Junctional Internal Carotid Artery Aneurysms: The Schrödinger's Cat of Vascular Neurosurgery

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Abstract

Keywords

- cerebral aneurysm
- paraclinoid
- internal carotid artery
- distal dural ring
- carotid cave
- ophthalmic

Objectives Despite advances in neuroimaging, it is not always definitive whether a paraclinoid aneurysm is intradural or entirely extradural. We illustrate the potential use of surgical exploration in these aneurysms that we refer to as “junctional” aneurysms.

Methods Retrospective review of eight patients with unruptured aneurysms who underwent a planned surgical exploration of a junctional aneurysm.

Results Of the eight patients, three underwent exploration of the aneurysm during surgery for a different aneurysm. All three of these were found to be extradural. Five patients underwent a craniotomy for the exclusive purpose of clarifying the location of the aneurysm. Two of these cases were found to be intradural and were clipped. Two cases were found to be extradural. In one patient, the initially extradural aneurysm was converted into an intradural aneurysm during removal of the anterior clinoid process, necessitating surgical clipping. One transient third nerve palsy was observed.

Discussion Until further progress in neuroimaging allows clinicians to determine unequivocally the exact anatomical location of a paraclinoid aneurysm, we advocate the use of the term *junctional aneurysm* to reflect the clinical uncertainty inherent in management decisions made regarding these aneurysms. We have illustrated a strategy of surgical exploration in select patients.

Introduction

“Schrödinger's cat” represents a classic physics thought experiment used to illustrate the concept of uncertainty of quantum mechanics. A theoretical cat is placed in a box where a radioactive particle may or may not decay, and that decay is measured by a device that would cause the death of the cat in the case of the decay. Without opening the box, the observer cannot know whether the cat is alive or dead, and so therefore the state of its life or death can only be described as a probability function rather than in absolute terms. In such a case of this “macroscopic indeterminacy,” the question can be resolved by direct observation but does not change the “pre-observation” probability state.

In the case of aneurysms of the paraclinoid internal carotid artery, a similar dichotomy in outcome revolves around the intradural location (which may cause a devastating subarachnoid hemorrhage [SAH]) or extradural location (which carries a relatively benign natural history).¹ Despite significant advances in neuroimaging techniques,^{2–10} a small number of these aneurysms remain in which the exact location with regard to the subarachnoid space cannot be determined. These aneurysms, to our clinical eye, therefore lie in a state of uncertainty and may therefore be better considered as a probability of being intra- or extradural. We refer to these as *junctional aneurysms*. Given this lack of absolutely reliable diagnostic information on junctional aneurysms, we have used, in a select group of patients, the strategy of surgical

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exploration as a definitive way to assess the intradural or extradural location of an unruptured aneurysm so as to proceed with treatment only if necessary. This report describes these cases and the decision making involved as well as the lack of an available definitive diagnostic technique in the literature.

Methods

The surgical databases of the senior authors (S.A. and H.v.L.) were searched with the aim of identifying those patients who presented with an unruptured aneurysm of the paraclinoid segment of the internal carotid artery (ICA) and for whom surgical intervention was performed with the specific aim (defined preoperatively and in the surgical consent) to “explore the paraclinoid carotid segment” and “treat the aneurysm if found to be intradural.”

Results

A total of eight patients operated on over a 3-year period were identified. Approximately 150 aneurysms are treated either with endovascular or surgical means per year, for an estimated 1.8% of all treated aneurysms. Their clinical characteristics are summarized in ► **Table 1**. All patients were evaluated with digital subtraction angiography after an initial screening test (magnetic resonance angiography [MRA] or computed tomography angiography [CTA]).

Patient 1, 2, and 3 shared a common clinical history that set them apart from the rest of the group. All three had, in addition to the junctional aneurysm, another aneurysm that was clearly intradural and required surgical clipping on its own merits. In these patients, the “exploration” of the junctional aneurysm was not undertaken as a “stand-alone”

craniotomy but rather as an “additional look” during a craniotomy performed for a well-accepted indication. In patients 1 and 2, the junctional aneurysm was ipsilateral to the intradural aneurysm, whereas in patient 3 the exploration of the junctional aneurysm required a crossover approach to the contralateral side in a patient who was already anosmic from a previous surgery.

