www.surgicalneurologyint.com

ScientificScholar® Knowledge is power
Publisher of Scientific Journals

Surgical Neurology International

Editor-in-Chief: Nancy E. Epstein, MD, Clinical Professor of Neurological Surgery, School of Medicine, State U. of NY at Stony Brook.

SNI: Neurovascular

Editor
Kazuhiro Hongo, MD
Shinshu University, Matsumoto, Japan

SNI® Open Access

Original Article

Endovascular treatment of medium and large intracranial aneurysms with large volume coils: A single-center experience

Giancarlo Saal-Zapata[1], Basavaraj Ghodke[2], Melanie Walker[3], Ivethe Pregúntegui-Loayza[4], Rodolfo Rodríguez-Varela[1]

[1]Department of Neurosurgery, Hospital Nacional Guillermo Almenara Irigoyen, La Victoria, Lima, Peru, Departments of [2]Radiology and [3]Neurosurgery, University of Washington, Seattle, Washington, United States, [4]Department of Neurosurgery, Clínica Tezza, Santiago de Surco, Lima, Peru.

E-mail: *Giancarlo Saal-Zapata - gian_carlo1987@hotmail.com; Basavaraj Ghodke - bghodke@uw.edu; Melanie Walker - walkerm@uw.edu; Ivethe Pregúntegui-Loayza - ivethepl@gmail.com; Rodolfo Rodríguez-Varela - rodoneuro@hotmail.com

***Corresponding author:**
Giancarlo Saal-Zapata,
Department of Neurosurgery,
Hospital Nacional Guillermo
Almenara Irigoyen, La Victoria,
Lima, Peru.

gian_carlo1987@hotmail.com

Received : 19 September 2021
Accepted : 26 December 2021
Published : 12 January 2022

DOI
10.25259/SNI_947_2021

Quick Response Code:

ABSTRACT

Background: Large volume coils are an alternative to conventional coils for the treatment of intracranial aneurysms. However, there are no published reports documenting occlusion and complication rates in medium and large intracranial aneurysms. Therefore, we present our results in this subgroup of aneurysms.

Methods: A single-center, retrospective analysis of consecutive patients treated with Penumbra coils 400 in aneurysms ≥7 mm was performed. Demographics, aneurysm features, procedural details, intraoperative complications, clinical outcomes, and occlusion rates were analyzed.

Results: Thirty-three patients were included for analysis, and a total of 33 intracranial aneurysms were analyzed. Mean age was 57.6 years (SD ± 12.4) and 85% of the patients were women. Large aneurysms represented 46% of cases. Paraclinoid (55%) followed by posterior communicating (30.3%) aneurysms was the most frequently treated. Ruptured and saccular aneurysms were found in 49% and 63% of the cases, respectively. The mean aneurysmal dimensions were 14.2 mm width, 11.9 mm length, 5.4 mm neck, and 2.4 dome-to-neck ratio. A dome-neck ratio <2 was identified in 39% of cases. The mean number of coils per aneurysm was 4.8. Immediate modified Raymond–Roy Grades 1, 2, and 3A were achieved in 15%, 21%, and 64%, respectively. Twenty-six patients were evaluated at a mean follow-up period of 11 months, with an adequate occlusion of 92% and a good clinical outcome (modified Rankin score ≤2) in 96% of patients.

Conclusion: Endovascular treatment with PC400 coils is an effective and safe option for medium and large intracranial aneurysms with high occlusion rates, few complications, and good clinical outcomes at follow-up.

Keywords: Coils, Intracranial aneurysm, Large aneurysm, Paraclinoid aneurysm, Wide neck

INTRODUCTION

Thirty years ago, Guglielmi detachable coil embolization was introduced as an alternative method for treating patients with intracranial aneurysms. Since that time, devices and techniques for endovascular repair of aneurysms have continued to evolve.[8] Today, interventionalists have many treatment options for intracranial aneurysms, but size and morphology are key considerations. For the management of challenging large and wide-necked aneurysms, several options have emerged: conventional stenting, remodeling, flow diverters, and intrasaccular devices.[1]

Penumbra PC400 coils (Penumbra, Inc., Alameda, CA, USA) were approved for endovascular repair of intracranial aneurysms in 2011, and since then, studies have consistently reported increased packing density, fewer coils per aneurysm, decreased operative time, and superior cost-effectiveness.[9-11] The wider diameter of these coils makes them ideal in cases of medium and large aneurysms to obtain a complete obliteration of the aneurysm sac with fewer coils and less operative time. Experience using these type of coils in cases of aneurysms >7 mm and aneurysms harboring wide necks is scarce and only few reports exist in the literature.[6,11,15]

Herein, we present our experience in the treatment of medium and large intracranial aneurysms with PC400 coils and report efficacy in terms of occlusion rates as well as safety in terms of complications and clinical outcomes.

MATERIALS AND METHODS

Patient selection

Between November 2017 and September 2019, consecutive patients who underwent embolization of ruptured and unruptured intracranial aneurysms with PC400 in the Hospital Nacional Guillermo Almenara Irigoyen from Peru were selected for this study. All patients signed a detailed informed consent before surgery. Medical records, angiographic images, and brain computed tomography scans were retrospectively analyzed. All patients who underwent embolization with PC400 presented with medium (7–12 mm), large (>12–25 mm), and giant (>25 mm) aneurysms per International Study of Unruptured Intracranial Aneurysms trial criteria.

