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Review Article

Ruptured intracranial infectious aneurysms: Single Canadian center experience

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ABSTRACT

Background: Ruptured intracranial infected aneurysms (IIAs) are relatively rare, but they portend high mortality. To the best of our knowledge, there is no Canadian case series on IIA, as well there is a relative paucity of international published experiences. Our purpose is to share the experience of a single Canadian tertiary center in managing ruptured IIA and to conduct a systematic review.

Methods: We did a retrospective case review series of adult patients with ruptured IIA treated at our institution. Second, we conducted a systematic review of the literature on ruptured IIA between 2011 and 2021 inclusive.

Results: At our institution, of a total eight cases with ruptured IIA, four were treated endovascularly and two by surgical bypass. For the systematic review, we included nine noncomparative studies with a total of 509 patients (318 males) and at least 437 ruptured IIA aneurysms. Favorable outcome was specified for 63.3% of patients (n = 57). Regarding ruptured IIA, favorable clinical outcome was described in 59.3% (n = 16).

Conclusion: This study highlights a single Canadian tertiary center experience in the management of IIA and compares it to the global trends of the past 10 years in a systematic review.

Keywords: Aneurysm, Endovascular, Infectious, Intracranial, Mycotic, Ruptured

INTRODUCTION

Intracranial infected aneurysms (IIAs) are a relatively rare complication of systemic infection. Due to their rarity, most of the available evidence is limited to retrospective single-center studies and case reports. We summarize evidence from the literature of the past decade and share our experience related to unique IIA features, as well as management and prognosis of ruptured IIAs.

IIAs are a complication of an ongoing systemic infection causing microbic infiltration and degradation of arterial vessel wall.[1] IIAs are sometimes referred to as "mycotic aneurysms;" however, this term is somewhat restrictive as it mainly implies a fungal pathogen when in fact, most IIAs (i.e., 72.8%) are caused by bacterial infection.[1] IIAs account for 2–12% of neurological complications in patients with infective endocarditis (IE).[9,16] Rupture status is the most important factor, in terms of mortality; while mortality is 10–30% for patients with unruptured IIA, it may be as high as 80% in patients with ruptured IIA.[1] While medical management with

antibiotics may be sufficient in patients with unruptured IIA who do not require immediate cardiac surgery, endovascular therapy is becoming the first-line treatment for the majority of patients.[1]

Despite the paucity of evidence, endovascular treatment of IIA is an attractive option. Unlike noninfectious aneurysms, IIAs tend to affect more distal intracranial vessels[17] which may be hard to identify during open surgery. Second, up to 25% of IIAs are multiple.[9] Inherent friability of infected vessels and aneurysms may also present challenges of hemostatic control.[19] In addition, the previous case reports suggest that endovascular procedures are well-tolerated and have high rates of technical success.[17] Finally, endovascular approaches may be preferred in patients who need emergent cardiothoracic surgery (which requires heparinization and anticoagulation), as the theoretical risks of bleeding would be less.[1]

Even for those clinical scenarios for which open neurosurgical treatment is necessary, endovascular treatments and intraoperative digital subtraction angiograms (DSA) may serve as useful adjuncts.

MATERIALS AND METHODS

Our series

We performed a retrospective chart review over a 10-year period (2010–2020) of all cases with ruptured IIA who were treated at the London Health Sciences Centre. Relevant data included age, gender, initial neurological condition, underlying diagnosis, number, location and characteristic of aneurysm, treatment, isolated bacteria, and clinical/radiological outcome.

All patients data were collected according to the Canadian Tri-Council policy statement on ethical conduct for research involving the secondary use of data originally collected for health-care purposes.

Literature search

We performed a comprehensive literature search using PubMed and EMBASE databases using the following terms: "aneurysm* AND (cereb* OR brain OR *cranial*) AND (infect* OR mycotic OR bacterial)." Wild character (*) was used to include variations of the words and to improve the sensitivity of the search. We limited our search to English language publications between 2010 and January 2021. The flowchart of the literature review and exclusion criteria is summarized in [Figure 1].

Data included the number of patients in each study, age, gender, median number of aneurysms, number of ruptured aneurysm cases, mean/median aneurysm size and shape, aneurysm locations, treatment modality, and favorable outcome. For aneurysm location, we considered "distal" as any aneurysm at the level of M3, M4, P3, P4, A2, and artery of Heubner. For clinical outcome, we considered "favorable" outcome as modified Rankin scale (MRS) score of 2 or less or as a Glasgow Outcome Scale (GOS) score 4 and 5. In cases, where neither MRS nor GOS was available, we considered "favorable" outcome if the study used the terms "good recovery," "no deficits," "functional baseline," "no morbidity," and "not worsened."

