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ORIGINAL ARTICLE - VASCULAR NEUROSURGERY - ANEURYSM

Early and midterm results of treatment of giant internal carotid artery paraclinoid aneurysms with trapping and flow diverters

Yerbol Makhambetov[1] · Assylbek Kaliyev[1] · Ken-ichiro Kikuta[2] · Faizulla Smagulov[1] · Yerkin Medetov[1] · Marat Kulmirzayev[1] · Talgat Kerimbayev[1] · Nurlan Kissamedenov[1] · Aigerim Tursynkhan[1] · Aidos Doskaliyev[1] · Serik Akshulakov[1]

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Abstract

Background Flow diverter devices (FDD) carry risks of postoperative complications when treating aneurysms with wide necks, stenosis, and severe tortuosity of the parent vessel. In this study, we evaluated early and midterm results for the treatment of giant paraclinoid aneurysms managed by trapping and endovascular deployment of FDD.

Methods Medical records were analyzed for patients with giant paraclinoid aneurysms treated between July 2008 and December 2017 at National Centre for Neurosurgery with either a flow diverter or by trapping the aneurysm with or without extracranial-intracranial (EC-IC) bypass surgery. We recorded age, sex, clinical presentation, treatment modality, morbidity, and mortality. Clinical outcomes were assessed using a modified Rankin scale (mRS).

Results Among 29 consecutive patients, 13 were treated with FDD, and 16 patients were managed by trapping the aneurysm, where 7/16 cases had preliminary EC-IC bypass. Of 16 trapping patients, six were trapped endovascularly and ten were trapped surgically. During the follow-up period (mean 33 months, range 6–96), total exclusion of the aneurysm from the circulation was observed 100% of aneurysms in the trapping group and 84.6% in the FDD group ($P = 0.192$). Early postoperative morbidity was observed in three (23%) cases in the FDD group, and four (25%) in trapping group ($P = 0.525$). The FDD group had one (7.7%) fatal complication due to stent occlusion and severe ischemic stroke after three months postoperatively, despite appropriate antiplatelet therapy. There were no mortalities in the trapping group ($P = 0.149$). The rate of mRS 0–2 did not differ significantly across groups at discharge (81.3% vs. 69.2%; $P = 0.667$), and all patients had mRS 0–2 at follow-up ($P = 1.000$).

Conclusions FDD deployment for giant paraclinoid aneurysms results in comparable angiographic and clinical outcomes to aneurysm trapping. Despite implementation of modern endovascular treatment methods, aneurysm trapping remains a valuable treatment option in carefully selected patients with giant paraclinoid aneurysms.

Keywords Giant aneurysms · Internal carotid artery · Paraclinoid · EC-IC bypass · Flow diverter devices

Introduction

Aneurysms in the paraclinoid segment of the internal carotid artery (ICA) constitute 5% of intracranial aneurysms [3] and are challenging to treat due to common anatomical complexities such as tight connection with cranial nerves, perforating arteries, presence of intraluminal thrombus, atherosclerotic process in the aneurysm wall and parent artery, and close proximity to bone structures [6]. Treatment for large and giant paraclinoid aneurysms is also complicated by high rates of morbidity and mortality, whether by endovascular therapy [11–16] or direct surgical management [7–10, 21], especially in ruptured cases.

Direct aneurysm trapping by simple parent artery occlusion is not always a safe and reliable option, especially in cases with insufficient collateral blood flow [24]. However, there is a shortage of available alternative methods besides direct clipping, as treatment of giant aneurysms with flow diverter

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✉ Assylbek Kaliyev
assylbek789@yahoo.com

[1] National Centre for Neurosurgery, Turan Ave 34/1, Nur-Sultan 010000, Kazakhstan

[2] University of Fukui, Fukui, Japan

devices (FDD) is associated with morbidity and mortality rates equal to 22.1% and 7.8%, respectively [22]. Data comparing outcomes of trapping vs. FDD in giant paraclinoid aneurysms is limited. In this report, we retrospectively evaluated results of treatment of giant paraclinoid aneurysms managed by ICA trapping or endovascular deployment of FDD.