In patients 4 through 8, the exploration of the junctional aneurysm required a “stand-alone” elective craniotomy. In all five cases, careful radiographic evaluation and multidisciplinary discussion at a neurovascular conference failed to reliably define the aneurysm as intradural or extradural. Furthermore, because of the particular angio-anatomy of the aneurysm and limitations of endovascular techniques at the time of presentation, coiling was either rejected or attempted but unsuccessful in all of them. After careful discussion with the patients and families, the decision was made to proceed with surgical exploration to both assess the exact location of the aneurysm and proceed with intraoperative treatment only if the aneurysm was found to be intradural. Their clinical histories are summarized here.

Patient 4 was a 44-year-old woman diagnosed with a 4-mm left junctional aneurysm during routine investigations for severe migraines with recent increase in pain intensity. The aneurysm location was slightly distal to the takeoff of the ophthalmic artery (which was thought to be atypically proximal) and pointing inferiorly and medially. Coiling was rejected because of an unfavorable fundus-to-neck ratio. Surgical exploration was undertaken. Along the proximal ophthalmic segment of the ICA, a dilatation of the vessel was mistaken for the aneurysm dome. To gain exposure, the anterior clinoid process was drilled and the distal dural ring opened. It was only after this maneuver that the extradural location of both the aneurysm and the ophthalmic artery

Table 1 Patient characteristics

	Age, y	Sex	Size, mm	Side	Fundus direction	
1	44	F	4	R	Medial	Confirmed extradural during clipping of ipsilateral posterior communicating artery aneurysm
2	55	F	2	R	Medial	Confirmed extradural during ipsilateral approach for basilar aneurysm clipping
3	60	F	4	L	Medial	Previously clipped left ICA bifurcations aneurysm anosmic since first surgery. Confirmed extradural during clipping of contralateral MCA and ICA aneurysm (crossover exploration)
4	44	F	3	L	Medial-inferior	Explored; found to be extradural, had to be clipped after the anterior clinoid process was removed and the distal dural ring had been opened
5	35	F	4	L	Medial	Explored; found to be intradural
6	32	F	3	L	Medial	Explored; found to be intradural
7	36	F	10	L	Inferior	Migraines, incidental diagnosis of left junctional aneurysm. Irregular ICA. Coiling denied. Explored; found to be extradural: negative exploration
8	40	F	6	L	Medial	Previously clipped contralateral MCA aneurysm. Left junctional aneurysm failed coiling. Explored; found to be extradural: negative exploration

Abbreviations: ICA, internal carotid artery; MCA, middle cerebral artery.

Fig. 1 Case example of a junctional aneurysm (patient 5). Angiography demonstrated a medially projecting left internal carotid aneurysm near the origin of the ophthalmic artery but not clearly intradural (arrow, left panel). Magnetic resonance angiography (right panel) showed the aneurysm to be at the level of the anterior clinoid, and no definitive statement with regard to the distal dural ring could be made.

origin, entirely proximal to the distal dural ring, was observed. Realizing that a clinoid-cavernous segment aneurysm had been converted into an intradural aneurysm, clipping was deemed necessary, and the aneurysm was successfully excluded with a fenestrated clip. There were no complications.

Patient 5 was a 35-year-old woman incidentally diagnosed with a 4-mm left junctional aneurysm pointing posteromedially. Coiling was attempted but failed, and the patient underwent surgical exploration (→ **Figs. 1** and **2**). The aneurysm was confirmed intradural, and it was clipped after exposure was completed with intradural clinoidectomy. There were no complications.

Patient 6 was a 32-year-old woman who experienced an SAH from a right middle cerebral artery (MCA) aneurysm that was successfully clipped. She was also known to have a

contralateral incidental left 3.2-mm junctional aneurysm that failed coiling and was surgically explored. The aneurysm was found to be intradural and successfully clipped. The patient suffered postoperatively from a transient cranial nerve III palsy.

