Incidence, classification, and treatment of angiographically occult intracranial aneurysms found during microsurgical aneurysm clipping of known aneurysms

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OBJECTIVE During the microsurgical clipping of known aneurysms, angiographically occult (AO) aneurysms are sometimes found and treated simultaneously to prevent their growth and protect the patient from future rupture or reoperation. The authors analyzed the incidence, treatment, and outcomes associated with AO aneurysms to determine whether limited surgical exploration around the known aneurysm was safe and justified given the known limitations of diagnostic angiography.

METHODS An AO aneurysm was defined as a saccular aneurysm detected using the operative microscope during dissection of a known aneurysm, and not detected on preoperative catheter angiography. A prospective database was retrospectively reviewed to identify patients with AO aneurysms treated microsurgically over a 20-year period.

RESULTS One hundred fifteen AO aneurysms (4.0%) were identified during 2867 distinct craniotomies for aneurysm clipping. The most common locations for AO aneurysms were the middle cerebral artery (60 aneurysms, 54.1%) and the anterior cerebral artery (20 aneurysms, 18.0%). Fifty-six AO aneurysms (50.5%) were located on the same artery as the known saccular aneurysm. Most AO aneurysms (95.5%) were clipped and there was no attributed morbidity. The most common causes of failed angiographic detection were superimposition of a large aneurysm (type 1, 30.6%), a small aneurysm (type 2, 18.9%), or an adjacent normal artery (type 3, 36.9%). Multivariate analysis identified multiple known aneurysms (odds ratio [OR] 3.45, 95% confidence interval [CI] 2.16–5.49, $p < 0.0001$) and young age (OR 0.981, 95% CI 0.965–0.997, $p = 0.0226$) as independent predictors of AO aneurysms.

CONCLUSIONS Meticulous inspection of common aneurysm sites within the surgical field will identify AO aneurysms during microsurgical dissection of another known aneurysm. Simultaneous identification and treatment of these additional undiagnosed aneurysms can spare patients later rupture or reoperation, particularly in those with multiple known aneurysms and a history of subarachnoid hemorrhage. Limited microsurgical exploration around a known aneurysm can be performed safely without additional morbidity.

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KEYWORDS microsurgical aneurysm clip occlusion; catheter angiography; angiographically occult aneurysm; vascular disorders

CEREBRAL catheter angiography is regarded as the gold standard for detecting ruptured and unruptured intracranial aneurysms.^{13–16} However, tiny aneurysms may be missed even with the best imaging technology and techniques due to small size, human error, and technical inaccuracies, including inadequate imaging

projections, the superimposition of other aneurysms or normal vessels, and clip or coil artifact from previously treated aneurysms. Studies in Japanese cohorts have reported the incidence of these angiographically occult (AO) aneurysms to be 3.7%–4.9%, most of which were micro-aneurysms less than 2 mm in diameter.^{6,9} During the mi-

ABBREVIATIONS ACA = anterior cerebral artery; AChA = anterior choroidal artery; ACoA = anterior communicating artery; AO = angiographically occult; BA = basilar apex; CTA = CT angiography; DSA = digital subtraction angiography; ICA = internal carotid artery; ISUIA = International Study of Unruptured Intracranial Aneurysms; MCA = middle cerebral artery; PCA = posterior cerebral artery; PCoA = posterior communicating artery; SAH = subarachnoid hemorrhage.

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crossurgical clipping of known aneurysms, these AO aneurysms are commonly found and treated simultaneously to prevent their growth and protect the patient from future rupture or reoperation.

In patients without a history of aneurysmal subarachnoid hemorrhage (SAH), detection of unruptured small aneurysms is less critical because the rupture risk associated with these aneurysms is low. However, accurate diagnosis of these aneurysms might affect the duration and frequency of follow-up imaging surveillance. In patients with a history of SAH, angiographic detection failure may have serious consequences. In the International Study of Unruptured Intracranial Aneurysms (ISUIA), risk of rupture of additional unruptured aneurysms after SAH (group 2) was found to be significantly higher compared to the risk of rupture of unruptured aneurysms in patients without prior SAH (group 1).⁷ Therefore, the identification of AO aneurysms is important in reducing these patients' risk of a second SAH and might justify limited surgical exploration in the regions adjacent to a known aneurysm being treated microsurgically. We reviewed an extensive series of aneurysms treated microsurgically to determine the incidence, treatment, and outcomes associated with AO aneurysms found during surgery for other known aneurysms. We aimed to determine whether limited surgical exploration around the known aneurysm was safe and justified in light of the known limitations of diagnostic angiography.