Methods and materials

Patient characteristics

We retrospectively analyzed medical records of 29 patients with giant paraclinoid aneurysms treated at our center between July 2008 and December 2017. Data about age, sex, clinical presentation, treatment modality, and morbidity and mortality were evaluated. We defined morbidity as any postoperative neurological deterioration. Complications were assessed postoperatively by the attending physician and during the follow-up period. Radiological and angiographic examination records were reviewed before the treatment and at follow-up. The study protocol was approved by the local bioethical committee (protocol no. 1 dated February 12, 2018). All patients gave their informed consent prior to their inclusion in the study.

Patients were divided into two groups: those treated with FDD deployment (Pipeline, Medtronic, USA) and those who underwent trapping of the aneurysm with or without EC-IC bypass surgery. Prior to treatment, all cases were reviewed by our dual trained neurovascular team, who assessed the morphology of the aneurysm and the parent artery via DSA, and cerebral collateral blood flow via routine balloon occlusion test (BTO). The decision-making strategy for treatment choice is shown in Fig. 1. Endovascular FDD deployment was performed in cases with no severe stenosis or kinking of the parent artery and suitable aneurysm neck (< 4 mm). Additional use of coils was performed in cases of extremely giant aneurysms. A protective EC-IC bypass was performed before FDD deployment for wide-necked aneurysms, those with stenosis and/or kinking of the ICA, positive BTO, or those lacking collateral blood flow. Parent artery occlusion either by coils or Hunterian ligation was carried out in cases with extremely large aneurysm dome size with wide neck, stenosis or severe kinking of the parent artery, and negative BTO.

Balloon occlusion test

BTO were performed using a Siemens Artis Zee Biplane machine (Siemens, Germany). All procedures were performed under local anesthesia. Both femoral arteries were catheterized. A guiding catheter was placed in the ipsilateral internal carotid artery (ICA), and a second catheter was placed in the contralateral ICA. Intravenous heparin was administered prior to balloon inflation. Balloon (HyperGlide, Medtronic, USA) positioning and inflation were performed in the petrous segment of the ICA. Digital subtraction angiography (DSA) was then performed from contralateral ICA to vertebral artery to analyze the collateral blood flow through anterior and posterior communicating arteries. The patient's neurological condition was evaluated. If the patient tolerated the first 15 min, we induced arterial hypotension to at least 25% from the nominal arterial blood pressure. During the BTO, we evaluated for capillary and venous phases, hypoplasia of communicating

