift in a coronal/axial projection and in a sagittal alignment, which is the strong point of the article and difference from the classical classification system. The authors concluded this system helps surgeons understand anatomical characteristics of SP AcomA AN and makes efficacious strategy. And they also emphasized usefulness of fenestrate clip for all sized aneurysms with superior direction. I support the new classification system; however, I disagree frequent use of fenestrate clip in this series which included mainly small aneurysm cases compared with previous report.[1] From the rate of postoperative ischemic changes per CT, it is hardly to say that fenestrated clips should be used so frequently for the SP AComA aneurysms. A single straight clip first is recommended by experts,[2, 3] and in some circumstance, fenestrated clips may be provided especially for large size aneurysms.[3] Better view of structures around the aneurysm could be achieved by coagulating and reshaping the dome after applying temporary clips on the both A1s and placing pilot clip with small resection of the gyrus rectus in many cases.[2]

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This is a paper reporting retrospective analysis of 44 patients with anterior communicating artery (AComA) aneurysm projecting superiorly (SP). They proposed new classification of SP AComA aneurysm based on angioarchitecture of the bilateral A2 arteries. They concluded that type 2 aneurysms, in which domes were oriented posterior to the virtual proximal A2 segment plane, yet remain completely within the superior projection quadrant, had a surgical risk.

The authors nicely analyzed the surgical cases, and they proposed new classification system. The SP AComA aneurysms are relatively difficult to clip especially in the standard pterional approach. They raised the important issue. At surgery for a SP AComA aneurysm via the pterional approach, adequate dissection of the interhemispheric fissure is necessary as the authors may apply this technique, although the surgical procedure on this point has not been described in detail. Especially for the type 2 aneurysm, adequate dissection of the interhemispheric fissure is needed to expose the aneurysm neck and to visualize the hypothalamic artery. With the usual pterional approach, the hypothalamic artery is not visible.

Another surgical option is the interhemispheric approach. Of course, the selection of the surgical approach is highly based on the surgeon's preference. The type 2 AComA aneurysm can be a good indication for the interhemispheric approach.

In any way, the authors focused the SP AComA aneurysm with proposing the new classification. The authors are to be congratulatory. With having this issue in mind, the surgical result of the SP AComA aneurysm can be better.