Methods

Inclusion Criteria

This study was approved by the IRB and performed in compliance with Health Insurance Portability and Accountability Act regulations. Patient consent was not obtained for this study. A prospectively maintained database was reviewed for all ruptured and unruptured aneurysms treated microsurgically by 1 surgeon (senior author M.T.L.) from 1 institution between July 1997 and September 2016. From the group of patients with multiple treated aneurysms, patients with AO aneurysms treated simultaneously during craniotomy for another known aneurysm were identified based on retrospective reviews of operative reports and preoperative angiography. Specifically, an AO aneurysm was defined as a saccular aneurysm detected using the operative microscope during microsurgical dissection to or around the other known aneurysm, and not detected on preoperative catheter angiography, based on retrospective review of the radiologists' reports. An AO aneurysm had to have a neck and dome that was separate from the other known aneurysm, which thereby eliminated blebs or multiple lobes on the known aneurysm. Patients without preoperative catheter angiographic imaging were excluded from the analysis. Clinical data, including age, sex, presentation, and surgical approach, were collected for all patients. Radiological data, including aneurysm location and morphology, were collected for all aneurysms. Adverse outcome was defined as any neurological changes in the brain supplied by the AO aneurysm's vascular territory or radiological evidence of infarct or vessel occlusion in the AO aneurysm's vascular territory.

Microsurgical Dissection

The extent of microsurgical dissection depended on the location of the known target aneurysm. For the standard lateral approaches (pterional or orbitozygomatic craniotomies), the sylvian fissure was split routinely to provide easy exploration of the supraclinoid internal carotid artery (ICA), including the posterior communicating artery (PCoA), anterior choroidal artery (AChA), and ICA terminus. Fenestration of the lamina terminalis was frequently performed to release CSF and relax the brain, especially in patients with ruptured aneurysms, which allowed inspection of the A₁ anterior cerebral artery (ACA) and anterior communicating artery (ACoA) complex. Fenestration of Liliequist's membrane was also frequently performed for CSF release and brain relaxation, again in patients with SAH, facilitating inspection of the basilar quadrifurcation.¹⁸ Primary microdissection focused on the exposure of the known target aneurysm, and common aneurysm sites within or adjacent to these areas were carefully examined. With other craniotomies, such as the anterior interhemispheric, far lateral, and suboccipital approaches, exploration was limited to the arteries in the dissection pathway to the known aneurysm. Limited exploration was defined as the complete exploration of all arterial segments leading to and adjacent to the known aneurysm, and the extent of exploration was individualized based on anatomy and condition of the brain.

Statistical Analysis

Statistical analysis was performed using R (version 3.1.1; <http://www.r-project.org>). Continuous variables are presented as means with standard deviations and/or ranges when appropriate. In univariable analysis, comparisons between groups were performed using Fisher's exact test for categorical variables and the Wilcoxon signed-rank test for numerical variables. Statistical significance was defined as $p < 0.05$.

Results

Incidence, Location, and Treatment of AO Aneurysms

AO aneurysms were identified in 115 patients (4.0%) during 2867 craniotomies performed for aneurysm treatment. Of the total number of craniotomies, 2770 were performed for saccular aneurysms only, 59 craniotomies were performed for dolichoectatic aneurysms only, and 38 craniotomies were performed for dissecting aneurysms or pseudoaneurysms only. AO aneurysms were identified in 100 (3.6%) of 2770 craniotomies in patients with known saccular aneurysms, 3 (5.1%) of 59 craniotomies in patients with known dolichoectatic aneurysms, and 1 (2.6%) of 38 craniotomies in patients with known dissecting aneurysms or pseudoaneurysms. The incidence of AO aneurysms was higher in patients treated without preoperative catheter angiography (37 of 132 [28%]) versus those treated with preoperative catheter angiography (115 of 2867 [4.0%]), reflecting the decreased sensitivity of CT angiography (CTA). These 132 patients without preoperative catheter angiography were excluded from our analysis.