RESULTS

At our institution, eight patients were diagnosed with ruptured IIA: six men and two women with a median age of 46 years (range from 20 to 62 years). Six out of eight patients included in the case series presented within the past 5 years. Baseline demographics, clinical presentation, aneurysm characteristics, treatment options, and clinical outcomes are summarized in [Table 1]. Each case decision for treatment type (endovascular vs. surgical and Onyx-18 vs. coiling) was made as per literature-based guidelines and consensus opinion after multidisciplinary case-by-case discussion with the interventional neurovascular group.

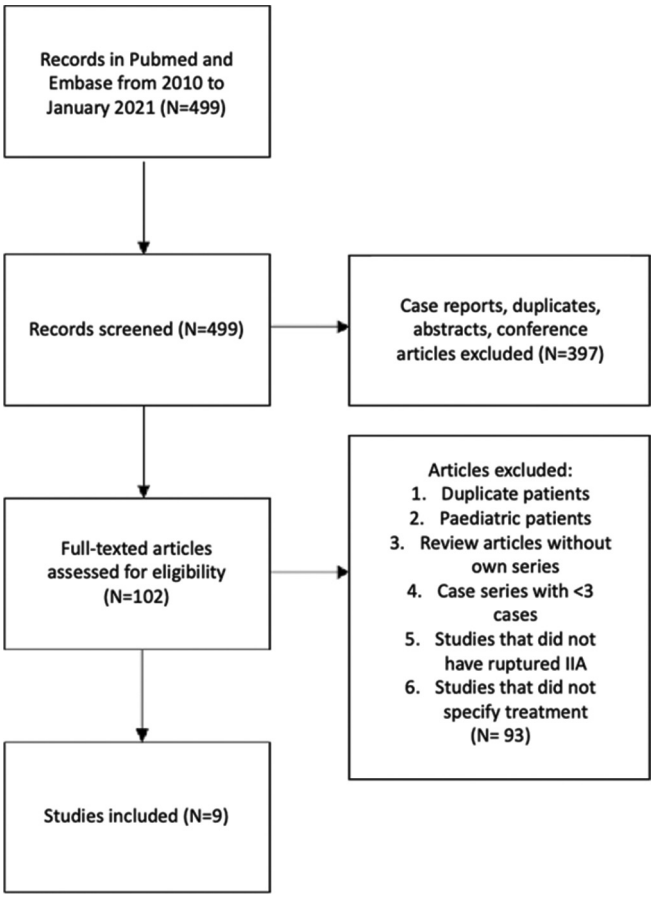

Figure 1: Flowchart of the literature review. IIA: Infected intracranial aneurysm.

Table 1: Summary for demographic characteristics, presentation, treatment, and outcome for our case series.

Case No.	Age/sex	Presentation	Bacteria isolated	Aneurysm No.	Rupture status	Location of IIA	Aneurysm size (mm)	Treatment	Clinical outcome
1	37/M	TIA severe H/A	None isolated	1	Ruptured	Distal superior R MCA	2	Endovascular only/Onyx	No deficit
2	20/F	Diplopia severe H/A	MSSA	1	CN VI palsy	L distal ICA	11	Endovascular only/Coils	No deficit
3	33/F	Severe H/A ↓ LOC	MSSA	2	Ruptured	Rt P2 bifurcation, Lt MCA	10, 2	Endovascular only/Coils	Death/ rebleeding
4	55/M	TIA severe H/A	MSSA, *Streptococcus mitis*	1	Ruptured	L M3 angular	9	EC-IC bypass	No deficit
5	31/M	Aphasic RT hemiplegia	MSSA	1	Ruptured	L M2	5	Endovascular only/Coils	No change
6	62/M	Severe H/A TIA	None isolated	1	Ruptured	L distal ICA	1.5	EC-IC bypass	No deficit
7	62/M	GCS 4 E1VTM3	*Strep. anginosus*	4	Ruptured	L M3, M4; bilateral distal PCA, Rt ICA occlusion	from 2×2 to 4.5×4	None	Death after 2 h
8	55/M	Mild RT arm and leg weakness	MSSA, *Strep. viridans*	1	Ruptured	L A3/4	4	None on DSA, aneurysm self thrombosed	No deficit

TIA: Transient ischemic attack, H/A: Headache, MSSA: Methicillin-susceptible *Staphylococcus aureus*, EC-IC: External carotid-internal-carotid, MCA: Middle cerebral artery, ICA: Internal cerebral artery, DSA: Digital subtraction angiogram, GCS: Glasgow Coma Scale, RT: Right

Four cases were treated through endovascular therapy (three patients treated with coiling and one patient was treated using Onyx-18); two cases surgical extracranial-intracranial (EC-IC) bypass using intraoperative diagnostic angiogram and mapping of the arteries. In two cases, no treatment was performed as one patient died shortly (2 h) after the initial presentation with GCS 4 and CTA demonstrating multiple intracranial aneurysms (case number 7). In the other case, an intracranial aneurysm was seen in CTA, and on next day, DSA demonstrated spontaneous thrombosis (case number 8); on close follow-up, the aneurysm remained thrombosed.