Patient 7 was a 36-year-old woman with an incidentally discovered 10-mm junctional aneurysm pointing inferiorly. Coiling was not considered feasible because of the shape of the aneurysm, and the patient was explored surgically. Upon exploration, the distal dural ring was observed with microscopic as well as endoscopic magnification to assure a maximal angle of observation medial to the ICA where a carotid cave might occur. The aneurysm was found to be extradural, and the surgery was terminated and considered a negative exploration. There were no complications.

Patient 8 was a 40-year-old woman with severe migraines. Three years before presentation to our institution, she was diagnosed with a right proximal MCA aneurysm and a left paraclinoid aneurysm during admission for a particularly severe attack of headaches. The right MCA aneurysm was clipped, and the left junctional aneurysm was placed in surveillance. She then moved to Florida and presented to our emergency department with another episode of unusually intense headaches of rapid onset that were sufficiently severe and different from her migraines to bring her to seek medical attention. Computed tomography (CT) and lumbar puncture were negative for subarachnoid hemorrhage. Management of the left junctional aneurysm (→ **Fig. 2A, 2B**) was discussed, and in view of the patient's young age, her recurring and sometimes unusual migraines, as well as her specific request for a definitive answer, it was decided to proceed with coiling. After coiling failed, surgical exploration was undertaken. Microscopic as well as endoscopic

Fig. 2 Intraoperative images from the same case as Fig. 1. (a) View of the optic nerve and carotid before drilling of the anterior clinoid. The origin of the ophthalmic artery is barely visible. (b) Drilling of the anterior clinoid and optic canal. (c) The aneurysm is now visible medial to the origin of the ophthalmic artery and clearly intradural (arrow). (d) The aneurysm is directly clipped.

exploration of the distal dural ring was able to demonstrate an extradural takeoff of the ophthalmic artery, the absence of a carotid cave, and the total extradural location of the aneurysm. This was also considered a negative exploration. The patient had no complications from this intervention.

Discussion

The paraclinoid segment of the ICA is one of the few areas of surgical neuroanatomy in which the tremendous advances of modern neuroimaging have not yet matched the level of detail achieved by cadaveric microsurgical dissection or demanded by clinical necessity. The anatomical classification of the ICA published by the senior author in 1996¹¹ has been widely accepted in the clinical and anatomical literature not only because of the detailed definition of its segments, but also because of the clinical relevance of each one of them. The division of the paraclinoid ICA into three distinct segments (cavernous, clinoid, and ophthalmic) was a response to the challenging management of unruptured aneurysms in this location and the significant differences between the natural history of aneurysms located proximally or distally to the dural carotid rings.¹ The description in 1989 by Kobayashi et al¹² of the carotid cave as an outpouching of the subarachnoid space medial to the ICA extending proximally to the insertion of the distal dural ring made the localization, risk assessment, and management of aneurysms in this region even more challenging. We build on this data to now propose that clinically, aneurysms at the junction of the cavernous and clinoid segment that cannot be definitively categorized as one or the other based on available imaging should be called junctional aneurysms. Treatment of these aneurysms is complex both in terms of surgical technique as well as decision making.

Junctional Aneurysms

Because of the clear dichotomy between the natural history of cavernous aneurysms and intradural aneurysms,¹ accurate

determination of the relationship between the aneurysm and the distal dural ring of the ICA represents a critical determinant of the aneurysm's risk profile. Patients with incidental cavernous aneurysms failing to show enlargement, CN deficits, localized pain, ipsilateral transient ischemic attacks, or aneurysm-related embolic stroke are safely managed with observation. These patients can be reassured that even in the unlikely event of rupture, such aneurysms, if strictly cavernous, rarely cause SAH and are therefore unlikely to cause any severe life-threatening complications. If, however, an aneurysm is located in the subarachnoid space, its potential for life-threatening hemorrhage will be proportional to its size, but even for small aneurysms is never null. Determining the exact location of the aneurysm as proximal or distal to the distal dural ring of the carotid becomes paramount in the evaluation, management, and counseling of patients and their families.