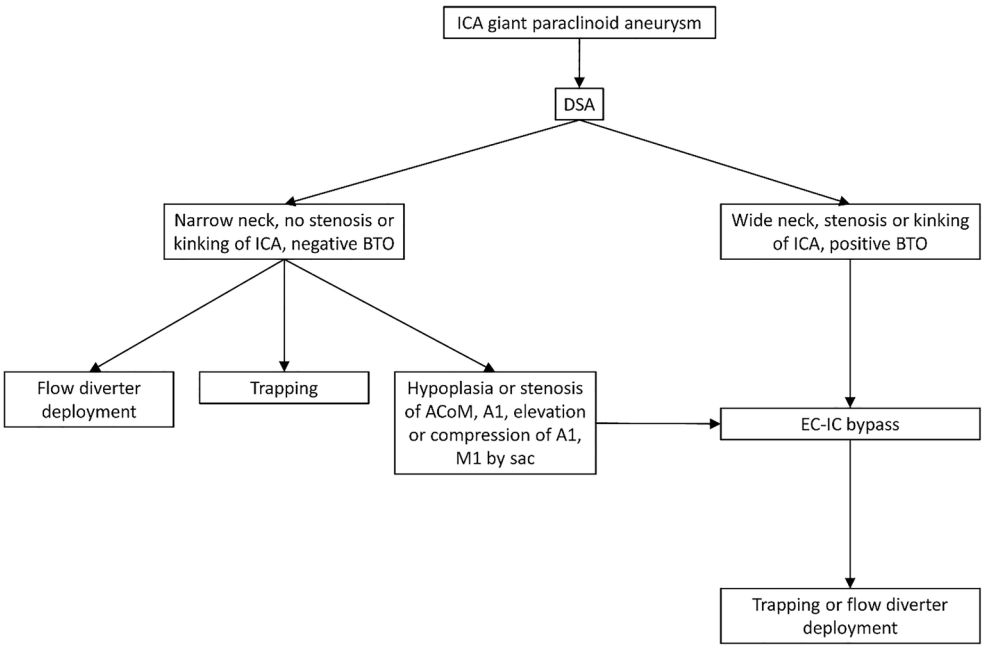

Fig. 1 Treatment decision-making strategy

arteries and compression by the aneurysm. BTO was evaluated as negative if the patient did not have neurological deterioration during 30 min of occlusion of the parent artery.

Endovascular flow diverter deployment

All patients were administered double antiplatelet therapy with clopidogrel (75 mg) and aspirin (100 mg) for one week prior to FDD deployment. Intravenous heparin (5000 units) was administered intraoperatively. All procedures were performed under general anesthesia. A Microcatheter Marksman (Medtronic, USA) with a 0.014-in. microguidewire was placed to the M1 segment of middle cerebral artery (MCA) passing the neck of the aneurysm. The FDD was then deployed to cover the neck of the aneurysm. Postoperative DSA was performed immediately after FDD deployment. Patients continued clopidogrel and aspirin for at least six months after surgery.

Aneurysm trapping

In all cases with negative BTO, patients underwent trapping of the aneurysm by Hunterian ligation or endovascular occlusion of the ICA. Hunterian ligation was performed under general anesthesia through a linear skin incision on the neck. After mobilizing the arteries of CCA bifurcation, we ligated the ICA with 5/0 non-absorbable suture. Postoperative DSA was performed at the same day of surgery. Through femoral artery approach, a guiding catheter navigated to the petrous segment of ICA. A Microcatheter Echelon (Medtronic, USA) with a 0.014-in. microguidewire was placed at the aneurysm neck.

Patients who did not tolerate BTO underwent preliminary low- or high-flow EC-IC bypass prior to aneurysm trapping. Low-flow bypass was performed if the patient had at least one communicating artery covering the territory of the anterior cerebral artery (ACA) or MCA. Under general anesthesia with the patient positioned supine, the frontal and parietal branches of the STA were located using a Doppler machine and were cut distally and washed with heparin solution. Cortical branches of MCA were dissected and prepared for side-to-end anastomosis. Prolene 10/0 sutures were used to create bypass. Flow verification was assessed with the Doppler machine, and bypass patency was confirmed by DSA on the day after surgery. After confirmation of bypass patency by DSA, either ligation or endovascular occlusion of the ICA was performed the day after the bypass surgery.

High-flow bypass was performed using a radial artery graft from ECA to MCA branches. Before high-flow bypass procedure, all patients underwent an Allen test to confirm patency of the palmar collaterals [1]. Under general anesthesia with the patient positioned supine with light neck extension, a skin incision was made on the head, with an ipsilateral linear skin incision of the neck. At the same time, a second surgeon harvested the radial artery. An extensive fronto-temporal craniotomy was performed with a wide Sylvian fissure dissection. The temporal M2 branches were prepared for anastomosis. The distal part of the graft was sutured to the M2 branch of the MCA, end to side, with 9/0 sutures. The graft then was placed under the zygomatic bone. The proximal portion of the radial artery was sutured to the external carotid artery using 8/0 sutures. All wounds were closed through standard procedure of meticulous hemostasis. Flow verification was assessed with the Doppler machine, and bypass patency was confirmed by DSA the day after surgery. After confirmation of bypass patency by DSA, either ligation or endovascular occlusion of the ICA was performed the day after the bypass surgery.

Outcome assessment

Clinical outcomes of the treatment were evaluated by a modified Rankin scale upon medical records' revision. Aneurysm volume and aneurysm occlusion rate were determined using postoperative DSA and MRI, respectively.

