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A narrative review in managing ICA aneurysms

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ABSTRACT

Introduction: Internal carotid aneurysms are among the most common intracranial aneurysms, with nearly 20-25% of the ruptured aneurysms patients succumbing to death before reaching hospital. Most aneurysms are discovered in the context of an SAH, unruptured aneurysms can also be detected in patients presenting with other clinical symptoms or incidentally through neuroimaging**.**

Materials and methods: We searched Google and indexed articles with the keywords "ICA aneurysm management". We took 45 articles to identify epidemiology, diagnosis and management of these aneurysms. Both microscopic and endovascular treatments were taken into account.

Results: Clipped aneurysms had a relatively lower percentage of recurrences as compared to endovascular modality, while the incidence of peri-procedural complications was higher with clipping patients.

Conclusion: The volume of cases an institution handles influences the procedure's success. Endovascular management of ICA aneurysms has recently gained in numbers compared to open procedures.

INTRODUCTION

Cerebral aneurysms are localized dilatations occurring at weakened areas within the brain's arterial circulation. They often occur at the branching points of smaller vessels and are usually saccular in shape, but they can also have fusiform or blister-type shapes. These aneurysms can vary in size, with small aneurysms being less than 0.5 mm, medium ranging from 6 to 25 mm, and large ones exceeding 25 mm. The majority are saccular (berry-shaped), characterised by a thin or absent tunica media and a severely fragmented or absent internal elastic lamina. Less commonly, aneurysms may be fusiform (circumferential) or mycotic (infectious). Most cerebral aneurysms are asymptomatic and are often discovered incidentally during neuroimaging or autopsy (1,2). Around 85% of these aneurysms are found in the anterior circulation, primarily at junctions or bifurcations along the circle of Willis. When rupture occurs, it often leads to subarachnoid haemorrhage (SAH), which is associated with high morbidity and mortality (2).

Keywords
ICA aneurysm,
clipping,
coiling

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Wiebers. et al. (2003), in the International Study of Unruptured Intracranial Aneurysms (ISUIA), reported that the most common location for a cerebral aneurysm was the Internal Carotid Artery (29.9%), followed by the Middle cerebral artery (29%) (3). Bouthillier's classification (1996) described seven parts of the Internal Carotid artery based on anatomy which was based on the original Fischer's classification.C1, cervical; C2, petrous; C3, lacerum; C4 cavernous; C5, clinoid; C6, ophthalmic; and C7, communicating (4).

Paraclinoid aneurysms are complex intracranial aneurysms arising from the internal carotid artery proximal to the posterior communicating artery and distal to the distal dural ring (DDR). They have complicated anatomy and project surgical difficulty (5). Paraclinoid aneurysms have a variable relationship with the distal dural ring that cannot be determined radiographically.

Paraclinoid aneurysms spanning the distal dural ring are partially in the subarachnoid space and at risk of subarachnoid haemorrhage. The paraclinoid aneurysms account for 5-10% of all intracranial aneurysms (6). Paraclinoid aneurysms are divided into four types based on the lateral view of ICA angiogram: Carotico-ophthalmic aneurysms (COA), Dorsal (D) or anterior wall aneurysms, Ventral (V) or posterior wall aneurysms and Transitional (T) aneurysms.

EPIDEMIOLOGY

Internal carotid artery aneurysms are believed to represent 30% to 50% of all intracranial aneurysms (3). Research suggests that patients with ICA aneurysms are more likely to have multiple aneurysms (7). They are more frequently seen in women and are typically diagnosed in individuals in their fifties or sixties (8).

CLINICAL MANIFESTATION

Approximately half of these aneurysms present with subarachnoid haemorrhage or symptoms caused by mass effect, while the other half are found incidentally (8). Subarachnoid haemorrhage (SAH) is often a catastrophic event. Around 20 to 25 per cent of patients succumb before arriving at the hospital, and among those who do receive timely medical care, only about one-third experience a favourable outcome post-treatment (9,10). Most SAHs result from ruptured intracranial saccular (berry) aneurysms (11,12).