The most common locations for AO aneurysms in patients with saccular target aneurysms were the middle ce-

TABLE 1. Characteristics of AO aneurysms

Characteristic	w/ Known Saccular Aneurysms (n = 111)	w/ Known Dolichoectatic Aneurysm or Pseudoaneurysm (n = 4)
Location		
ACA/ACoA	20 (18.0)	0 (0)
AChA	11 (9.9)	0 (0)
BA	5 (4.5)	0 (0)
ICA bifurcation	3 (2.7)	0 (0)
MCA	60 (54.1)	3 (75)
OphA	4 (3.6)	0 (0)
PCA	1 (0.9)	0 (0)
PCoA	6 (5.4)	0 (0)
Supraclinoid ICA	1 (0.9)	1 (25)
Same vessel or segment as known aneurysm	56 (50.5)	1 (25)
Morphology		
Thin-walled	29 (26.1)	1 (25)
Dysplastic	3 (2.7)	1 (25)
Treatment		
Microsurgical clipping w/ temporary clip	27 (24.3)	2 (50)
Microsurgical clipping w/o temporary clip	79 (71.2)	2 (50)
Wrapping	5 (4.5)	0 (0)

OphA = ophthalmic artery.

All data given as number (%).

rebral artery (MCA; 60 AO aneurysms, 54.1%), ACoA (20 AO aneurysms, 18.0%), AChA (11 AO aneurysms, 9.9%), and PCoA (6 AO aneurysms, 5.4%; Table 1). Fifty-six AO aneurysms (50.5%) were located on the same artery as the known saccular aneurysm and were found during dissection of the target aneurysm, while 55 AO aneurysms (49.5%) required limited exploration to find the AO aneurysm. Eleven patients had 2 AO aneurysms noted at the time of craniotomy; in 7 of those patients, the AO was in the same vessel segment as the target aneurysm (63%).

All AO aneurysms in patients with known dolichoectatic aneurysms were found on the MCA. Only 1 AO aneurysm (33.3%) was located in the same vessel or segment as a known dolichoectatic aneurysm. AO aneurysms were noted to be thin-walled or “blister-like” in 29 patients (25.2%).

The incidence of AO aneurysms varied over time as shown in Fig. 1A, with a range of 0.9% to 8.1% and no significant trend. The advent of 3D rotational angiography did not reduce the incidence of AO aneurysms in this study population (Fig. 1B).

Overall, 95.5% of AO aneurysms were treated by microsurgical clipping using a 3-mm straight or 2.8-mm curved mini-clip in all cases. Aneurysm size could not be measured preoperatively (according to the definition of an AO aneurysm), but AO aneurysm size was inferred to have been smaller than 2 mm by the aneurysm clip used. Temporary clipping of the parent artery was required for 29 AO aneurysms (25.2%, Table 1), mainly because these

A

B

FIG. 1. AO aneurysm rate over time in years (A) and proportion of cases with and without 3D angiography in patients with and without AO aneurysms (B).

aneurysms were sessile and small, and softening the aneurysm with a temporary clip facilitated clip application. Use of temporary clipping was not significantly associated with AO aneurysm location ($p = 0.290$; Table 2). There

TABLE 2. Location of AO aneurysms treated with microsurgical clipping with and without temporary clipping of the parent artery

Location	Temporary Clip	
	Yes (n = 27)	No (n = 79)
ACA/ACoA	4 (14.8)	16 (20.3)
AChA	1 (3.7)	10 (12.7)
BA	1 (3.7)	3 (3.8)
ICA bifurcation	1 (3.7)	2 (2.5)
MCA	16 (59.3)	41 (51.9)
OphA	0 (0)	3 (3.8)
PCA	0 (0)	1 (1.3)
PCoA	4 (14.8)	2 (2.5)
Supraclinoid ICA	0 (0)	1 (1.3)

All data given as number (%).