Statistical analysis

Baseline characteristics between the two groups were compared with a *U* test. Quantitative data are reported as mean ± standard deviation (SD). The statistical significance of various values for binary and nominal values was determined using Fisher's exact test. A P value < 0.05 was used to indicate statistical significance. Statistical analysis was carried out using Statistics 10 software (Tibco, Palo Alto, USA).

Results

Baseline characteristics

A total of 29 patients were included in this study. Mean patient age was 52 ± 7.62 years (range 36–69). Of the 29 patients, 21 (72.5%) were female and eight (27.6%) were male. Clinical presentations included headache in 15 cases, cranial nerve palsy in two cases, and visual disturbances such as lowering of visual acuity and visual field impairment in 12 cases. In our series, 27 (93%) aneurysms were unruptured and two (7%) patients had a previous history of aneurysmal subarachnoid hemorrhage. Mean follow-up period was 33 ± 17.4 months (range 6–96). Overall, mean dome size was 32.1 ± 1.35 mm (range 25–51), mean neck size was 10.6 mm (range 5–25), and mean dome:neck ratio was 3.7 ± 1.8 mm. At the time of treatment, six aneurysms were partially thrombosed.

Patient and aneurysm characteristics compared across treatment groups are shown in Table 1. There was a significant

Table 1 Baseline patient and aneurysm characteristics

	Trapping	FDD	*P* value
Patient characteristics			
Headache	6/16 (37.5%)	9/13 (69.2%)	0.139
Cranial nerve palsy	2/16 (12.5%)	0/13 (0/0%)	0.488
Visual disturbances	8/16 (50.0%)	4/13 (30.8%)	0.022
Aneurysm characteristics			
Unruptured	14/16 (87.5%)	13/13 (100.0%)	0.488
Ruptured	2/16 (12.5%)	0/13 (0.0%)	0.488
Dome size	31.5 [29.3–38.0]	28 [26.0–30.0]	0.042
Neck size	10 [8–10.3]	9 [6.5-10.5]	0.574
Dome:neck ratio	3.35 [2.95–4.65]	3.13 [2.63–4.29]	0.713

Data are reported as *n* (%) or medians (IQR)

difference in the number of patients with visual disturbances, with eight (50.0%) patients in the trapping group vs. four (30.9%) in the FDD group ($P = 0.022$). There were no significant differences in the number of patients with headache (37.5% vs. 69.2%; $P = 0.139$) or cranial nerve palsy (12.5% vs. 0.0%; $P = 0.488$). Mean aneurysm dome size was significantly higher in the trapping group vs. the FDD group (33.6 vs. 28.8; $P = 0.042$). There were no significant differences in neck size (11.1 vs. 9.6; $P = 0.574$) or dome:neck ratio (3.8 vs. 3.7; $P = 0.722$) between the trapping and FDD groups.

Procedure characteristics

We did not experience any complications during angiography and BTO. FDD deployment was performed in 13 patients. FDD alone was used except for one case in which we combined FDD deployment with loose packing of coils. In all FDD cases, we deployed only one device and observed contrast stagnation in the aneurysm lumen. In three cases, we performed a protective EC-IC bypass before FDD deployment due to the absence of collateral blood flow and possible risk of stent thrombosis.

A total of 16 patients underwent aneurysm trapping. Trapping was performed by Hunterian ligation in ten cases, and in six cases, endovascular occlusion of the ICA by coils at the origin of the ophthalmic artery was performed. Seven patients were treated with preliminary low- or high-flow EC-IC bypass.