DIAGNOSIS

The majority of cerebral aneurysms are unruptured and are asymptomatic clinically. However, a ruptured cerebral aneurysm presents with a sudden onset headache, which is severe in intensity (thunderclap headache). In about 30% of cases, the pain tends to be localised on the ipsilateral side. Sudden death can happen in 10 to 15% of patients. Physical examination may reveal signs of raised ICT, i.e. elevated blood pressure, dilated pupils, visual field or cranial nerve deficits, etc. The Hunt and Hess grading system, commonly used to predict patient outcomes based on their initial neurological status, consists of 5 grades, reflecting symptoms' severity and correlating with mortality rates (2). While most aneurysms are discovered in the context of an SAH, unruptured aneurysms can also be detected in patients presenting with other clinical symptoms or incidentally through neuroimaging. Unruptured cerebral aneurysms are often detected on MRI, CTA, or conventional angiography; however, ruptured aneurysm resulting in subarachnoid haemorrhage (SAH) can be detected on a non-contrast CT(NCCT) brain. Once SAH is diagnosed, the bleeding source must be identified through CTA, MRA, or digital subtraction angiography (DSA) (2).

TREATMENT

The management of the ventral ICA aneurysm can be broadly divided into two approaches: Open surgical and endovascular approach. Anatomical factors—including size and location—and other shape-related characteristics often play a crucial role in determining the most suitable treatment for a patient.

MICROSURGICAL APPROACH

The surgical management of cerebral aneurysms, involving the placement of a clip across the aneurysm's neck, can be used in both unruptured or ruptured aneurysms.

It involves ipsilateral Pterional craniotomy followed by removal of the anterior clinoid process, Extradural drilling of the optic strut and then linear dural opening along the Sylvain fissure, which is followed by distal dural ring dissection, then

Proximal dural ring dissection and lastly application of clip under the ventral ICA.

For aneurysms projecting inferiorly or medially, extradural clinoidectomy is safe and may require less time than intradural clinoidectomy

Inferiorly projecting aneurysms can be clipped with an up-curved clip rather than the usual fenestrated clips.

Clipping requires complete visualisation of the aneurysm, so the rate of intraoperative difficulties and complications like inadequate exposure, injury to brain tissue, vessel injury leading to haemorrhage, and vessel occlusion causing ischemia is relatively high. Taha et al., in a centre retrospective analysis of cases undergoing surgical clipping, found a notable 19.35% incidence of periprocedural technical complications (13).

Clipping lowers the incidence of residual and recurrent aneurysms. Akyuz et al. (2004) followed 136 patients with 166 aneurysms at an average of 46.6 months after surgery and found that 5.1% of aneurysms had residuals. Still, no recurrences were observed, and Brown et al. (2017), in 431 ruptured and 327 unruptured aneurysms, found that 7.8% had residual aneurysms on early postoperative imaging after one month, with a single recurrence detected at an average of 7.2 years post-discharge (14,15).

Several studies were done to assess survival, morbidity, and mortality rates associated with surgical clipping for unruptured aneurysms. Britz et al. (2004), in a retrospective study, found higher survival rates among patients who underwent clipping, with a 2.3% risk of death due to neurological causes (16). The International Study of Unruptured Intracranial Aneurysms (ISUIA), led by Wiebers et al. (2003), reported an overall morbidity and mortality rate of 11% to 13.7% and 10.1% to 12.6% at 30 days and one-year post-surgery, respectively (3). In a study, Ogilvy et al. (2003) found an overall mortality rate of 0.8% and a morbidity rate of 15.9% (17). Morbidity in these studies encompassed long-term neurological deficits, residual or reformed aneurysms, bleeding, and ischemic stroke due to vessel occlusion.

