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The Evaluation of Low-Profile Surpass Evolve Flow Diverter for Endovascular Treatment of Distal Cerebral Artery Aneurysms: A Single-Center Experience

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ABSTRACT

AIM: We report our experience with the 2.5-mm Surpass Evolve flow diverter (FD) in the treatment of distal small artery aneurysms.

MATERIAL and METHODS: This study included 41 patients with 52 aneurysms. Clinical and radiological records and procedural and follow-up outcomes were reviewed retrospectively.

RESULTS: The aneurysm morphology was saccular in 45 patients, dissecting in five patients, and fusiform in two patients. Fifty-two aneurysms were treated with 41 Surpass Evolve FDs. The mean diameters of the proximal and distal parent arteries were 2.56 and 2.17 mm, respectively. The mean duration of follow-up was 16.2 ± 6.6 (6–28) months. Four (10%) patients had acute subarachnoid hemorrhage. In the same session, two patients with two tandem aneurysms and one patient with four tandem aneurysms were treated using a single FD. Intraprocedural hemorrhage and femoral artery pseudoaneurysm occurred in two patients during the procedure. Digital subtraction angiography was performed on 38/41 (92%) patients with 47/52 (88%) having aneurysms. Complete occlusion (OKM D) was observed in 39/47 (82%) aneurysms, and near complete–complete occlusion (OKM C-D) was observed in 46/47 (98%) aneurysms.

CONCLUSION: Endovascular treatment of distal cerebral aneurysms with the 2.5-mm Surpass Evolve FD provides a high rate of aneurysm occlusion with low periprocedural complications, even in ruptured and tandem aneurysms.

KEYWORDS: Flow diverter, Low-profile, Small artery aneurysm, Surpass evolve

ABBREVIATIONS: ACA: Anterior cerebral artery, **aSAH:** Acute subarachnoid hemorrhage, **DACA:** Distal anterior cerebral artery, **DSA:** Digital subtraction angiography, **FD:** Flow diverter, **ICA:** Internal carotid artery, **MCA:** Middle cerebral artery, **MRA:** Magnetic resonance angiography, **mRS:** Modified Rankin Scale, **OKM:** O'Kelly–Marotta grading scale, **PCA:** Posterior cerebral artery, **SCA:** superior cerebral artery

INTRODUCTION

Endovascular treatment with a flow diverter (FD) is appropriate for wide-necked, giant, fusiform, dissecting, blister-like, uncoilable aneurysms or previously treated but failed aneurysms (4,9,16). Due to decreased flow into the aneurysm, the FD redirects blood flow toward the parent artery lumen, causing aneurysm sac thrombosis (10,11,21). Large aneurysms in the proximal ICA between the petrous and ophthalmic segments were selected for treatment with FD in

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the first applications (3,5,8,12,18). The Surpass Intracranial Aneurysm Embolization System Pivotal Trial (SCENT TRİAL) is a prospective, nonrandomized clinical trial that included 26 centers and 180 patients with large or giant wide neck aneurysms (15). In the SCENT trial, 85% of aneurysms were found in the proximal internal carotid artery segments, which included the ophthalmic, posterior communicating, and anterior choroidal artery segments with large and giant aneurysms.

The use of FDs in endovascular treatments for peripherally located small vessels and bifurcation aneurysms has recently increased (11,26). A2 anterior cerebral artery (ACA), M2 middle cerebral artery (MCA), P2 posterior cerebral artery (PCA), s2 superior cerebellar artery (SCA), a2 anterior inferior cerebellar artery (AICA), and p2 posterior inferior cerebellar artery (PICA) segments are located beyond the circle of Willis (24). Low-profile FD is a newer device that is used to treat aneurysms in small cerebral arteries beyond the Willis circle.

Surpass Evolve (Stryker Neurovascular, Kalamazoo, MI) is a second-generation FD that was released in March 2019. It is advantageous in the treatment of distal aneurysms because low-profile sizes are available. In this single-center retrospective study, we evaluated long-term safety and efficacy in ruptured and unruptured aneurysms located beyond the Willis circle treated with 2.5-mm-diameter Surpass Evolve. We compared our results with other low-profile FD stent series with similar sizes of small vessel aneurysms that had been published.

MATERIAL and METHODS

Study Design and Data Collection

Forty-one patients with 52 aneurysms who were treated by a single neurointerventional team using 2.5-mm-diameter Surpass Evolve between October 2019 and February 2022 were retrospectively evaluated. Written informed consent was obtained, implying that their medical records and images could be used for future research. This study was approved by the ethics committee in our hospital (E1-21-1456). The study included anterior and posterior circulation aneurysms located beyond the Willis circle. Data on patient demographics, clinical status, aneurysm morphology (location, size, shape, and ruptured or unruptured), periprocedural details, and clinical and angiographic follow-up outcomes were collected from the hospital database. Aneurysms were classified as small (<10 mm), large (10–25 mm), giant (>25 mm), wide-necked (>4 mm), saccular, fusiform, and dissecting as described in the SCENT trial (15). Complications were classified as intraprocedural, early periprocedural (within 30 days), and late periprocedural (after 30 days). Neurological complications were classified as minor or major neurological deficits. Follow-up imaging was obtained with digital subtraction angiography (DSA) and magnetic resonance angiography (MRA). The O'Kelly–Marotta (OKM) scale was used to define the degree of angiographic filling and contrast stasis in the aneurysm lumen (19).