Angiographic outcomes

Angiographic outcomes are presented in Table 2. During the follow-up period, aneurysm volume reduction was achieved in ten (76.9%) aneurysms treated with FDD and in 12 (75.0%) treated with trapping ($P > 0.999$). In all (100%) cases of trapping, we achieved immediate occlusion of the aneurysm and ICA. FDD deployment demonstrated immediate

Table 2 Angiographic outcomes

	Trapping	FDD	*P* value
Reduced aneurysm volume	12/16 (75.0%)	10/13 (76.9%)	> 0.999
Complete occlusion	16/16 (100.0%)	11/13 (84.6%)	0.192

Data are reported as *n* (%)

postoperative aneurysm exclusion in one case. In the remaining 12 cases, stagnation of the contrast inside the aneurysm lumen was observed. During the follow-up period, total exclusion of the aneurysm from the circulation was observed in 11 (84.6%) cases. One giant fusiform aneurysm had small remnant filling, which did not require additional treatment. There was no significant difference in the rate of complete occlusion as follow-up ($P = 0.192$).

Clinical outcomes

Morbidity and mortality rates are reported in Table 3. Early postoperative morbidity in the FDD group was observed in three (23.1%) cases, and four (25.0%) in trapping group ($P > 0.999$). There was one (7.7%) mortality in the FDD group despite appropriate antiplatelet medications after three months postoperatively, due to stent occlusion and severe ischemic stroke. There were no mortalities in the trapping group, and there was no significant difference in mortality between groups ($P = 0.45$).

mRS scores at discharge and follow-up are shown in Table 4. At discharge, the median mRS was 1.00 [1.00–1.75] in the trapping group vs. 1.00 [1.00–3.00] in the FDD group, and there was no significant difference in the rate of mRS 0–2 (81.3% vs. 69.2%; $P = 0.667$) or mRS 3–6 (6.3% vs. 30.8%; $P = 0.145$). At follow-up, the median mRS for both groups was 1.00 [1.00–1.75], and all patients had mRS 0–2 ($P = 1.000$).

Complications

In the FDD group, we faced complex ICA anatomy in three cases, which led to stent occlusion. In one of these patients, no aneurysm occlusion was found on follow-up DSA, and thus, a second FDD was deployed three months after the first. This patient died from a severe ischemic stroke after the second FDD was deployed. Other patient had good collateral blood

Table 3 Early morbidity and mortality rates

	Trapping	FDD	*P* value
Morbidity	4/16 (25.0%)	3/13 (23.1%)	> 0.999
Mortality	0/16 (0.0%)	1/13 (7.7%)	0.448

Data are reported as *n* (%)

Table 4 Modified Rankin Scale (mRS) outcomes at discharge and follow-up (mean 33.0 ± 17.4 months; range 6–96)

Evaluation period	Trapping ($N = 16$)	FDD ($N = 13$)	P value
Discharge	1.00 [1.00–1.75]	1.00 [1.00–3.00]	
mRS 0–2	13/16 (81.3%)	9/13 (69.2%)	0.667
mRS 3–6	1/16 (6.3%)	4/13 (30.8%)	0.145
Follow-up	1.00 [1.00–1.75]	1.00 [1.00–1.75]	
mRS 0–2	16/16 (100.0%)	12/12* (100.0%)	1.000

Data are reported as *n* (%) or median (IQR)

*1 mortality in the FDD group at follow-up

flow via the anterior communicating artery and did not have any complications.

We encountered one case of stent and ICA occlusion during six months follow-up. Fortunately, this patient did not suffer any ischemic complications due to the presence of protective high-flow EC-IC bypass.

Of the four patients with visual disturbances on admission in the FDD group, visual function was stable in two patients during the follow-up period. In the other two cases we observed improvement of visual functions. Of the eight patients with visual disturbances on admission in the trapping group, visual function was stable in three patients during the follow-up period. Other five patients experienced improvement of visual acuity and visual fields. There was no worsening of visual functions in either group.

Discussion

In this study, we demonstrate safe and effective occlusion of giant paraclinoid aneurysms treated with FDD deployment and trapping, resulting in comparable rates of morbidity and mortality, as well as comparable clinical outcome at follow-up. ICA occlusion by Hunterian ligation or endovascular occlusion at the level of the aneurysm neck is a minimally invasive and effective treatment modality. However, the risk of postoperative complications increases as the neck becomes wide and in the presence of stenosis and severe tortuosity of the parent vessel. In light of the increased implementation of modern treatment methods such as FDD, a subset of patients may be best treated with ICA trapping with bypass, and this technique should be considered a safe and effective alternative strategy in the management of giant paraclinoid aneurysms.