Mortality and morbidity rates significantly increase when a ruptured aneurysm is treated through surgical clipping. According to the International Subarachnoid Aneurysm Trial, a randomised controlled trial conducted by Molyneux et al. (2005), the combined morbidity and mortality rate was 30.6% in the surgical treatment group. Additionally, the trial demonstrated an absolute risk reduction of 6.9% in dependency or death among those treated surgically (18).

The volume of cases an institution handles also influences the procedure's success. Rinaldo et al. (2017) discovered a negative correlation between case volume and complication rates (19). Barker et al. (2003) conducted a retrospective cohort study. They found that high-volume hospitals, which treated 20 or more cases annually, discharged 84.4% of patients and had a mortality rate of 1.6%. In contrast, low-volume hospitals (handling fewer than four cases per year) discharged 76.2% of patients and had a higher mortality rate (2.2%) (20).

With the advent of less invasive procedures like coil embolisation, surgical clipping has become less prominent in managing intracranial aneurysms. Despite ongoing advancements in transcranial approaches and clipping techniques, coiling has emerged as the preferred treatment option in many institutions; nonetheless, clipping remains essential when coiling is not feasible, such as in cases involving very large aneurysms (21).

ENDOVASCULAR APPROACH

There is a majority of endovascular approaches, which include coil embolisation and newer techniques like stent-assisted coiling, balloon-assisted coiling, flow diverters, disruptors, and new embolic materials.

Coil Embolization involves the insertion of platinum coils into the aneurysm's lumen, forming a local thrombus around the coils, effectively obliterating the aneurysmal sac. The procedure begins with gaining vascular access, usually through a peripheral artery like the femoral artery, and then locating the aneurysm, followed by inserting a detachable platinum coil in the aneurysm. Once the coil is placed in the aneurysm, clot formation is triggered. It is followed by dye injection to look for any position of the coil, condition of the parent artery and residual blood flow to the aneurysm. The procedure can be performed under general anaesthesia or sedation (22,23).

Coiling is a relatively new approach to treating intracranial aneurysms. Guglielmi detachable coil was developed and approved in the 1990s for unruptured aneurysms after a study by Eskridge et al. (1998), who examined 150 cases of both ruptured and unruptured aneurysms that were unsuitable for surgical intervention. They suggested that selected patients(not candidates for clipping) had better outcomes regarding reduced morbidity and mortality than those managed conservatively (24).

The Raymond-Roy Occlusion Classification (RROC) is the standard method for evaluating the success of coiled aneurysms (25). Mascitelli et al. (2015) refined RROC and divided class III into classes IIIa and IIIb. They found that class IIIa aneurysms had a significantly higher likelihood of progressing to class I or II than class IIIb aneurysms (83.3% vs. 14.9%) (25).

Since its initiation, the coiling technique has undergone substantial advancements. Nguyen et al. (2008) assessed aneurysms treated with coiling between 1992 and 2007 and found a rupture rate of 11.7% in very small aneurysms 3 mm or smaller, compared to just 2.3% in larger aneurysms (21,26).

Advances such as softer and smaller coils (around 1 mm in diameter) have made it safer to treat smaller aneurysms. In contrast, larger-diameter coils have been developed to pack larger aneurysms more efficiently (27).

The Analysis of Treatment by Endovascular Approach of Unruptured Aneurysms (ATENA) study, led by Pierot et al. (2008), assessed the effectiveness, morbidity, and mortality rates of coiling in multicenteric prospective study involving 649 patients with 1,100 unruptured aneurysms. They found that procedure-related adverse events occurred in 15.4% of patients, and morbidity and mortality rates after one month were 1.7% and 1.4%, respectively. They concluded that coiling has low morbidity and mortality rates (28).

Numerous studies have explored the safety and effectiveness of coiling, but all found that coiling has a low rate of complete occlusion. Gallas et al. (2008) reported a 70% immediate total occlusion rate in a retrospective study, with a 26.1% subtotal occlusion rate and 14.4% treatment-related morbidity (29). Similarly, Bradac et al. reported a 64% complete occlusion rate, a 34% nearly complete rate, and a 13% complication rate (30). Murayama et al. reported a 55% complete occlusion rate and a 35.4% neck remnant rate, with a 20.9% recanalisation rate primarily linked to the size of the aneurysm's dome and neck and 1.6% delayed aneurysm rupture (31). The International Study of Unruptured Intracranial Aneurysms (ISUIA) found that treatment-related morbidity and mortality were higher in patients with prior subarachnoid haemorrhage than in those without (9.8% vs. 7.1%) (3).