TABLE 3. Classification of AO aneurysms in patients with known saccular aneurysms

Classification	AO Aneurysms (n = 111)
Type 1 (superimposition of larger adjacent aneurysm)	34 (30.6%)
Type 2 (superimposition of small adjacent aneurysm)	21 (18.9%)
Type 3 (superimposition of vessels or inadequate projections)	41 (36.9%)
Type 4 (concealed by treatment artifact)	15 (13.5%)

were no complications or new neurological deficits associated with treatment of AO aneurysms.

Causes of Angiographic Detection Failure in Patients With Saccular Aneurysms

Failure to detect AO aneurysms was categorized into 4 types: 1) superimposition of an adjacent large aneurysm (> 5 mm in diameter; type 1, 34 AO aneurysms, 30.6%); 2) superimposition of an adjacent small aneurysm ($\leq$ 5 mm in diameter; type 2, 21 AO aneurysms, 18.9%); 3) superimposition of adjacent normal vessels, with inadequate projections or poor filling of the PCoA (type 3, 41 AO aneurysms, 36.9%); and 4) artifact from prior microsurgical clipping and/or endovascular coiling (type 4, 15 AO aneurysms, 13.5%; Table 3). Type 1 aneurysms were most commonly located on the MCA (47.1%) and supraclinoid ICA (26.5%). Type 2 and 3 aneurysms were most commonly located in the MCA segment (71.4% and 63.4%, respectively; Table 4). In our cohort, large (> 5 mm) and small ($\leq$ 5 mm) MCA aneurysms were identified on preoperative vascular imaging prior to 298 and 334 craniotomies, with type 1 and type 2 AO incidences of 5.7% (17/298) and 4.8% (16/334), respectively.

Predictors of AO Aneurysms in Patients With Known Saccular Aneurysms

Multiple known aneurysms ($p < 0.0001$), known MCA aneurysm ($p = 0.0306$), and younger age ($p = 0.0310$) were identified as significant predictors of AO aneurysms in univariable analysis (Table 5). Sex, aneurysmal SAH, known supraclinoid ICA aneurysm, and chronology of surgery were not significantly associated with AO aneurysms. In multivariable analysis, only multiple known an-

TABLE 4. Location of AO aneurysms in patients with known saccular aneurysms

AO Aneurysm Type	ACA/ACoA	BA/PCA/SCA	MCA	Supraclinoid ICA*
Type 1	5 (14.7)	4 (11.8)	16 (47.1)	9 (26.5)
Type 2	4 (19)	1 (4.8)	15 (71.4)	1 (4.8)
Type 3	11 (26.8)	1 (2.4)	26 (63.4)	3 (7.3)
Type 4	1 (6.7)	0	10 (66.7)	4 (26.7)

SCA = superior cerebellar artery.

All data given as number (%).

* Including the AChA and PCoA.

TABLE 5. Predictors of AO aneurysms in patients with known saccular aneurysms

Predictor	AO Aneurysm		p Value
	Yes (n = 100)	No (n = 2670)	
Mean age $\pm$ SD (yrs)	53.0 $\pm$ 12.0	56.0 $\pm$ 14.0	0.0310
Sex			0.897
Male	28 (28.0)	718 (26.9)	
Female	72 (72.0)	1952 (73.1)	
Aneurysmal SAH	53 (53.0)	1235 (46.3)	0.220
Multiple known aneurysms	42 (42.0)	533 (20.0)	<0.0001
Known ACA/ACoA aneurysm	37 (37.0)	740 (27.7)	0.0554
Known MCA aneurysm	39 (39.0)	761 (28.5)	0.0306
Known supraclinoid ICA aneurysm	36 (36.0)	852 (31.9)	0.453
Date of surgery			0.205
7/1997–6/2002	13 (13.0)	501 (18.8)	
7/2002–6/2007	32 (32.0)	729 (27.3)	
7/2007–6/2012	28 (28.0)	871 (32.6)	
7/2012–9/2016	27 (27.0)	569 (21.3)	

All data given as number (%) unless otherwise indicated.

eurysms (odds ratio [OR] 3.45, 95% confidence interval [CI] 2.16–5.49, $p < 0.0001$) and young age (OR 0.981, 95% CI 0.965–0.997, $p = 0.0226$) were independent predictors of AO aneurysms.