The imaging of the distal dural ring and related carotid cave is the subject of a constant and ongoing research effort in the surgical and neuroradiologic community. The challenge of this field is that the only true gold standard is surgical viewing of the aneurysm to determine intra- or extradural status. Although many techniques have been proposed that seem to offer a high degree of precision and theoretical benefit, the true accuracy of these techniques remains unproven due to very limited series with surgical confirmation. We briefly summarize the available data, particularly focusing on the cases with surgical confirmation (► **Table 2**).

Modern techniques have essentially supplanted techniques that were based on angiographic images of the ophthalmic artery,¹³ the anterior clinoid,¹⁴ or the tuberculum sella.^{15,16} The advent and refinement of high-resolution CTA allowed for a more detailed assessment of the paraclinoid region, and Murayama and colleagues¹⁷ reported that an indentation in the ICA representing the distal dural ring between the tuberculum sella and anterior clinoid could be reliably seen in almost half of 79 patients; however, studies with thick subarachnoid hemorrhage, calcification, or other

Table 2 Studies with gold standard evaluation (surgical exploration) evaluating intra- or extradural location of paraclinoid aneurysms

Study	Method of evaluation	Surgical aneurysms	True intradural	False intradural	True extradural	False extradural	Ambiguous
Murayama et al ¹⁷	CTA concavity	1	1				
Ito et al ¹⁸	CT cisternogram	1	1				
Gonzalez et al ⁵	CTA optic strut	9	6		1		2
Hashimoto et al ⁶	CTA optic strut	18	14		1	2	1
Tsuboi et al ⁷	Contrast-enhanced TOF MRA	7	4		3		
Hirai et al ⁸	Contrast-enhanced MRA and CISS MRI	11	4		5		2
Thines et al ³	T2-weighted MRI in plane of carotid	2	1		1		
Total	All techniques	49	29	0	11	2	5

Abbreviations: CISS, constructive interference in steady state; CT, computed tomography; CTA, computed tomography angiography; TOF MRA, time-of-flight magnetic resonance angiography.

artifact were excluded from the analysis. Only five patients with aneurysm were assessed, and only one was confirmed with surgical assessment (an aneurysm judged to be intradural was found indeed to be intradural.) A case report by Ito et al¹⁸ demonstrated the use of CT cisternography to demonstrate an aneurysm indenting the subarachnoid space that was confirmed surgically to be intradural. Barami et al¹⁹ used magnetic resonance imaging (MRI) as well as anatomical location to subclassify C5 and C6 segment aneurysms projecting medially as either above or below the dorsum sellae, although they recognized that this distinction could be difficult and reported no surgical confirmation.

Gonzalez and colleagues⁵ reported what is now likely the most widely accepted method—using the most inferior attachment of the inferior root of the optic strut seen on CTA as the marker. They reported surgical results in four patients with nine paraclinoid aneurysms. Six intradural aneurysms were found to indeed be intradural, and one extradural aneurysm was not seen at surgery so thought to be extradural. In two cases, however, the imaging was ambiguous. One was directly at the optic strut and found to be intradural at surgery; one straddling the strut was found to be extradural at surgery. An additional 18 aneurysms were assessed using this technique by a different group, all of whom had surgical exploration. Fourteen judged to be intradural were in fact intradural at surgery; however, of three judged to be extradural, two in fact were found to have a portion of the dome intradural while one was truly extradural. There was one case of diagnostic ambiguity (straddling the optic strut) that was found to be partially intradural at surgery.⁶

Thines and colleagues presented a series of three technical descriptions based on T2-weighted MRI, by identifying the plane of the carotid and the diaphragm sellae to allow direct imaging of the distal dural ring.^{2–4} Seventeen aneurysms were assessed using this technique,³ but only two cases went on to surgery: One judged to be intradural was indeed intradural, and one described as “transitional” was extradural. This “transitional” terminology is a reflection of ambiguity in the test, and 7 of 17 aneurysms were classified this way. Three of these were treated. None of the six aneurysms judged to be extradural were treated, so the incidence of false-negative tests is unknown. A follow-up study using 3-T MRI with a similar T2-weighted sequence reported evaluation of seven aneurysms, none of whom had surgery, which showed significant discordance when location was compared with location determined from angiography or optic strut position on CTA.² Tsuboi and colleagues⁷ reported a more detailed MRI technique in which intravenous contrast was administered before performing a time-of-flight MRA that allowed visualization of the contrast within the cavernous sinus to better delineate this border. Seven of the 21 aneurysms went on to surgical exploration, and the imaging findings accurately predicted the location observed in surgery (3 intradural and 3 extradural). Hirai et al⁸ used a similar technique using a more detailed MRI sequence (constructive interference in steady state [CISS]), reporting results in 11 aneurysms explored surgically. The five thought