Stent-assisted embolisation as a treatment for intracranial aneurysms was first introduced by Henkes et al. (2002) in a multi-centric prospective study (32).

It was the initially accepted treatment method for unruptured ICA aneurysms with a broad neck and unfavourable neck-to-fundus ratio (dome-to-neck ratio less than 2 or a neck length of 4 mm or more). It was difficult to treat by surgical or traditional coiling. Stent-assisted coil embolisation facilitates proper coil placement while preventing the coils from protruding into the parent vessel. Moreover, intracranial stents may reduce the likelihood of aneurysm recanalisation (33). Stents are positioned in the artery, so antiplatelet regimens are required to prevent arterial thromboembolic complications, making using stents more challenging in cases of recently ruptured aneurysms (34).

Bechan et al. (2016), in a prospective observational study on 45 patients with ruptured and 47 patients with enraptured aneurysms, found that complication rates like visible thrombus, vessel occlusion, rebelled were 10 times more common when Stent assisted coil embolisation was done in ruptured aneurysm as compared to enraptured aneurysm (35).

Recently, its use has expanded to treat all types of aneurysms (34). Coiling is performed mainly in general anaesthesia.

Firstly, stent placement is simulated using computer graphics on the 3D dataset with standard machine software. The software accurately calculated the diameters and length of the targeted vessel segment, allowing for selecting the appropriate stent size and length. A microcatheter is used to navigate past the aneurysm. After placing the stent, the delivery microcatheter is removed, and a lower-profile microcatheter is introduced through the stent struts into the aneurysm. Coils are then deployed to occlude the aneurysm (35).

In a randomised clinical trial, Boisseau et al. (2023) assessed the superiority of Stent-assisted coiling over coiling alone in treating unruptured cerebral aneurysms in a 10-year study on 205 patients. They found that Stent-assisted coiling did not offer any advantage over traditional coiling in terms of recurrence of the lesions, intracranial bleeding, retreatment, modified Rankin scale of 3-5 or death (34).

Newer endovascular techniques have emerged that may complement or replace coiling. Liquid embolics, particularly OnyxHD500, have gained attention for treating wide-neck aneurysms (27). Dalyai et al. (2011) achieved a 90% complete occlusion rate in patients with wide-neck aneurysms who were unamenable to coiling alone (36).

Additional innovations, including endoluminal flow diversion and aneurysmal neck reconstruction, are being evaluated as treatment options (37,38).

Balloon-assisted coiling, also known as the remodelling technique, was first introduced by Moret et al. (1997) to extend endovascular treatment (EVT) to wide-neck intracranial aneurysms. In this technique, a non-detachable balloon is temporarily inflated across the aneurysm neck during the placement of each coil. The balloon is positioned within the parent vessel adjacent to the aneurysm neck for sidewall aneurysms. Once the coiling is completed, the balloon is deflated and removed unless stenting is required as a follow-up procedure (39,40). A 2006 single-centre retrospective study on both ruptured and unruptured aneurysms suggested that BAC was linked to a higher complication rate. Specifically, the rates of thromboembolic events and intraoperative ruptures in the BAC group were 9.8% and 4.0%, respectively, compared to 2.2% and 0.8% in the coiling-alone group (41). However, more recent data from two large multicenter prospective studies have provided a clearer picture. In the ATENA study (which focused on unruptured aneurysms), the rate of thromboembolic events was similar between the BAC group (5.4%) and the coiling-alone group (6.2%) (28).