Variables

Age, sex, preoperative clinical status, angiographic aneurysm characteristics, endovascular techniques employed, intraoperative complications, postoperative clinical outcomes, and angiographic follow-up variables were included in the analysis. Angiographic features included (a) aneurysm location, (b) status of rupture, (c) length and width of the sac, (d) neck diameter, (e) number of coils, (f) dome-neck ratio, (g) presence of blebs, and (h) morphology (saccular or dysplastic). A wide-neck aneurysm was defined as a dome-neck ratio <2. Barami classification was employed for paraclinoid aneurysms.[2] Intraoperative complications were grouped as (a) coil protrusion into the parent artery, (b) coil migration, (c) intraoperative bleeding due to perforation of the aneurysm sac or distal vessel during catheterization, and (d) intraoperative parent artery thrombosis. Postoperative functional status was determined at discharge and at past follow-up, according to the modified Rankin score (mRS), which was dichotomized as good outcome (mRS 0–2) and poor outcome (mRS ≥3). Follow-up was performed by digital subtraction angiography with three-dimensional rotational angiography at the same institution. The modified Raymond–Roy occlusion classification (mRROC) was used to assess the obliteration rates. An adequate occlusion was catalogued as an mRROC 1 or 2.

Penumbra coils 400 main characteristics

The PC400 is a new generation of bare platinum coils with a 0.020″ outer diameter which has a stretch resistant nitinol inner wire. The larger diameter of these coils compared to conventional coils allows for improved packing density and offers 400% more volume per unit length than traditional coils. A 0.025″ inner diameter microcatheter (PX Slim; Penumbra) is required to deploy the coils within the aneurysm sac. A large guide catheter (Neuron Max 088 8F) should be used when remodeling or stenting is considered.

Endovascular treatment: Technical considerations

All procedures were performed in a biplane angiography unit (Philips Allura Xper FD20/10, Philips Medical Systems, Best, The Netherlands) under general anesthesia. The femoral approach was used in all cases.

For coiling only, a 6F guide catheter was navigated into the artery of interest, whereas for balloon-assisted coiling (BAC) and stent-assisted coiling (SAC) cases, the Neuron Max 088 (Penumbra, Inc., Alameda, CA, USA) guide catheter was employed. The PX Slim microcatheter (ID = 0.025″, Penumbra, Inc., Alameda, CA, USA) over a 0.014″ microwire was used for navigation and catheterization of the aneurysm sac. Once the coil was completely deployed within the aneurysm sac, it was detached mechanically with the Penumbra Coil Detachment Handle (Penumbra, Inc., Alameda, CA, USA). For stenting in cases of coil protrusion into the parent artery, intraoperative dual antiplatelet therapy with 300 mg of aspirin and 300 mg of clopidogrel was initiated through a nasogastric tube. Low-profile Visualized Intraluminal Support Device (LVIS; MicroVention, Tustin, CA, USA), LEO (Balt, Montmorency, France), and Neuroform EZ (Stryker Neurovascular, Fremont, CA, USA) stents were employed. For remodeling cases, the Scepter XC balloon (MicroVention, Tustin, CA, USA) was employed.

In cases of complex anatomy of the carotid siphon and difficult catheterization of the aneurysm sac, reshaping of the microcatheter was performed. In cases of unruptured aneurysms, the size and length of the coil were chosen based on the maximum diameter of the aneurysm. For ruptured aneurysms, the coil was 1 mm undersized based on the maximum diameter. The mean number of coils per aneurysm was determined according to the size of the aneurysm.

Statistical analysis

Categorical variables were expressed as percentages whereas continuous variables as mean ± standard deviation. Differences among groups were obtained by *t*-test and Chi-square if variables were continuous or categorical, respectively. $P < 0.05$ was defined as statistically significant. The statistical software Stata v14.0 (StataCorp, Texas, USA) was used for analysis.

RESULTS

Baseline characteristics of the patients

Thirty-three patients harboring 33 aneurysms were analyzed. The mean age was 57.6 ± 12.4 years (27–81 years). Women represented 85% of the patients. At admission, patients with unruptured aneurysms presented a good preoperative mRS, except one patient with a pre-existing neurological deficit. Four patients (12%) with ruptured aneurysms showed a poor functional status, with a median Hunt-Hess of 2 (1–4). Three recanalized aneurysms were treated (9%), in which conventional coils were used. Overall, a good preoperative mRS was found in 28 patients (85%) and five patients presented a poor functional preoperative status. Detailed patient information is shown in [Table 1].

Angiographic characteristics

Large aneurysms (>12 mm) represented 46% of the study cohort. Paraclinoid aneurysms were found in 18 cases (55%) followed by posterior communicating artery aneurysms in 10 cases (30%). Using Barami classification for paraclinoid aneurysms, the most frequent aneurysm was type 1A in 33% of the cases, followed by type 1B and type 3A, representing 28% and 17% of the cases, respectively. Sixteen aneurysms (49%) were ruptured. Saccular aneurysms were found in 21 cases (64%), followed by dysplastic aneurysms (36%). Only one aneurysm was located in the posterior circulation (ruptured basilar tip aneurysm). Overall, blebs were found in 40% of the aneurysms and in 69% of the ruptured cases. Differences among ruptured and unruptured aneurysms are shown in [Table 2].