Case Presentations

Case 1: Type 1 AO Aneurysm. This 44-year-old woman presented with rupture of a large, superiorly projecting right P₁ posterior cerebral artery (PCA) aneurysm (Fig. 2A–C). The aneurysm was microsurgically clipped via an orbitozygomatic-pterional craniotomy. During microdissection, a small basilar apex (BA) aneurysm was identified and clipped (Fig. 2D). Postoperative angiography confirmed clipping of both aneurysms (Fig. 2E and F). Failure to detect the BA aneurysm on preoperative angiography was most likely due to its small size and superimposition of the large PCA aneurysm over the basilar quadrifurcation.

Case 2: Type 2 AO Aneurysm. This 45-year-old man with a history of amphetamine abuse presented with sudden headache and confusion. A small, ruptured ACoA aneurysm was found on catheter angiography (Fig. 3A–C). This was surgically clipped through a left pterional craniotomy (Fig. 3D and E). An additional anteriorly and inferiorly projecting unruptured aneurysm with a wide neck was found during dissection of the ACoA complex and clipped with a slightly curved mini-clip (Fig. 3F–H). Postoperative angiography confirmed complete occlusion of both aneurysms (Fig. 3I and J) and the patient recovered without deficits. The occult ACoA aneurysm was not visualized on preoperative angiography, most likely due to its small size and superimposition of the small, ruptured ACoA aneurysm nearby.

Case 3: Type 3 AO Aneurysm. This 53-year-old woman presented with a ruptured ICA pseudoaneurysm. Initial

FIG. 2. Case 1. A 44-year-old woman with a right PCA (P₁ segment) aneurysm clipped via an orbitozygomatic transsylvian approach. During surgery an additional small BA aneurysm was found and clipped (D), which was not observed on preoperative angiography (A–C; circles indicate region of additional aneurysm found during surgery). Postoperative angiography confirmed clipping of the 2 aneurysms (E and F).

CTA revealed only a small aneurysm, which had increased significantly in size at the time of catheter angiography (Fig. 4A–C). Microsurgical clipping was successful and a bypass procedure was not required (Fig. 4D). A small MCA bifurcation aneurysm was discovered when splitting the sylvian fissure and clipped with a slightly curved mini-clip with temporary M₁ MCA clipping (Fig. 4E–G). Postoperative CTA and catheter angiography confirmed complete occlusion of both aneurysms (Fig. 4H), but the ICA pseudoaneurysm recurred 1 week later. This was reclipped and the pseudoaneurysm remained occluded thereafter. The patient recovered well and remained neurologically intact. In our cohort, 50.4% of AO aneurysms were located on an artery different from the known aneurysm and discovered on approach to the target aneurysm. In this case, the occult aneurysm was not seen on preoperative angiography due to its small size, with possible superimposition of branching vessels of the MCA bifurcation.

Discussion

In this report, we define the incidence, location, treatment, outcomes, and predictors of AO aneurysms. We also categorized the likely causes of angiographic detection failure into 4 types. With an overall incidence of 4.0%, AO aneurysms are not uncommon findings at surgery for another known aneurysm. This incidence was comparable to two previously reported case series.^{6,9} We included only patients with AO aneurysms with preoperative

digital subtraction angiography (DSA); had we included patients with AO aneurysms without preoperative DSA, the 28% incidence in this group would have increased the overall incidence of AO aneurysms. AO aneurysms were located most frequently on the MCA and ACoA, and furthermore, there was a significantly higher incidence of AO aneurysms in the MCA and ACoA segments in patients with known MCA and ACoA aneurysms (5.2% vs 1.3% for MCA aneurysms [$p < 0.0001$] and 2.6% vs 0.6% for ACoA aneurysms [$p < 0.0001$] in patients with and without known aneurysms there, respectively). This finding implicates aneurysm superimposition as a significant cause of failed angiographic detection.

Villablanca and coworkers also attributed angiographic detection failure to superimposition of adjacent normal vessels at the MCA bifurcation and ACoA complex, due to complex branching patterns at these sites. These authors also implicated a failure to obtain adequate imaging projections at locations such as the BA, and poor filling of the PCoA in the setting of balanced anterior and posterior circulation flows (type 3).¹⁷ In our cohort, these technical inadequacies were the most common causes of angiographic detection failure (36.9% of AO aneurysms), more than large aneurysm superimposition (type 1, 30.6%) and small aneurysm superimposition (type 2, 18.9%).