Literature results

We included nine studies from the past 10 years into the final analysis. Without exception, all studies were retrospective chart reviews. Most studies were originated from a single center, with a few exceptions.[2,7,14,18]

Data from 509 patients with IIA were collected. Males composed 62.4% (n = 318) of all known cases. Detailed demographics and numbers of clinical symptoms are summarized in [Table 2]. Of note, the majority of patient data was included from one study with 393 patients with at least 361 IIA.[18]

The percentage of ruptured IIA was at least 79.3% (at least 437 IIA out of at least 551 intracranial aneurysms). Only some studies reported aneurysm characteristics: 31.5% of patients had multiple IIA (28 out of 89 patients); 68.5% of IIA had irregular or fusiform shape (50 out of 73 IIA); and 77.6% of IIA were located distally (83 out of 107 IIA). Detailed aneurysm characteristics are found in [Table 3].

Of the studies that reported on treatment modalities, more patients underwent endovascular treatment than open surgical treatment: while 22.7% of patients (n = 115) underwent endovascular treatment, only 11.4% of patients (n = 55) had open surgical treatment. It should be noted that the majority of patients in one large cohort have not received any intervention.[8] When the management of ruptured IIA was specified, 50.8% of patients (n = 31) underwent endovascular treatment; 33.3% of patients (n = 12) underwent open surgical treatment. Treatment details are summarized in [Table 4].

In addition to our own case series, only six studies reported clinical outcomes.[6,9,12,14,15] Favorable outcome was specified for 63.3% of patients (n = 57). Regarding ruptured IIA, favorable outcome was described in 59.3% (n = 16). Where deaths were specified, one study reported 40% death rate (n = 4) in patients who were treated with antibiotics and 12.5% death rate (n = 2) in patients who underwent neurosurgical treatment.[2] Furthermore, our case series and Fukuda *et al*. each reported one death that occurred before neurosurgical intervention.[7]

Table 2: Literature review: patient characteristics.

Study	Country	Study type	Patients with IIA, N	Mean or median age, years	Males, n (N)	Neurological symptoms, n (N)	Imaging findings, n (N)
Fukuda *et al*., 2012	Japan	R, SC	5	30.1	4 (5)	5 (5)	S 3 (5), SAH 1 (5)
Allen *et al*., 2013	US	R, MC	26	45	18 (26)	n/a; symptoms known for 81% of patients	S 9 (25), SAH 10 (25), ICH 8 (25)
Grandhi *et al*., 2014	US	R, SC	7	41.3	n/a	n/a	SAH 3 (7), ICH/IVH 4 (7)
Esenkaya *et al*., 2015	Turkey	R, SC	15	42.8	9 (15)	n/a	S 2 (15), ICH 8 (15), SAH 3 (15), SDH 1 (15)
Matsubara *et al*., 2015	Japan	R, MC	20	46	10 (20)	15 (20)	S 3 (15), SAH 5 (15), ICH 5 (15), Mass effect 2 (15)
Singla *et al*., 2015	US	R, MC	393	53.5	244 (393)	n/a	SAH 361 (393)
Hamisch *et al*., 2016	Germany	R, SC	6	57	6 (6)	6 (6)	ICH 6 (6)
Nonaka *et al*., 2016	Japan	R, MC	4	42.8	3 (4)	4 (4)	S 1 (4), SAH 1 (4), ICH 2 (4)
Park *et al*., 2017	South Korea	R, SC	25	48	18 (25)	n/a	ICH 12 (12)
Our series, 2021	Canada	R, SC	8	46	6 (8)	8 (8)	S 2 (8), SAH 4 (8), ICH 1 (8), Mass effect 1 (8)

ICH: Intracerebral hemorrhage, IVH: Intraventricular hemorrhage, MC: Multicenter, n: Number with a particular characteristic within a study, N: Total number of cases in a study, R: Retrospective, S: Ischemic stroke, SAH: Subarachnoid hemorrhage, SC: Single center. n/a: Not applicable, no data

Table 3: Literature review: aneurysm characteristics.