The mean aneurysm length was 14.2 mm ± 5.7 mm (7–26.8) and the mean width of the aneurysm sac was 11.9 mm ± 4.97 mm (3.1–22.5). The mean neck diameter was 5.4 mm. A neck diameter >4 mm was found in 25 aneurysms (76%). The mean dome-neck ratio was 2.4. Wide-neck aneurysms were found in 13 cases (39%) and most of them were between 7 mm and 12 mm (92%). The right-sided aneurysms were found in 63% of the cases. Differences among dome-neck ratios are shown in [Table 3].

Endovascular treatment

Intracranial navigation of the PX Slim microcatheter was successful in 100% of the cases, achieving the catheterization of the aneurysm sac. Coiling alone was performed in 15 cases (46%) followed by SAC in 14 cases (42%). Five of 14 SAC cases were done following coil protrusion or migration. Remodeling was employed in 4 cases (12%). Coiling was used in 46% of the ruptured cases, whereas SAC was used in 53% of unruptured cases. Three recanalized aneurysms were treated with stenting. Endovascular treatment with coil assistance was performed in 55% of the cases. The mean number of coils per aneurysm was 4.8, with a slight difference among wide necked (3.9 coils/aneurysm) and the rest (5.3 coils/aneurysm) which was not significant ($P = 0.233$). In five cases (9, 25, 28, 30, and 31), conventional coils were used to improve the occlusion. Two representative cases are shown in [Figures 1 and 2].

Intraoperative complications

Coil protrusion occurred in 5 cases (16%) which required stent placement to avoid parent artery occlusion. In one of these five patients, despite stenting, internal carotid artery thrombosis occurred without clinical consequences due to a patent anterior communicating artery. Coil migration occurred in one patient who required stent placement, without clinical consequences. One patient developed a middle cerebral artery thrombosis which was treated with mechanical thrombectomy with the Solitaire stent retriever (ev3) with an uneventful clinical evolution. Taking into consideration the two thrombotic events, the complication rate was 6% and mortality rate was 0%.

Clinical outcomes

At discharge, a good postoperative mRS was achieved in 29 patients (88%). Thirteen cases were ruptured aneurysms (45%). Three out of the four patients with poor outcome were ruptured. At follow-up, 26 patients were evaluated with 96% of good clinical outcomes.

Immediate and follow-up occlusion rates

Immediate mRROC Grades 1, 2, and 3A were achieved in 15%, 21%, and 64% of the cases, respectively. No case of a Grade 3B occlusion was observed. Overall, an immediate adequate obliteration was achieved in 36% of cases, including the three recanalized aneurysms. Twenty-six patients were evaluated with a mean follow-up period of 11.1 months (4.9–22.8). The most of the aneurysms (65%) were between 7 mm and 12 mm. An occlusion Grades 1, 2, and 3B were achieved in 58%, 35%, and 7% of the cases, respectively. Only one

Table 1: Baseline characteristics of patients treated with Penumbra coils 400.

Case	Age/sex	Status	Location	Side	Barami	Morphology	Bleb	Length	Width	Neck	D/N ratio	Coils	Technique	Complications	Imm RR	Preop mRS	Preop HH	Postop mRS	FU RR
1	39/F	UR	Paraclinoid	R	1A	Saccular	No	21.6	17.3	4.26	4.06	7	Coils	None	1	0	–	0	1
2	49/M	R	Paraclinoid	L	1B	Saccular	No	11.43	15.04	9.78	1.54	7	SAC*	None	3A	0	1	0	1
3	49/F	UR	PCom	R	–	Saccular	Yes	5.99	3.09	4.02	0.77	2	Coils	None	3A	0	–	0	2
4	27/F	R	PCom	R	–	Dysplastic	Yes	14.72	8.32	2.04	4.08	7	Coils	None	2	4	4	1	1
5	50/M	R	MCA	R	–	Dysplastic	Yes	12.76	15.83	5.16	3.07	3	Coils	None	3A	4	4	3	1
6	81/F	R	PCom	R	–	Saccular	No	11.68	9.14	5.46	1.67	4	BAC	None	2	0	1	0	2
7	64/F	UR	Paraclinoid	L	4	Dysplastic	No	10.92	14.53	6.77	2.15	1	SAC*	Protrusion‡	3A	0	–	0	2
8	68/F	UR	Paraclinoid	L	1A	Saccular	Yes	16.6	14.8	6.1	2.43	3	Coils	None	3A	0	–	0	1
9	59/F	R	Paraclinoid	L	1A	Saccular	No	23.28	17.95	4.7	3.82	10	BAC	None	2	2	3	0	3B
10	47/F	R	Paraclinoid	R	2	Saccular	No	15.25	10.6	4.13	2.57	3	Coils	Thrombus	2	0	1	0	3B
11	68/F	UR	PCom	R	–	Saccular	Yes	11.8	8.02	2.4	3.34	4	Coils	None	3A	0	–	0	1
12	74/F	UR	Paraclinoid	R	4	Saccular	No	10.1	7.9	5.7	1.39	3	Coils	None	3A	0	–	0	1
13	63/F	R	Paraclinoid	R	1A	Saccular	No	18.3	13	6.05	2.15	3	Coils	None	3A	0	1	0	–
14	50/F	R	Paraclinoid	R	3A	Dysplastic	Yes	11.5	7.26	3.51	2.07	3	BAC	None	1	0	2	0	2
15	74/F	R	PCom	R	–	Saccular	Yes	7.68	9.68	7.01	1.38	4	Coils	None	3A	0	2	0	–
16	68/F	UR	Paraclinoid	R	1B	Saccular	No	10.69	18.26	8	2.28	4	Coils	None	1	0	–	0	1
17	36/F	UR	Paraclinoid	L	1B	Saccular	No	7	5.85	4	1.46	2	SAC*	Protrusion‡	3A	0	-	0	1
18	55/F	R	PCom	R	–	Dysplastic	Yes	10.7	6.66	5.85	1.14	3	BAC	None	3A	1	1	0	2
19	45/F	R	PCom	L	–	Dysplastic	Yes	9.4	5	2.9	1.72	2	Coils	None	2	0	2	0	2
20†	54/M	UR	Paraclinoid	R	3A	Saccular	No	14.2	11.7	3.52	3.32	4	SAC*	Protrusion‡	1	0	–	0	1
21	72/F	R	Paraclinoid	L	1A	Saccular	No	10	10.8	5.7	1.89	3	SAC*	Protrusion‡, ICA thrombosis	3A	0	2	0	1
22	55/F	R	PCom	L	–	Saccular	Yes	7.9	9.94	4.39	2.26	3	SAC***	Protrusion‡	3A	0	2		1
23	66/M	R	Basilar tip		–	Dysplastic	Yes	10.14	9.03	7	1.29	3	SAC**	None	3A	0	1	0	1
24†	68/F	UR	PCom	L	–	Saccular	Yes	19.96	11.34	2.34	4.85	5	SAC**	None	2	4	–	3	–
25	54/M	UR	Paraclinoid	R	3A	Dysplastic	No	23.76	19.54	4.61	4.24	10	Coils	None	3A	0	–	0	–
26	48/F	R	MCA	R	–	Dysplastic	Yes	21.81	11.18	5.13	2.18	4	Coils	None	3A	3	3	3	–
27	62/F	UR	Paraclinoid	R	1B	Saccular	No	10.8	8.78	6.08	1.44	3	SAC*	None	3A	0	–	0	1
28	72/F	UR	Paraclinoid	R	1B	Dysplastic	No	26.79	22.52	10.04	2.24	12	SAC*	None	3A	1	–	1	–
29	55/F	UR	Paraclinoid	L	1A	Saccular	No	11.26	8.47	3.82	2.22	5	SAC*	None	3A	0	–	0	1
30	57/F	UR	PCA P1	R	–	Dysplastic	No	25	22	11.4	1.93	13	SAC*	None	3A	0	–	0	1
31†	66/F	R	PCom	L	–	Dysplastic	No	20.53	17.68	3.95	4.48	12	SAC*	None	2	3	2	3	–
32	41/F	UR	Paraclinoid	L	2	Saccular	No	12.3	13.2	4.5	2.93	3	Coils	None	3A	0	–	0	1
33	64/F	UR	ACA A1	R	–	Saccular	No	10	6.5	6.31	1.03	2	SAC*	None	1	0	–	0	1