to be extradural were indeed extradural; four thought to be intradural were indeed intradural. Two were thought to be partially intradural and partially extradural, one of which had an intradural component and one of which did not. Similar techniques have become more widely used, with another series reporting radiographic evaluation of 39 patients. Reportedly five of these patients underwent surgery that confirmed the location; however, no details of these surgical patients were discussed.¹⁰ A similar technique using 3-T MRI sampling perfection with application optimized contrasts using different flip angle evolutions was found to be similar to CISS at locating the dural ring in normal volunteers, although no clinical assessment with aneurysms has been evaluated.⁹

Taken together, all these studies report gold standard evaluation (surgical exploration) with any imaging technique in < 50 patients. Even within these studies, there remains diagnostic uncertainty in a significant number of patients (5 of 47) and incorrect assessments reported in two. These data as well as our clinical experience leads us to conclude that despite currently available high-resolution imaging techniques, there are cases where the correct position of an aneurysm with regard to the subarachnoid space will be ambiguous.

We propose that based on the currently available data and the most widely used noninvasive imaging (CTA), if the aneurysm is distal to the optic strut, it is almost certainly intradural and should be treated as such. If the aneurysm straddles the optic strut or is in the distal cavernous segment, the aneurysm may be junctional. Small aneurysms proximal in the cavernous segment are almost certainly extradural, although in larger aneurysms, the clinician must judge if a component of the dome may in fact be intradural and so should also be considered junctional. In these cases, the concept of Schrödinger's cat can be evoked, arguing that to our perception, the aneurysm exists in a state of probability of being intra- or extradural and therefore does carry some risk. This concept underlies the philosophy of surgical exploration as described in this small series. The terminology describing these aneurysms as “junctional” reflects this lack of absolute certainty and matters in terms of management. This allows both the treating team as well as the patients themselves to understand the important concept that clinical decisions in such cases are made using a certain degree of uncertainty on the exact anatomical location of the aneurysm that can have a profound effect on the natural history of the lesion and currently can only be answered definitively with surgical inspection.

Surgical Scenarios

In our small series we have illustrated three different clinical and surgical scenarios. The scenario that will certainly be familiar to our readers is the one encountered in the first three patients in which the junctional aneurysm was explored because surgery was already being pursued based on indications related to another aneurysm. Exploring and eventually treating a “bystander” aneurysm within the same operative field as a primary aneurysm with strong

surgical indication is not an unusual occurrence, albeit not specifically analyzed in the literature. In these cases, the risk of exploring and possibly going on to clip the bystander aneurysm is incremental to the risk of the primary procedure and therefore generally accepted. We believe that this “exploratory” paradigm should be extended to a highly selected subset of paraclinoid aneurysms that we call junctional.

The surgical scenario of patients 5 to 8 reflects the same thought process whereby, when an aneurysm has been considered a threat and treatment has been recommended, surgical exploration was performed after endovascular coiling had failed to exclude the aneurysm from the intracranial circulation. Certainly in these last four cases the junctional aneurysm bore the entire risk of the craniotomy; however, it must be emphasized that even in the cases where an aneurysm was found to be extradural, the treating physician's preoperative understanding of the location of the aneurysm (and therefore risk of rupture) is the risk with which the surgical intervention is compared rather than the natural history of an extradural aneurysm.