Study	Patients with IIA, N	Neurological symptoms, n (N)	Ruptured aneurysms, n (N)	More than 1 aneurysm, n (N)	Mean/ Median size, mm	Fusiform/ irregular shape, n (N)	Distal location, n (N)
Fukuda *et al*., 2012	5	5 (5)	2 (5)	n/a	n/a	n/a	n/a
Allen *et al*., 2013	26	n/a; symptoms known for 81% of patients	At least 15 (40)	10 (26)	Mean 5, median 4	n/a	n/a
Grandhi *et al*., 2014	8	n/a	At least 7 (16)	4 (8)	Mean 3.9, median 3	n/a	16 (16)
Esenkaya *et al*., 2015	15	n/a	12 (17)	2 (15)	Mean 7, median 5	11 (17)	14 (17)
Matsubara *et al*., 2015	20	15 (20)	11 (23)	3	Mean 6.5, median 6	13 (23)	16 (23)
Singla *et al*., 2015	393	n/a	At least 361 (at least 393)	n/a	n/a	n/a	n/a
Hamisch *et al*., 2016	6	6 (6)	6 (6)	n/a	n/a	n/a	n/a
Nonaka *et al*., 2016	4	4 (4)	4 (6)	1 (4)	n/a	n/a	6 (6)
Park *et al*., 2017	25	n/a	12 (33)	6 (25)	5.2	26 (33)	23 (33)
Our series, 2021	8	8 (8)	7 (12)	2 (8)	5.4	n/a	8 (12)

IIA: Infectious intracranial aneurysm, n: Number with a particular characteristic within a study, N: Total number of cases in a study; n/a: Not applicable

Illustrative cases from our center

Case 1. Endovascular embolization of ruptured IIA with Onyx 18

Patient 1 was a 37-year-old male with a remote history of intravenous drug use and IE resulting in severe aortic insufficiency, eventually requiring a porcine valve. He was admitted for aortic root abscess. While no bacteria were isolated, the presumed etiology was a dental infection. During his admission, 1 day before cardiac surgery, he developed severe headache with transient word finding difficulty. He was found to have focal subarachnoid hemorrhage (SAH) secondary to the right middle cerebral artery (MCA) IIA with a trace of the right frontal convexity SAH on computed tomography (CT) [Figure 2a]. CT angiogram [Figure 2b] demonstrated a tiny outpouching in a distal branch of the right MCA near the SAH. MRI showed the SAH as high signal on FLAIR imaging [Figure 2c]. DSA confirmed an

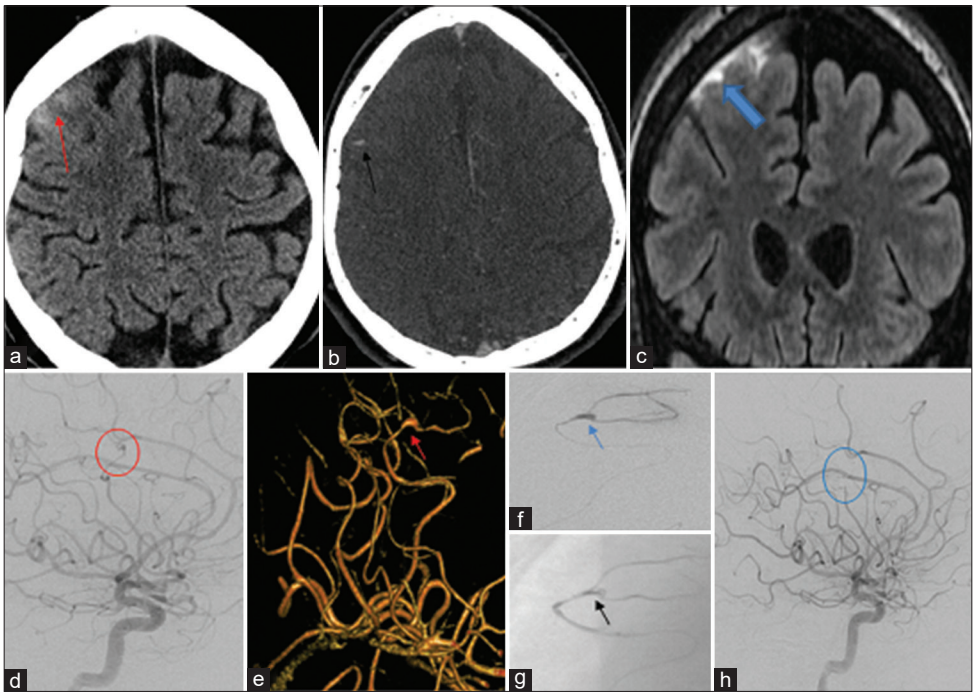

Figure 2: A 36-year-old male admitted for aortic root abscess treatment and developed slurred speech. Noncontrast brain CT (a) demonstrated trace of subarachnoid hemorrhage over the right frontal convexity (red arrow), CTA (b) demonstrated tiny outpouching (black arrow) in a distal branch of the right middle cerebral artery in the region of the subarachnoid hemorrhage. Coronal FLAIR sequence MRI (c) confirmed the subarachnoid hemorrhage (blue arrow). Cerebral angiogram (DSA) right ICA injection lateral view (d) showed an irregular 2 mm aneurysm (red circle) in the distal branch of the superior division of the right middle cerebral artery. The small aneurysm was better seen on 3D image (e) (red arrow) and on the microcatheter injection (blue arrow) (f) Pre-embolization and postembolization (g) image with the onyx cast filling the aneurysm (black arrow) and the supplying arterial pedicle. Follow-up 6 months postembolization right ICA injection lateral view (h) demonstrated complete occlusion of the aneurysm (blue circle) with maintained patency of the MCA.