F: Female, M: Male, PCom: Posterior communicating artery, MCA: Middle cerebral artery, R: Right, L: Left, SAC: Stent-assisted coiling; BAC: Balloon-assisted coiling, D/N ratio: Dome-neck ratio, mRS: Modified Rankin scale, Imm RR: Immediate Raymond–Roy, Preop mRS: Preoperative modified Rankin scale, Preop HH: Preoperative Hunt-Hess classification, Postop mRS: Postoperative modified Rankin scale, FU RR: Follow-up Raymond–Roy, *LVIS **LEO ***Neuroform, ‡Coil protrusion: Stenting, † Recanalized aneurysms treated with PC400

Table 2: Characteristics of ruptured and unruptured intracranial aneurysms treated with Penumbra coils 400.

	Ruptured (*n*=16)	Unruptured (*n*=17)	*P*-value
Age	56.7±13.3	58.4±11.7	0.696
Female (%)	13 (46.4)	15 (53.6)	0.656
Frequent location (%)	PComA (43.8)	Paraclinoid (70.6)	0.127
Type (%)	Dysplastic (62.5)	Saccular (60)	0.373
Presence of bleb (%)	9 (69.2)	4 (30.8)	0.06
Aneurysm length (mm)	13.6±4.9	14.7±6.3	0.574
Aneurysm width (mm)	11.1±3.9	12.6±5.9	0.392
Aneurysm neck (mm)	5.2±1.8	5.5±2.9	0.652
Neck >4 mm (%)	12 (75)	13 (76.5)	0.922
DN ratio <2 (%)	7 (46.2)	6 (53.8)	0.619
Aneurysm ≥12 mm (%)	7 (46.3)	8 (53.3)	0.849
Mean number of coils	4.6	4.9	0.822
Main technique (%)	Coiling (43.8)	SAC (52.9)	0.075
Immediate obliteration rates (%)			0.056
mRROC 1	1 (20)	4 (80)	
mRROC 2	6 (85.7)	1 (14.3)	
mRROC 3A	9 (42.9)	12 (57.1)	
Follow-up obliteration rates (26 patients) (%)	12 (46.2)	14 (53.8)	0.046
mRROC 1	4 (26.7)	11 (73.3)	
mRROC 2	6 (66.7)	3 (33.3)	
mRROC 3B	2 (100)	0	
Mean follow-up (months)	13.5±5.4	9.1±3.2	0.016

mRROC: modified Raymond-Roy occlusion classification, PComA: Posterior communicating artery aneurysm, SAC: Stent-assisted coiling, DN ratio: Dome-neck ratio

Table 3: Differences among the dome-neck ratios.