Additionally, the rate of intraoperative rupture was 3.2% in the BAC group and 2.2% in the coiling-alone group. Clinical outcomes were also comparable, with a permanent deficit or death in 0.6% of the coiling group and 1.4% of the BAC group. Morbidity rates were 2.2% for coiling alone and 2.3% for BAC, while mortality was 0.9% and 1.4%, respectively (28,42).

In the CLARITY study (which focused on ruptured aneurysms), the two groups' thromboembolic event rates were similar: 12.7% in the coiling group and 11.3% in the BAC group. The rate of intraoperative rupture was 4.4% for both groups, with morbidity and mortality rates being comparable as well (43).

The impact of BAC on anatomical outcomes remains uncertain. One study found that aneurysms treated with BAC had a higher rate of incomplete occlusion (27.7%) compared to those treated with standard coiling (16.9%), as well as a higher rate of retreatment (16.9% versus 9.0%) (41). However, another series reported better initial and follow-up anatomical results with BAC. This study achieved total occlusion in 73% of BAC-treated patients postoperatively compared to 49% with coiling alone, with similar results observed during follow-up (44). Conversely, the ATENA series on unruptured aneurysms did not show better anatomical outcomes with BAC (28,42).

BAC was initially developed for wide-neck aneurysms, but it has also demonstrated utility in cases of intraoperative rupture, where balloon assistance may improve clinical outcomes (45). In this scenario, the balloon is left deflated across the aneurysm neck and is only inflated if rupture occurs, serving as a protective measure. This "sentinel" use of BAC has contributed to its increased adoption in recent years, with one study showing a rise in its use from 23.9% in 2008 to 43.9% in 2010(46). The study also highlighted the versatility of BAC, noting its application in both ruptured and unruptured aneurysms of various locations, particularly those with an unfavourable dome-to-neck ratio (≤1.5) (39,46).

Flow diverters (FDs), developed over the past two decades based on in vivo and in vitro research, were introduced for clinical aneurysm treatment in the late 2000s(39,47,48) . These low-porosity, stent-like implants work through two primary mechanisms:

- Flow Redirection: The FD is placed across the aneurysm neck, reducing blood flow into the aneurysm sac by increasing resistance with its mesh structure while still allowing blood to pass through nearby perforators and side branches. This redirection decreases circulation within the aneurysm, leading to flow stasis and the formation of a stable thrombus inside the aneurysm.

- Tissue Overgrowth: The FD acts as a scaffold, encouraging neoendothelialization over the aneurysm neck, which helps further seal the aneurysm.

Preclinical studies have shown FDs to be effective and safe in treating aneurysms with good occlusion rates and fewer thromboembolic complications (49,50).

Initially, two FDs were available: the Pipeline Embolization Device (EV3-MTI, Irvine, CA) and Silk (Balt, Montmorency, France). Recently, other devices like Surpass (Stryker, Fremont, CA) and FRED (Microvention, Tustin, CA) have been introduced (51–55). Early clinical experience with FDs, primarily from smaller single-centre or multicenter retrospective studies, demonstrated treatment feasibility, acceptable periprocedural complication rates, and favourable morbidity and mortality outcomes (51–55). Larger retrospective and prospective series have since confirmed these findings (56–58).

Flow diversion is typically used for treating complex aneurysms, such as large, giant, wide-neck, fusiform, or recanalised aneurysms after coiling. A recent international multicenter prospective study focused on treating complex aneurysms in the intracranial internal carotid artery in 108 patients. The treatment was feasible in 99.1% of cases, achieving complete occlusion in 73.6% of aneurysms at 180 days without significant vessel stenosis. The study also showed an acceptable safety profile, with 5.6% of patients experiencing a major ipsilateral stroke or neurological death (59).

Although the precise indications for flow diversion (FD) are still evolving, clinical experience has shown that FDs are primarily used for treating large and giant aneurysms (including fusiform aneurysms), wide-neck aneurysms, aneurysms within diseased arterial segments with multiple aneurysms, and recurrent aneurysms. Due to the need for dual antiplatelet therapy, most aneurysms treated with FD are unruptured. However, small studies have highlighted the effectiveness of FD in managing very small aneurysms, including blister-like aneurysms, which are difficult to treat with standard coiling techniques (60).