1.9 × 1.8 mm irregular aneurysm in a distal branch of the superior division of the right MCA [Figures 2d-2g].

A decision was made in liaison with the cardiothoracic surgery team to treat the aneurysm before the cardiac surgery.

Procedure: under general anesthesia, a 6Fr 80 cm Shuttle sheath guide catheter (Cook Medical Inc., Bloomington, USA) was positioned in the proximal ICA, through which a 5 Fr Sofia intermediate catheter (MicroVention, Tustin, California) was positioned in the M1 segment of the right MCA, an Apollo microcatheter (Ev3, Irvine, CA) with a 1.5 cm detachable tip was navigated over a Balt Hybrid 008 (Balt, Montmorency, France) microwire into the deeper branch of the MCA. Angiography through the Apollo microcatheter confirmed the feeder of the mycotic aneurysm. The branch was embolized using Onyx 18 (Ev3, Irvine, CA) liquid embolic agent. There was complete occlusion of the inflow and outflow to the mycotic aneurysm. There was no evidence of contrast extravasation or nontarget vessel occlusion. The patient remained asymptomatic after the procedure, and next day, he underwent cardiac surgery for his aortic root abscess.

Follow-up angiogram after 6 months revealed persistent complete occlusion of the aneurysm [Figure 2h].

Case 2. Endovascular embolization of symptomatic IIA aneurysm with coils

Patient 2 was a 19-year-old female with extensive medical history dating back to a motor vehicle accident at age of 10 years. She initially sustained a mesenteric vascular injury and there have been numerous confounding issues resulting in extensive medical therapy since. This has included MSSA bacteremia, osteomyelitis, and endocarditis. After a 2-week therapeutic period of IV antibiotics, she developed severe headache and diplopia. On presentation, she was found to have a sixth nerve palsy and CT/CTA [Figures 3a and b] demonstrated left ICA occlusion from the bifurcation to the communicating segment (3b, yellow arrow). Distal to this, there was an irregular aneurysm which was suspected to be infectious in origin in addition to occlusion of the left A1 segment and severe irregular narrowing of the left posterior communicating artery (PCOM) and proximal M1 segment (not shown).

Cerebral angiogram demonstrated total ICA occlusion from the cervical bifurcation. The right vertebral injection