	Dome-neck ratio <2 (*n*=13)	Dome-neck ratio >2 (*n*=20)	*P*-value
Aneurysm size (%)			0.001
7–12 mm	12 (66.7)	6 (33.3)	
12–25 mm	0	13 (100)	
>25 mm	1 (50)	1 (50)	
Immediate angio (%)			0.422
mRROC 1	1 (20)	4 (80)	
mRROC 2	2 (28.6)	5 (71.4)	
mRROC 3A	10 (47.6)	11 (52.4)	
Follow-up angio (%)			0.361
mRROC 1	7 (46.7)	8 (53.3)	
mRROC 2	5 (55.6)	4 (44.4)	
mRROC 3B	0	2 (100)	
Mean number of coils	3.9	5.3	0.233

mRROC: Modified Raymond–Roy occlusion classification

recanalized aneurysm was followed up (mRROC 1). Overall, an adequate obliteration was achieved in 92% of cases at follow-up. Occlusion rates among aneurysm sizes are shown in [Table 4]. A comparison between anterior and posterior circulation aneurysms is shown in [Table 5].

DISCUSSION

In our study, endovascular treatment of medium and large aneurysms with PC400 coils was most commonly performed in unruptured and paraclinoid aneurysms. We observed obliteration rates of 92% at mid-term follow-up, a complication rate of 6%, minor technical difficulties during the procedure, and good clinical outcomes. In this cohort, three recanalized aneurysms were successfully treated with PC400 coils in which conventional coils were previously used.

The physical and mechanical properties of different type of coils have been described previously.[18] Complex aneurysms,

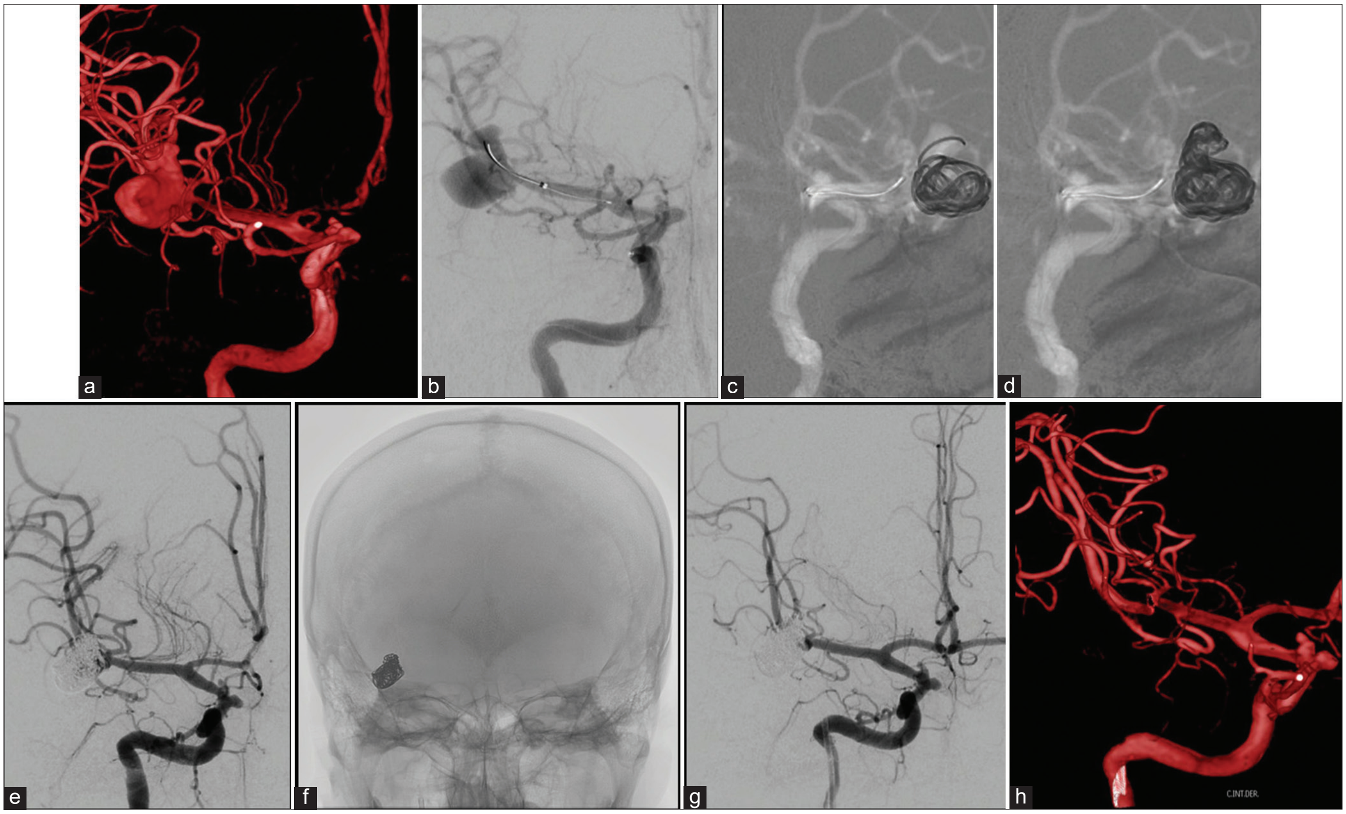

Figure 1: Endovascular treatment of a middle cerebral artery (MCA) aneurysm. (a) Three-dimensional rotational angiography of a right MCA aneurysm. (b) Navigation of PX Slim microcatheter into aneurysms sac. (c-f) Deployment of PC400 into the aneurysm sac and immediate angiographic control shows an adequate obliteration. (g and h) Follow-up angiographic control with 3D reconstruction shows a complete obliteration of the aneurysm (modified Raymond–Roy 1) with patency of distal vessels.