Surprisingly, we found no difference in detection of AO aneurysms over the 20-year time period of the study, suggesting that improvements in imaging technology such as

FIG. 3. Case 2. A 45-year-old man with a small, ruptured ACoA aneurysm (arrow, A) that was found on catheter angiography (A–C), which was surgically clipped through a left pterional craniotomy (D and E). An additional anteriorly and inferiorly projecting unruptured ACoA aneurysm was found and clipped (F–H), which was not seen on preoperative angiography (B and C, circles indicate region of additional aneurysm found during surgery). Postoperative angiography confirmed complete occlusion of both aneurysms (I and J). iA1 = ipsilateral A₁ ACA; iA2 = ipsilateral A₂ ACA; HA = recurrent artery of Heubner; cA2 = contralateral A₂ ACA. *known aneurysm; **occult aneurysm.

3D rotational angiography have not lowered the incidence of AO aneurysms. Previously published studies showed a higher sensitivity and specificity of 3D rotational angiography compared to standard biplane DSA to detect aneurysms.^{10,20} Wong et al. demonstrated that although 2D DSA had a false-negative aneurysm detection rate of 6.8% compared to 3D rotational angiography in CT-negative patients, the aneurysm size in the detected aneurysms was comparable between 2D and 3D angiography.²⁰ Kucukay et al. pointed out that aneurysms missed by 2D angiography had a mean size of 2.79 ± 0.74 mm,¹⁰ which is above the AO aneurysm size range observed during surgery. This might explain why there was no difference in the AO aneurysm incidences in patients with and without 3D rotational angiography, because some of these AO aneurysms are too small even for current 3D rotational angiography. Because objective aneurysm size measurements are not possible preoperatively (by definition), we used aneurysm clip size to estimate aneurysm size. In our cohort, all AO aneurysms were treated with a mini-clip less than or equal to 3 mm, which infers an AO aneurysm size of approximately 2 mm. It is worth remembering that contrast-based DSA only shows contrast filling within the aneurysm without imaging the aneurysm wall, and with such small aneurysms, magnified inspection of wall thinning and aneurysmal expansion under the microscope at surgery is probably superior to luminal filling with contrast.

All AO aneurysms in our cohort were safely treated, mostly by microsurgical clipping. Our working hypothesis was that limited microsurgical exploration around a known aneurysm could be performed safely without causing additional morbidity, and the results of this study support this hypothesis. The incidence of AO aneurysms and the safety of limited surgical exploration around known aneurysms argue for vigilance during subarachnoid dissection. High-

risk patients and high-risk locations should be actively examined during microdissection and treated if found. We are not advocating for exhaustive explorations or risky microdissection, but simply for increased inspection of aneurysm sites that are already within the surgical corridor. This practice is particularly relevant in patients presenting with SAH and multiple aneurysms, with inspection of the ACA and MCA segments in particular. Pterional or orbitozygomatic craniotomies with transsylvian dissection that includes double fenestration of the lamina terminalis and membrane of Lilliequist for CSF drainage and prevention of hydrocephalus provide easy opportunities to inspect multiple sites for AO aneurysms without much extra microdissection.¹⁹ With these steps as our routine, we were able to screen the MCA bifurcation, supraclinoid ICA, ACoA, and less commonly the BA. However, we caution against overdissection in patients with extensive SAH and swollen brains.