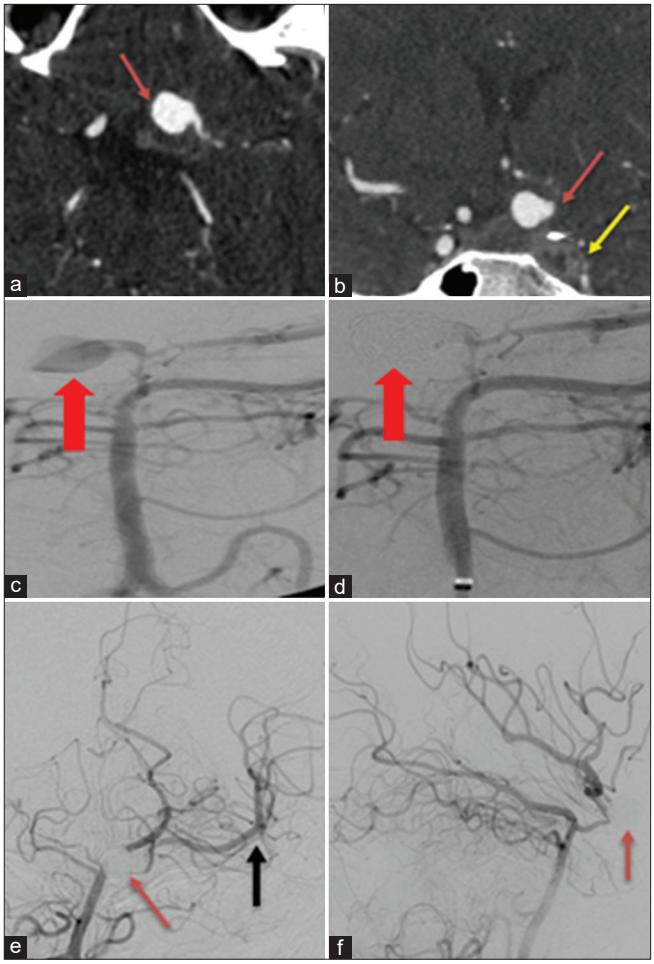

Figure 3: A 19-year-old female with the left cranial nerve VI palsy, CTA axial image (a) demonstrates saccular aneurysm from communicating segment of the left ICA (red arrow). Coronal plane (b) shows small lobulated extension anterolaterally (red arrow) and thrombosed left ICA with no contrast opacification (yellow arrow) compared to the contra lateral side which is normally opacified (not labeled). Cerebral angiogram right vertebral injection preembolization (c) demonstrates a 10 mm irregular lobulated aneurysm (red arrow) extending from the dysplastic communicating segment of left ICA. Post coil embolization (d), there is complete occlusion of the aneurysm (red arrow). One-month follow-up cerebral angiogram right vertebral injection anterior-posterior projection (e and f) shows the coil pack to be stable (red arrow) with complete occlusion and no evidence of recurrence. Persistent antegrade flow in the left middle cerebral artery (black arrow).

[Figure 3c] demonstrated a 10 mm irregular lobulated aneurysm extending from the dysplastic communicating segment of the left ICA. Endovascular coil embolization of the left ICA communicating segment IIA was performed through the left PCOM while preserving patency of the left PCOM and terminal ICA segment which were supplying the left MCA. Post coil embolization [Figure 3d], there was complete occlusion of the aneurysm.

Given the demonstration of robust collateral filling in the left MCA, PCOM sacrifice was left as a secondary treatment option should any increase in aneurysm filling or other worrisome change present on follow-up imaging.

The headache and sixth nerve palsy improved and she was discharged home after 2 days after a repeat single-vessel DSA confirmed stability of the coil pack with complete IIA occlusion (not shown).

On a 1-month follow-up, cerebral angiogram [Figures 3e and f] single-vessel right vertebral injection demonstrated coil pack stability with complete occlusion and recurrence (red arrow). Antegrade flow to the left MCA (black arrow) was also preserved.

Case 3: Endovascular embolization of ruptured IIA with coils

A 33-year-old female had a complex medical history of Crohn's disease, total colectomy and ileostomy, multiple cutaneous fistulae, and endocarditis related to a peripherally inserted central catheter (PICC) line infection.

During her admission for the treatment of recurrent PICC line infection, mitral valve endocarditis, and pneumonia, she developed headache and decreased level of consciousness. CT head scan [Figure 4] demonstrated diffuse SAH in the prepontine cistern and the right Sylvian fissure [Figure 4a] in addition to parenchymal hemorrhage in the right temporal lobe (green arrow). CTA [Figure 4b] showed a 9 mm aneurysm extending from the sidewall of the right P2/3 junction (red circle).

After multidisciplinary consideration, a decision was made to take an endovascular approach to the aneurysm and with a secondary option of parent artery sacrifice. DSA [Figure 4c] showed the aneurysm (yellow arrow) and post coil embolization DSA [Figure 4d] illustrated complete aneurysm occlusion (blue arrow).

After the procedure, the patient awoke with no deficits. She was kept in an intensive care unit for close observation. After 6 h, her level of consciousness deteriorated and her GCS was found to be 3. Repeat CT demonstrated increased SAH and hydrocephalus. In light of these findings and her clinical status, her family elected for a palliative course to her care, and she passed shortly thereafter.

DISCUSSION

Aneurysm characteristics

IIA is rare; in one single-center retrospective study, IIA represented only 0.5% of all diagnosed intracranial aneurysms (33 IIA out of 7229 intracranial aneurysms).[15] Despite a relative paucity of evidence, several important characteristics