Table 4: Occlusion rates by size

	Aneurysm size (mm)		
	7–12 mm	**12–25 mm**	**>25 mm**
Immediate occlusion (%)*			
mRROC 1	3 (60)	2 (40)	0
mRROC 2	2 (28.6)	5 (71.4)	0
mRROC 3A	13 (61.9)	6 (28.6)	2 (9.5)
Follow-up occlusion (%)**			
mRROC 1	9 (60)	5 (33.3)	1 (6.7)
mRROC 2	8 (88.9)	1 (11.1)	0
mRROC 3B	0	2 (100)	0

mRROC: Modified Raymond–Roy occlusion classification, *33 patients, **total follow-up = 26 patients

such as large and wide-neck aneurysms, remain a challenge for endovascular treatment due to the high recanalization rates ranging from 40% to 70%.[12] For this purpose, new devices have emerged as complementary tools to increase obliteration rates.[1] Mascitelli *et al.* first described the advantages of these large volume coils compared to standard coils with less operative time, fewer coils, and an increased packing density, but without follow-up.[10] In 2015, the same author evaluated 76 aneurysms of which 25% were large and achieved an immediate complete occlusion (RR1) of 13.2%, and a good occlusion rate in 79.5% of the cases at 3-month follow-up.[9] The same benefits of the PC400 were demonstrated in 18 aneurysms, including cost-effectiveness.[11] A case of a giant middle cerebral artery aneurysm treated with SAC with good results was also published.[13] Nevertheless, some authors have recommended to avoid the use of balloons or coils when the PC400 is used.[17]

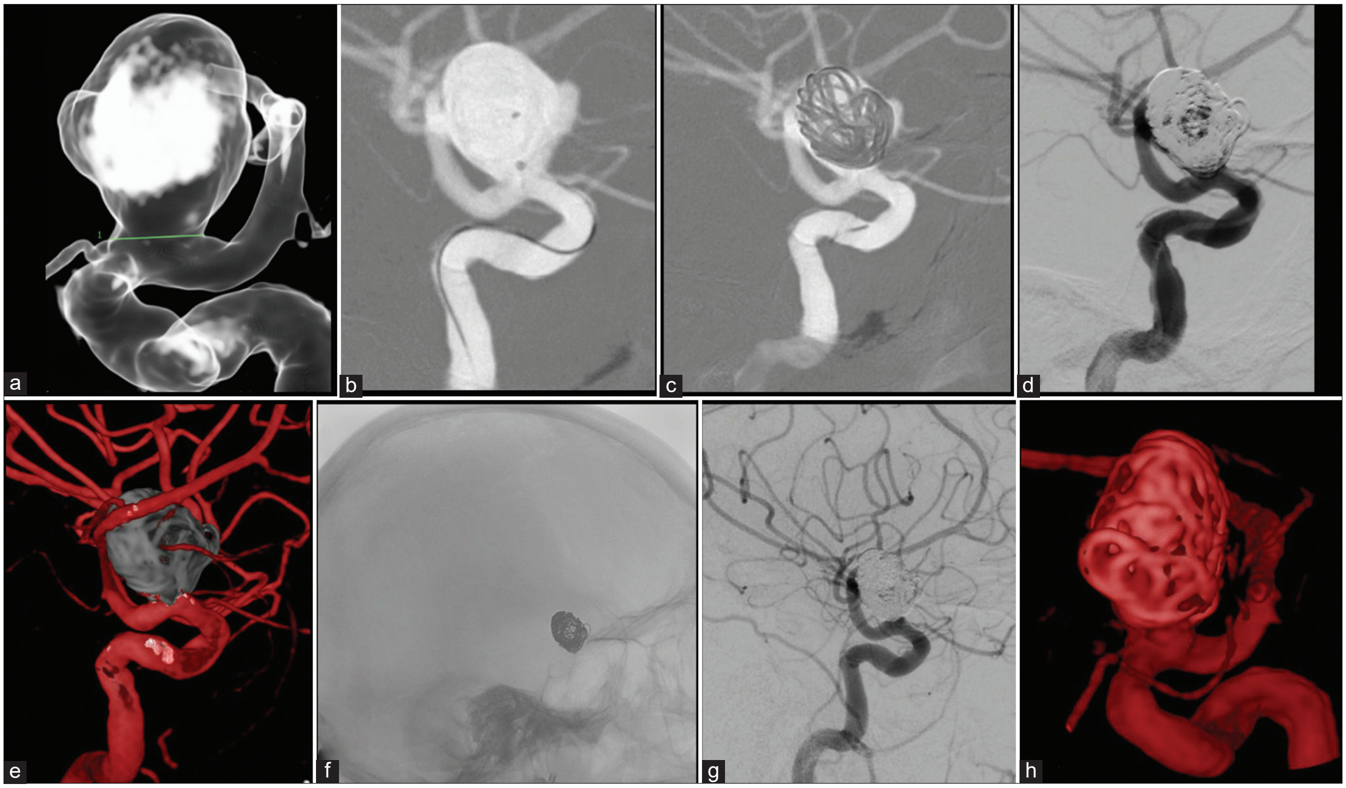

Figure 2: Endovascular treatment of a paraclinoid aneurysm. (a) Three-dimensional rotational angiography of a large paraclinoid aneurysm. (b-f) Navigation of PX Slim microcatheter into aneurysm sac, PC400 deployment within the aneurysm sac, and immediate angiographic control with 3D reconstruction. (g and h) Follow-up angiography with 3D reconstruction shows complete occlusion of the aneurysm (modified Raymond–Roy 1).