AO aneurysms likely represent newly formed aneurysms that might enlarge over time if left untreated. However, the natural history of AO aneurysms is unknown and difficult to study. In addition, 25.2% of AO aneurysms were noted to be thin-walled or “blister-like,” a morphological observation that has been associated with a high risk of aneurysm rupture.¹² Associated aneurysms in patients with another ruptured aneurysm are especially dangerous, because unruptured aneurysms in these patients have a higher risk of rupture compared to unruptured small aneurysms in patients without prior SAH. Treatment of even small unruptured aneurysms is recommended in these ISUIA group 2 patients.⁷ Of note, the presence of multiple aneurysms has been identified as a risk factor for de novo aneurysm formation in prior reports.^{1–3,18} The presence of multiple aneurysms was a strong and independent predictor of AO aneurysms in our cohort (42.0% vs 20.0%, OR

FIG. 4. Case 3. A 53-year-old woman underwent clip placement for a right ICA pseudoaneurysm (asterisk, **D**). Preoperative catheter angiography (**A–C**, circles indicate region of additional aneurysm found during surgery) was not able to show an additional AO MCA aneurysm (arrow) found during surgery (**E**), which was clipped with temporary occlusion of the M₁ segment (**F** and **G**). Postoperative CTA shows the clipped aneurysms (**H**). CN II = cranial nerve II.

3.45, $p < 0.0001$), suggesting that certain individuals may be predisposed by genetic, hemodynamic, and other risk factors to a dynamic process of aneurysm formation.⁴

In addition to meticulous microsurgical inspection during clipping of known aneurysms, we also advocate long-term angiographic follow-up 5 years after both endovascular and microsurgical therapy in patients with multiple aneurysms. This report has focused on AO aneurysms associated with a known aneurysm, but similar aneurysms not associated with a known aneurysm may account for some cases of nonperimesencephalic angiography-negative SAH, which has an estimated incidence of up to 24% in the literature.^{5,8,11}

Limited surgical exploration around the known aneurysm raises some issues regarding informed consent. When an aneurysm is found unexpectedly at surgery, the patient cannot participate in the decision to treat or not to treat. Therefore, it is important to mention the possibility of an AO aneurysm beforehand with the patient. In our practice, most patients willingly consent to treating these additional AO aneurysms, and are quite relieved to learn postoperatively that they were treated.

This study is limited by its retrospective design, but the data summarize a long, consecutive experience of a single neurosurgeon with a high-volume practice and a standardized approach to microsurgery for intracranial aneurysms. The results from this single-surgeon experience may not be generalizable to other practices. Our reported incidence of AO aneurysms underestimates their true incidence because exploration was limited to areas within the dissection pathway to target aneurysms, intraoperative inspection was limited by the surgical exposure, and tiny aneu-

rysms can easily be hidden. The retrospective nature of this study precluded detailed quantification of the extent of exploratory dissection. The measured incidence of AO aneurysms was influenced by this variable extent of exploration. Adverse outcomes associated with the treatment of AO aneurysms might be difficult to differentiate from the overall outcomes associated with the target aneurysm when the two aneurysms were in close proximity. The problem of failed angiographic detection of aneurysms with catheter angiography represents a shortcoming of the diagnostic study with the highest imaging resolution. Our reported incidence of AO aneurysms also underestimates the magnitude of the clinical problem because CTA is being used increasingly as a less invasive alternative to catheter angiography. The aneurysm detection problem is even worse with CTA and MR angiography because of their lower imaging resolution. We excluded such patients from our analysis, and the inclusion of 37 patients with AO aneurysms after CTA would have increased their overall incidence in our report. Therefore, the importance of limited microsurgical exploration around a known aneurysm to find AO aneurysms will grow as the use of CTA and MR angiography increases or supplants invasive catheter angiography.

Conclusions

This analysis of AO aneurysms found during microsurgical dissection of another known aneurysm demonstrates the importance of meticulous inspection of common aneurysm sites within the surgical field. Simultaneous identification and treatment of these additional undiagnosed

aneurysms can spare patients later rupture or reoperation, particularly in patients with multiple known aneurysms and a history of SAH. Although extra inspection might require more subarachnoid dissection, limited microsurgical exploration around a known aneurysm can be performed safely without causing additional morbidity. However, our results are not generalizable because they represent a single-surgeon experience.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Lawton, Burkhardt. Acquisition of data: Burkhardt, Chua, Winkler, Rutledge. Analysis and interpretation of data: Burkhardt, Chua, Winkler, Rutledge. Drafting the article: Burkhardt, Chua. Critically revising the article: Lawton, Winkler, Rutledge. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Lawton. Statistical analysis: Burkhardt, Chua. Administrative/technical/material support: Lawton. Study supervision: Lawton.

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