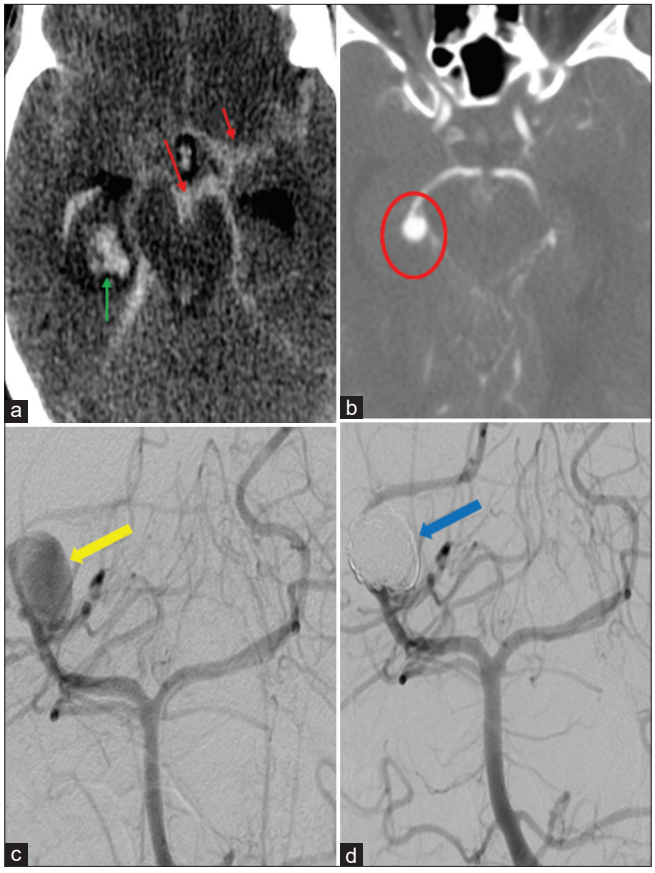

Figure 4: A 33-year-old female with decreased level of consciousness; noncontrast CT (a) demonstrates diffuse SAH in the prepontine cistern and the right Sylvian fissure (red arrows), in addition to intraparenchymal hemorrhage in the right temporal lobe (green arrow). On CTA (b), a 9 mm round aneurysm extending from the sidewall of the right P2/3 junction (red circle) is seen. DSA AP view pre coil embolization (c) shows the aneurysm (yellow arrow) and postembolization (d) complete occlusion with no flow at the coil pack (blue arrow).

of IIA have emerged.[1,9,17] We outline several key features of IIAs that distinguish them from noninfectious aneurysms. First, we note the relationship between aneurysm size and rupture status. While there is a clear correlation between large aneurysm size and rupture in noninfectious aneurysms,[1,9,19] this trend is less apparent for IIA. According to our calculations, IIA was found to rupture at smaller sizes, with the median ruptured IIA size being only 4.6 mm. One possible explanation could be from the animal studies on the formation of infectious aneurysms. Molinari *et al.* described how embolization of septic material and subsequent infection of the adventitial arterial layer would eventually result in vessel wall erosion and formation of easily friable aneurysms.[13] Furthermore, the dynamic angiographic nature of IIA has a potential for rapid changes, even in the same patient.[10] Rupture status is the most important factor, in terms of mortality; while mortality is 10–30% of the patients with unruptured IIA, it may be as high as 80% in patients with ruptured IIA.[1,10]

One study reports that while the absence of focal neurological deficits or even intracranial hemorrhage had both low sensitivity and specificity for the presence of IIA.[4]

Other differences between noninfectious aneurysms and IIA that may have impact treatment include aneurysm shape, location, and number of aneurysms: IIA tends to have an irregular or fusiform shape, is more distally located, and is more numerous than noninfectious aneurysms.[1,9,15]

Management of ruptured IIA

At present, there are no consensus guidelines for the management of ruptured IIA. Initial antimicrobial therapy remains a staple treatment strategy for all suspected IIA. The cases of symptomatic, large, rapidly expanding, or ruptured IIA are treated with urgent endovascular or open surgical intervention. In our series, 5 patients (62.5%) had excellent clinical outcomes with full resolution of deficits on follow-up, which supports the finding that 63.3% of patients ($n = 57$) had favorable outcomes [Table 3] as well as another analysis.[17] The literature suggests a reduction in mortality with surgical or endovascular intervention as opposed to medical treatment alone.[1] The choice of intervention depends on several factors. In general, more recent reports favor endovascular treatment as opposed to open surgery.[6,9,8,14,15,18] In part, this is attributable to the fact that to date, there is no evidence of continuing infection due to the presence of coils and stents.[5,18] Neurological deficits after endovascular parent vessel occlusion may be as high as 37.5%.[1] The risk of early rebleeding after endovascular coiling without scarifying parent may be as high as 5.8% and represents a major limitation of endovascular treatment in the management of ruptured IIAs.[9] As we described in Case 3, early rebleeding can often lead to patients' poor outcomes and this important issue cannot be ignored. Several reasons favoring endovascular treatment include decreased risk of anesthesia due to shorter anesthetic time,[14,15,17,19] an option of rapid institution of anticoagulation therapy,[17-19] and reduced treatment delay.[17,19] The latter two factors may be especially important in patients who need urgent cardiac surgery.[1,9,17] The inherent friability of the IIA wall and a lack of a well-defined neck may present a challenge for open surgical techniques.[5] Conversely, endovascular techniques may be favored for patients with surgically inaccessible or multiple IIA as well as for patients deemed at extremely high surgical risk.[3]

Endovascular therapy options are diverse: liquid embolization (with Onyx or NCBI)[2,6,8,12,15] or coiling with or without parent artery sacrifice.[2,6,9,12,14,15,18]

In cases where open surgery is indicated, such as in the management of increased intracranial pressure, neurosurgeons have several options. Open surgical options

Table 4 : Literature review: aneurysm characteristics.