Giant paraclinoid aneurysms frequently have complex anatomy and risk to surrounding structures. Although minimally invasive endovascular methods have undergone significant improvements with the implementation of stent and balloon assistance, embolization of giant aneurysms is associated with high rates of aneurysm recurrence and high cost of treatment [14, 23]. Thus, the implementation of FDDs was a major breakthrough in the treatment of giant and wide-necked aneurysms [2]. A systematic review by Lv et al. included nine studies with 40 giant intracranial aneurysms treated with the Pipeline FDD revealed total aneurysm thrombosis in 23 (57.5%) cases in follow-up ranging between six and 34 months. Intracranial hemorrhages were detected in seven (17.5%) cases, five patients (12.5%) suffered from ischemic stroke and in 13 cases (32.5%) [14]. A recent large retrospective study by Silva et al. of 115 patients with a paraclinoid aneurysm found a high rate of aneurysm occlusion (57/64, 89%) and comparable rates of procedural complications among patients treated with the Pipeline FDD (10/64, 16%) compared with clipping (5/30, 17%) or coiling (2/23, 9%). Our series did not experience aneurysm rupture after FDD deployment. In addition to the data from the present study, these data suggest that ICA occlusion and FDD deployment yield outcomes comparable to direct microsurgical clipping of giant paraclinoid aneurysms during early and midterm period.

An important issue in the management of large and giant paraclinoid aneurysms is the preservation of visual functions [19]. Endovascular management of giant paraclinoid aneurysms by coils may lead to increased mass effect of the surrounding brain structures, which can cause worsening of visual disturbances [5, 9]. FDDs are hypothesized to improve visual function by reducing mass effect and decompressing the optic nerve [20]. A systematic review and meta-analysis of 64 patients with paraclinoid aneurysms reported that postoperative vision improved in 71% of patients after FDD deployment and worsened in only 5% of patients [20]. These results were more promising compared with patients treated with clipping (307 patients; 58% improved, 11% worsened) and coiling (149 patients; 49% improved, 9% worsened) and demonstrate the efficacy of FDD for the treatment of paraclinoid aneurysms with visual deficits.

Risks associated with aneurysm trapping include ischemic complications after ICA occlusion, formation of de novo aneurysm, or growth of existing aneurysms [4, 6, 18]. In cases of ICA proximal ligation, there can be remnant filling of the aneurysm through ophthalmic or meningeal branches. Such cases could require parent artery occlusion using endovascular techniques, such as deployment of coils at the origin of ophthalmic artery. Although proximal ICA ligation is less costly to perform than endovascular occlusion, there is a report of remnant filling and rupture of an aneurysm treated with this technique [15]. Nakajima et al. reported a series of five patients with large and giant ICA aneurysms who underwent endovascular parent artery occlusion at the origin of ophthalmic artery [17]. Nearly complete shrinkage of the aneurysm was observed in four cases, and cranial nerve function improved in three cases. In all cases, outcomes ranged between 0 and 1 mRS scores. These data suggest that clipping of giant paraclinoid aneurysms is effective and has an acceptable risk of complications when performed by an experienced neurosurgeon.

Limitations

The results of this study are based on a small number of patients with a short follow-up period, and therefore, treatment decisions should not be based on these results alone. Further studies with more patients and long-term follow-up are required to define the best treatment strategy.

Conclusions

This study demonstrates the clinical safety and efficacy of treating large and giant paraclinoid aneurysms with FDD deployment or trapping, with the choice of treatment based on the angiographic characteristics of the aneurysm. Our study shows comparable angiographic and clinical outcomes in both the early postoperative period and during the follow-up period. To evaluate comprehensive results of different treatment modalities, further large studies with a longer follow-up period must be carried out.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee (local bioethical committee, protocol no. 1 dated February 12, 2018) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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