Table 5: Comparison of outcomes in anterior versus posterior circulation aneurysms.

	Anterior circulation	Posterior circulation
Postoperative clinical condition (%)		
mRS 0–2	27 (93)	2 (7)
mRS ≥3	4 (100)	0
Immediate occlusion (%)	5 (100)	0
mRROC 1	7 (100)	0
mRROC 2	19 (90)	2 (10)
mRROC 3A		
Follow-up occlusion		
mRROC 1	14 (93)	1 (7)
mRROC 2	8 (89)	1 (11)
mRROC 3B	2 (100)	0

mRS: Modified Rankin scale, mRROC: Modified Raymond–Roy occlusion classification

Because of a relatively high proportion of aneurysms >12 mm (46%), the most reliable parameter to identify a wide-neck aneurysm was a dome-neck ratio <2, which was present in 39% of the aneurysms. Other parameters to asses a wide-neck aneurysm have also been described and can predict the use of adjunctive devices.[4,14] Only one paper described the dome-neck ratio when PC400 coils were used, with a mean of 2,[6] whereas the rest of authors measured the diameter of the aneurysm itself. In this setting, the mean neck diameter in our study was 5.4 mm, which is larger than that of the previously reported studies.[3,6,7,9,11,15,17] In our study, few coils were used for wide-neck aneurysms (3.9/aneurysm) because the most of these cases (67%) sized between 7 mm and 12 mm, whereas more coils (5.3/aneurysm) were used in aneurysms >12 mm which more frequently harbored a dome-neck ratio >2. In addition, we reported a larger mean diameter of the aneurysm sac (length = 14.2 mm and width = 12.1 mm) when compared to the largest mean aneurysm diameter previously reported when PC400 coils were used (10.5 mm).[17] A greater proportion of paraclinoid aneurysms was also treated in our series (55%).

Two studies reported a variable proportion of medium and large aneurysms (100% and 83.8%, respectively) with obliteration rates between 55% and 72.2% at follow-up. Coiling with adjunctive devices was used in 22% and 27% of the cases, respectively.[6,15] A previous paper on large and wide-neck aneurysms showed a complete occlusion in 40.2–82.8% with coiling and 40.5–87.8% with flow diversion, with an overall obliteration using both techniques of 62–75%.[1] Our findings showed a higher obliteration rates when compared with the previous results, and therefore, we encourage the use of large volume coils for medium and large aneurysms. Furthermore, a recent meta-analysis showed no differences in obliteration rates among ruptured (72%) and unruptured (71%) very large and giant aneurysms using reconstructive techniques.[5]

An immediate obliteration was considered adequate (mRROC1 and mRROC2) in 36% of our cases. Differences among ruptured and unruptured aneurysms were not found in this scenario in our cohort. These results are in accordance with the previous reported good obliteration rates (13.2%–94%). The highest immediate obliteration rate reported with PC400 was that of Berge *et al.* with 94% of total immediate occlusion, nevertheless, all the aneurysms were <10 mm.[3] Our immediate occlusion rate revealed a higher proportion of mRROC Grade 3A (64%) in both ruptured and unruptured aneurysms. This finding corresponded to the contrast material that is retained between the coil interstices left inside the aneurysm sac due to the larger volume of the coils.[9] A higher permeability of the PC400 has been described previously in an *in vitro* model of an 8 mm aneurysm when compared to other coils.[16] Only Kaesmacher *et al.* reported an immediate 3A/3B mRROC in 29.7% of cases.[6] Nevertheless, at follow-up, we demonstrate that the proportion of a good obliteration rate increased significantly (24 out of 26 cases: 92%), especially in unruptured aneurysms (100% of the cases). Previously, good obliteration rates at follow-up were between 55% and 91%. In the case of medium and large aneurysms, adequate obliteration rates were between 55% and 72.2%.[6,15] The high occlusion rates at follow-up in our cohort can be attributable to the high proportion of adjunctive devices (55%; balloons and stents) used for the treatment and because 65% of the controlled aneurysms were between 7 mm and 12 mm, making them more suitable to obliterate completely. The highest occlusion rates reported at follow-up were between 85% and 91%.[3,7,17] Our 11-month follow-up period was longer than that of the previously published studies, which were between 7.4 months and 8.6 months.[7,11] We did not report any coil compaction nor recurrence in our cohort at past follow-up.

Regarding technical complications, Popiela *et al.* reported a failed catheterization due to the stiffness of the PX Slim microcatheter.[15] Despite the PX Slim is a microcatheter with a larger diameter, in our series, no technical difficulties were detected which could affect the navigation and catheterization of the aneurysm sac. On the other hand, our study yielded a higher proportion of coil protrusion into the parent artery (15.6%) which was treated with stenting. This mainly occurred in wide-neck, paraclinoid, and unruptured aneurysms. Nevertheless, only one patient developed an intraoperative thrombosis of the parent artery without clinical consequences. Coil migration and intraoperative thrombosis of the parent artery occurred in one case, respectively. No cases of intraoperative rupture were detected in our cohort. Overall complications occurred in the same proportion in ruptured and unruptured aneurysms without clinical manifestations at follow-up (96% of the patients with a mRS ≤2).