Study	Endovascular treatment, all pts n (N)	Endovascular treatment ruptured pts n (N)	Surgical treatment all pts, n (N)	Surgical treatment of ruptured pts n (N)	Favorable clinical outcome all pts, n (N)	Favorable clinical outcome ruptured pts n (N)	Treatment details, n (N)	Complications, n (N)
Fukuda *et al.*, 2012	0	0	3 (5)	1 (2)	4 (5) "improved," 1 (5) "died"	1 (2)	Clipping 3 (5)	n/a
Allen *et al.*, 2013	9 (26)	n/a	9 (26)	n/a	4 (10) died in antibiotic arm; 2 (16) died in interventional arm	n/a	Clipping 5, bypass 3, coiling 7, glue 2, coagulation 1 (40)	n/a
Grandhi *et al.*, 2014	8 (8)	8 (8)	0	0	4 (7)	4 (7)	Onyx 16 (16)	1 (8) cardiac arrest, recovered
Esenkaya *et al.*, 2015	15 (15)	12 (15)	0	0	13 (15)	n/a	Coiling 10, onyx 3, balloon 1, spontaneous occlusion 4 (17)	2 (15) hematoma evacuation
Matsubara *et al.*, 2015	10 (20)	6 (20)	6 (20)	4 (20)	13 (20)	n/a	Clipping 1, trapping 4, bypass 1, NCBI 7, coil 3, medical 7 (23)	13 (23)
Singla *et al.*, 2015	46 (393)	n/a	27 (393)	n/a	n/a	n/a	Clipping 27 (37), coiling 46 (63)	n/a
Hamisch *et al.*, 2016	1 (6)	1 (6)	5 (6)	5 (6)	3 (6)	3 (6)	Resection 3, resection + clipping 2, coiling 1 (6)	n/a
Nonaka *et al.*, 2016	5 (5)	4 (4)	0	0	3 (4)	3 (4)	Direct embolization 1, PAO 4 (5)	0 (0)
Park *et al.*, 2017	9 (25)	n/a	3 (25)	n/a	12 (25)	n/a	NCBA 5, coiling 6, surgery 2, PAO with surgery 3 (33)	2 (25)
Our series, 2021	4 (8)	4 (8)	2 (8)	2 (8)	5 (8)	5 (8)	Bypass 2, onyx 1, coiling 3 (12)	1 (8) SAH, death after coiling

IIA: Infectious intracranial aneurysm, n: Number with a particular characteristic within a study; N: Total number of cases in a study; n/a: Not applicable; NCBA: N-butyl cyanoacrylate, PAO: Parent artery occlusion, pts: Patients

include IIA clipping,[2,9,11,12,18] trapping, wrapping, or resection[9] with or without arterial bypass.[2] In addition, open surgery can be combined with endovascular therapy using deconstructive or reconstructive approaches. Finally, diagnostic angiogram may be used by some surgeons during arterial bypass (such as EC-ICA) for intraoperative mapping of the arteries, as illustrated in Cases 4 and 6 from our series [Table 1].

Prognosis of IIA

Despite increased experience and a wide choice of interventional options, mortality remains high, at 10–30% for patients with unruptured IIA and nearly 80% in patients with ruptured IIA.[1] Fortunately, morbidity and mortality rates have continually decreased over time with one study reporting 12.1% mortality for the past 5 years.[1] This reduction is likely due to an improvement in systemic antimicrobial therapy, techniques of diagnostic work-up, as well as techniques of surgical and endovascular interventions.

Limitations

The majority of studies included in this article are retrospective single-center case series, which are more likely to report positive results. As such, we were unable to control for publication bias. Furthermore, since the effect estimates could not be calculated, we could not directly assess the degree of publication bias. To partially mitigate this issue, we excluded studies and reports with <3 patients, thereby limiting our analysis to only nine studies. Another inherent methodological limitation of working with retrospective and noncomparative studies is the fact that direct comparisons cannot be made. Despite our best efforts to synthesize the evidence of the past decade, our systematic review cannot be used to draw generalizable conclusions.

CONCLUSION

In the past few years, there has been a trend for patients to be treated more often by endovascular approaches. However, in the absence of definitive data, the decision for the best treatment option for a given patient with a ruptured IIA should be taken after a multidisciplinary discussion of both open and endovascular neurovascular physicians.

This study highlights a single Canadian tertiary center experience in the management of ruptured IIA and compares it to the global trends of the past 10 years in a systematic review.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

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Conflicts of interest

There are no conflicts of interest.

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