As FD use becomes more widespread, more information on potential complications has emerged. Like other endovascular treatments (EVT) for aneurysms, thromboembolic events and intraoperative rupture can occur. The risk of intraoperative rupture is generally lower with FD due to the absence of endovascular manipulation. Still, the risk of thromboembolic events is higher than standard coiling or balloon-assisted coiling (BAC) since FD is placed in the parent artery. To reduce this risk, both preoperative and postoperative antiplatelet therapy (single or dual) is recommended.

More extensive clinical experience with FD has also revealed complications not typically seen with standard coiling or BAC, such as delayed aneurysm rupture and remote parenchymal hematomas. Most of these complications have been reported in large and giant aneurysms, which have a high natural risk of bleeding and were previously untreatable (61–64). The Retrospective Analysis of Delayed Aneurysm Ruptures (RADAR) study showed that delayed aneurysm rupture occurred in about 1% of patients after FD treatment (65). Turowski et al. reported 13 cases of delayed ruptures with the Silk implant, with early ruptures (within 3 months) occurring more frequently than late ones (after 3 months). Early ruptures occurred between 2 and 48 days post-treatment, with patients typically still on dual antiplatelet therapy (aspirin and clopidogrel). Late ruptures, which occurred in patients only receiving aspirin, were seen between 110 and 150 days post-treatment. Delayed ruptures were most common in symptomatic, large, or giant aneurysms, particularly those with high dome-to-neck ratios (61,62,65).

Another severe complication associated with FD use is delayed ipsilateral parenchymal haemorrhage, with its incidence varying across studies. In the Cruz et al. study, delayed haemorrhage occurred in 8.5% of patients, while the RADAR study reported a 1.9% incidence (65,66). This complication was observed between 1 and 6 days post-treatment and was associated with variable clinical outcomes. A separate small series achieved favourable outcomes following surgical hepatoma evacuation after platelet transfusion. The proposed mechanisms behind delayed parenchymal haemorrhage include the haemorrhagic transformation of ischemic lesions, altered intracranial blood pressure in distal territories, and loss of autoregulation in the distal arteries. Dual antiplatelet therapy may also contribute to the size of the hematoma or trigger spontaneous bleeding, similar to what is occasionally seen after carotid artery stenting (65,66).

Another concern with FD is the patency of perforating arteries and side branches covered by the device.

Finally, long-term follow-up is necessary to monitor for late thrombosis of FDs, which has been reported in certain aneurysms (67).

FLOW DISRUPTION

Intravascular flow disruption is an endovascular technique akin to intraluminal flow diverter (FD) technology. The primary distinction lies in placing the flow disruptor's mesh directly within the aneurysm sac rather than the parent artery. This strategic placement induces blood flow stasis inside the aneurysm, leading to thrombosis and stabilisation of the aneurysm. Preclinical research has demonstrated that this method is feasible and practical, with a strong safety profile (68). In an initial retrospective multicenter study involving 20 patients treated with the WEB device (Sequent Medical Inc., Aliso Viejo, CA), the treatment achieved a 100% technical success rate, with no mortality and a low % morbidity rate of 4.8%(69). Subsequent prospective single-centre studies have reported comparable outcomes, reinforcing the reliability of the WEB device (70). The preliminary data suggest that the WEB device is particularly suitable for managing wide-neck bifurcation aneurysms in the basilar artery, middle cerebral artery, anterior communicating artery, and internal carotid artery (71). A significant advantage of this intravascular approach is that the flow disruptor remains entirely within the aneurysm, eliminating the need for antiplatelet therapy (71). This feature makes the technique especially promising for treating ruptured aneurysms. Additionally, there have been successful applications of the WEB device in treating recanalised aneurysms, further highlighting its versatility and potential in various clinical scenarios (69).

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