This study has certain limitations: the number of aneurysms treated was small and there was no comparison group with other types of coils to determine statistical differences or associations with the main outcomes. Other types of treatments for these types of aneurysms such as flow diversion were not employed to make comparisons. The rationale to use PC400 was based on the interventionalist decision, with no randomized selection of the cases and according to the aneurysm size, shape, and location. Fluoroscopy times and packing density were not collected in this cohort. Longer follow-up periods are required to determine long-term occlusion rates when large volume coils are used in this group of aneurysms. The study was retrospective and further prospective studies must be performed when these large volume coils are selected for the treatment.

CONCLUSION

The results of this study showed that the selection of large volume coils for endovascular treatment of medium and large intracranial aneurysms was technically safe – with a low complication rate and good clinical outcomes – and effective, with high obliteration rate at mid-term follow-up. In resource-constrained settings, PC400 coils offer a safe and effective endovascular alternative for medium and large intracranial aneurysms. Further studies including long-term follow-up are needed to demonstrate the good obliteration rates shown at mid-term follow-up in this study.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Agnoletto GJ, Meyers PM, Coon A, Kan PT, Wakhloo AK, Hanel RA. A contemporary review of endovascular treatment

of wide-neck large and giant aneurysms. World Neurosurg 2019;130:523-529.e2.
2. Barami K, Hernandez VS, Diaz FG, Guthikonda M. Paraclinoid carotid aneurysms: Surgical management, complications, and outcome based on a new classification scheme. Skull Base 2003;13:31-41.
3. Berge J, Gariel F, Marnat G, Dousset V. PC400 volumetric coils minimize radiation, reduce procedure time and optimize packing density during endovascular treatment in medium sized cerebral aneurysms. J Neuroradiol 2016;43:37-42.
4. Brinjikji W, Cloft HJ, Kallmes DF. Difficult aneurysms for endovascular treatment: Overwide or undertall? AJNR Am J Neuroradiol 2009;30:1513-7.
5. Cagnazzo F, Mantilla D, Rouchaud A, Brinjikji W, Lefevre PH, Dargazanli C, *et al*. Endovascular treatment of very large and giant intracranial aneurysms: Comparison between reconstructive and deconstructive techniques-a meta-analysis. AJNR Am J Neuroradiol 2018;39:852-8.
6. Kaesmacher J, Müller-Leisse C, Huber T, Boeckh-Behrens T, Haller B, Shiban E, *et al*. Volume versus standard coils in the treatment of intracranial aneurysms. J Neurointerv Surg 2016;8:1034-1040.
7. Kulcsár Z, Wanke I, Rüfenacht D, Wetzel SG, Göricke S, Kolia K, *et al*. Safety and effectiveness of large volume coils in the treatment of small aneurysms. J Neurointerv Surg 2016;8:1260-3.
8. Laurent P, Wakhloo AK. Endovascular treatment of intracranial aneurysms current status. Stroke 2013;44:2046-54.
9. Mascitelli JR, Patel AB, Polykarpou MF, Patel AA, Moyle H. Analysis of early angiographic outcome using unique large diameter coils in comparison with standard coils in the embolization of cerebral aneurysms: A retrospective review. J Neurointerv Surg 2015;7:126-30.
10. Mascitelli JR, Polykarpou MF, Patel AA, Kamath AA, Moyle H, Patel AB. Initial experience with Penumbra Coil 400 versus standard coils in embolization of cerebral aneurysms: A retrospective review. J Neurointerv Surg 2013;5:573-6.
11. Milburn J, Pansara AL, Vidal G, Martinez RC. Initial experience using the Penumbra coil 400: Comparison of aneurysm packing, cost effectiveness, and coil efficiency. J Neurointerv Surg 2014;6:121-4.
12. Murayama Y, Nien YL, Duckwiler G, Gobin YP, Jahan R, Frazee J, *et al*. Guglielmi Detachable Coil embolization of cerebral aneurysms: 11 years' experience. J Neurosurg 2003;98:959-66.
13. Ordónez-Rubiano EG, Von-Diemling C, Cortes-Lozano W, Lobelo-Garcia NO. Stent-assisted embolization of a giant aneurysm of the middle cerebral artery using small and large coils (penumbra coil 400). Cureus 2016;8:e762-2.
14. Park HS, Kwon SC, Park ES, Park JB, Kim MS. A new definition for wide-necked cerebral aneurysms. J Cerebrovasc Endovasc Neurosurg 2019;21:193-8.
15. Popiela TJ, Brzegowy P, Łasocha B, Urbanik A. The effectiveness of Penumbra 400 micro-coils in the embolization of large cerebral aneurysms. Neurol Neurochir Pol 2017;51:304-10.
16. Sadasivan C, Swartwout E, Kappel AD, Woo HH, Fiorella DJ, Lieber BB. *In vitro* measurement of the permeability of endovascular coils deployed in cerebral aneurysms. J Neurointerv Surg 2018;10:896-900.
17. Villwock MR, Singla A, Padalino DJ, Deshaies EM. The penumbra coil 400 system for treatment of wide-necked intracranial aneurysms: Initial single-center experience. Acta Neurochir Suppl 2015;191-195.
18. White JB, Ken CG, Cloft HJ, Kallmes DF. Coils in a nutshell: A review of coil physical properties. AJNR Am J Neuroradiol 2008;29:1242-6.

How to cite this article: Saal-Zapata G, Ghodke B, Walker M, Pregúntegui-Loayza I, Rodríguez-Varela R. Endovascular treatment of medium and large intracranial aneurysms with large volume coils: A single-center experience. Surg Neurol Int 2022;13:9.