The clinical scenario of patient 4 illustrates the challenges of surgical exploration of junctional aneurysms because visualization of the distal dural ring of the carotid is often obscured by the anterior clinoid process. Complete removal of the anterior clinoid process exposes the clinoid segment of the ICA and can turn a previously extradural aneurysm into an intradural one, therefore mandating its surgical clipping. We found that in selected cases, use of a 30-degree endoscope allowed inspection of the medial wall of the carotid artery without removal of the anterior clinoid process or mobilization of the optic nerve. This case underlines the need for careful planning of the surgical procedure when exploration is the goal, to avoid converting a negative exploration into a mandatory clipping of a potentially complex aneurysm.

Rupture Risk and Treatment Risk

Based on the international study on unruptured intracranial aneurysms,¹ anterior circulation aneurysms carry a 1.5 to 40% 5-year cumulative risk, depending on size. Cavernous aneurysms carried a 0% chance of SAH in their series. In intradural anterior circulation aneurysms, the authors defined a cut-off of 7 mm where, without previous SAH, the risk of rupture was very low, and so most surgeons do not recommend treatment for these aneurysms. In the 7- to 12-mm range, the risk increases to a 2.6% 5-year cumulative risk that is still quite low. Greater than 12 mm, the risk increases to 14.5%. The same authors reported the largest prospectively collected data on surgical and endovascular treatment as well, with overall morbidity and mortality of 12.6% in the surgically treated group and 9.8% in the endovascularly treated group. In recent series with modern devices, the rate of complications has decreased to the range of 3 to 5% for small aneurysms.²⁰ A strict cut-off, therefore, cannot be clearly defined for junctional aneurysms because it will depend on weighing the estimated risk of rupture if the aneurysm is intradural against the risk of intervention.

Endovascular Techniques and Decision Making

Endovascular techniques for treatment of aneurysms are clearly evolving, becoming increasingly safe and leading many clinicians to treat aneurysms that might otherwise be considered relatively low risk.^{1,21} Other social factors may influence the treatment as well. Examples that we encountered in our practice include denial of a commercial vehicle driver's license, qualification as a commercial pilot, acceptance to the military, and a professional sports contract for patients diagnosed with an aneurysm unless the threat of “sudden brain bleed” can be completely and permanently eliminated. In more general terms, the need to disclose any preexisting medical conditions with potential for future harm when applying for certain occupations can lead patients to favor a “cure” over a low probability of future problems when faced with the uncertainty of the intradural or extradural location of an aneurysm. In the case of endovascular treatment of junctional aneurysms, the practice of treating aneurysms where the exact location is not clear is becoming more widely accepted due to the relatively low morbidity of the procedure. That said, risk is certainly associated with the treatment as well as follow-up imaging, antiplatelet therapy in the case of stents, and future treatment of recurrence. The preprocedure risks must therefore be assessed overall and the junctional status of the aneurysm factored into that decision making. As a simplified example, if the clinician believes that a given aneurysm has a 5% yearly rupture risk (probability of rupture) and the probability of the aneurysm being intradural is 50%, the overall probability of rupture *and* intradural location would be 2.5% (0.05×0.5). This risk must then be weighed against the cumulative risk of treatment, whether endovascular (e.g., including procedural, follow-up, antiplatelet therapy, retreatment) or surgical, particularly the risk of craniotomy.

The concept and terminology of junctional aneurysms should be used in all decision making where there is not diagnostic certainty. In these cases, junctional aneurysms exist as a probability function that is factored into the decision to treat so that even if an aneurysm is later found to be extradural, the decision making for treatment may have still been correct. From this perspective, a surgically explored aneurysm is not a “negative exploration” if found to be extradural, but rather “proven extradural,” therefore pushed into a category of certainty. We feel this is a valid treatment approach.

Conclusion

Until further progress in neuroimaging allows clinicians to determine unequivocally the exact anatomical location of a paraclinoid aneurysm, we advocate the use of the term *junctional aneurysm* to reflect the clinical uncertainty inherent in all management decisions made regarding these aneurysms, whether surgical or endovascular. The terms *cavernous*, *clinoid*, or *ophthalmic segment aneurysm* should be reserved for those paraclinoid aneurysms in which neuroimaging determines their location with certainty. We have illustrated the strategy of surgical exploration to manage a selected series of junctional aneurysms in which the preoperative location is not definitively known.

Disclosure

The authors have no financial sources to disclose.

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