Antiplatelet Regimen

All patients were treated with a loading dose of clopidogrel (300–450 mg) or prasugrel (30–60 mg), depending on their weight. Prasugrel was administered twice daily 2 days before the procedure to patients who were resistant to clopidogrel according to VerifyNow testing. Because of the acute settings for ruptured aneurysms, prasugrel loading doses were initiated just before the procedure. Systemic heparinization (80 IU/kg) was administered before the procedure. A 25-mcg/kg intravenous (i.v.) tirofiban infusion was administered perioperatively and discontinued within 24 h in patients at high risk of thromboembolic events. For all patients, DAPT was maintained for the first 6 months and 75-mg clopidogrel or 10-mg prasugrel daily with 100-mg ASA. The antiplatelet regimen was continued with ASA.

Device Description

Surpass Evolve is a new-generation FD of Surpass with improved mesh density, radial force, and deliverability. It is built on the previous Surpass Streamline architecture (Stryker Neurovascular, Kalamazoo, MI). The number of wires of Surpass Evolve has been reduced, but its braided angle and tractability have been improved. Surpass Evolve has excellent radial force, good wall apposition with lower foreshortening, and stable deployment. Its unique design helps pushability through the Excelsior XT-27 microcatheter (Stryker Neurovascular, Kalamazoo, MI).

Surpass Evolve is available in diameters ranging from 2.5 to 5.0 mm and lengths ranging from 12 to 40 mm. The first 64-wired Surpass Evolve FD allows for faster aneurysm occlusion. Surpass Evolve with 3.25-, 4.0-, 4.5-, and 5.0-mm diameters are made of 52 cobalt–chromium wires and 12 platinum–tungsten wires integrated into the mesh to improve visibility (25). A 2.5-mm diameter Surpass Evolve consists of 48 wires with a length of 12–20 mm.

Endovascular Procedure

Treatment decision was taken jointly by two neurosurgeons and two interventional neuroradiologists with more than a decade of endovascular experience. The procedure and stent size were planned after a detailed examination of the arterial anatomy and the aneurysm characteristics with 2D and 3D rotational angiograms. All procedures were performed under general anesthesia via a transfemoral arterial approach. A 6-Fr-long introducer sheath was first inserted into the internal carotid artery or vertebral artery. The target arterial segment was then catheterized using a distal access catheter (DAC) 0.44 (Stryker, Concentric Medical, Mountain View, CA), 0.027″ microcatheter (Excelsior XT-27, Stryker Inc.), and a Synchro 0.014″ microguidewire (Stryker Neurovascular, Fremont, CA). Surpass Evolve was inserted into the parent artery to cover the aneurysm neck. An additional device was used if necessary. Serial angiograms were performed after the Surpass Evolve was implanted to assess parent artery patency and aneurysm stasis. In the case of vasospasm, nimodipine (Nimotop, Bayer, Germany) was administered through a catheter. An arterial closure device was used to achieve femoral hemostasis.

Follow-Up

A 24-h postoperative computer tomography control was

performed to exclude hemorrhagic complications. A modified Rankin Scale (mRS) was used to evaluate clinical follow-up. The mRS ranges from 0 (*no symptoms*) to 6 (*death*). Major procedural complications were defined as procedure-related morbidity with mRS ≥2 or mortality. Radiologic follow-up (DSA or MRA) was performed at 1, 6, and 12 months. All patients were evaluated with MRA. We routinely perform MRA imaging in the first month following surgery to check for asymptomatic ischemic findings. Our clinical policy is to perform proceed a DSA postoperatively at 6–12 months to evaluate the efficacy of the procedure as a gold standard. According to the OKM grading scale, aneurysm occlusion grades were as follows: A = total filling (>95%), B = subtotal filling (5%–95%), C = entry remnant (<5%), and D = no filling (0%). Adequate aneurysm occlusion was defined as OKM C and OKM D. Some patients were only followed with MRA due to their reluctance to DSA. MRA outcomes were classified according to Raymond–Roy Classification (13,23). A joint team of interventional radiologists and neurosurgeons performed radiological follow-ups on these patients. Retreatment was recommended if there was no significant reduction in aneurysm opacification after a 1-yr follow-up. Patients were instructed to stop taking clopidogrel or prasugrel after 6 months and continue taking ASA indefinitely.

RESULTS

Baseline Population and Aneurysm Features

This study included 41 patients with 51 aneurysms. Twenty-three patients had a single aneurysm. Twenty-nine (70.7%) patients were female. The median age was 56.3 yr (range 37–78 yr). The aneurysms were located as follows: 33/52 (63%) in MCA, 12/52 (23%) in ACA, 5/52 (10%) in PCA, and 1/51 (0.2%) in anterior communicating artery. Four patients (nos. 6, 22, 30, and 31) with five aneurysms were previously surgically clipped and had residual filling. Six patients (nos. 7, 9, 10, 13, 28, and 31) had two aneurysms, one patient (no. 15) had three aneurysms, and one patient (no. 34) had four aneurysms.

The morphology of the aneurysms was 45 saccular, five dissecting, and two fusiform. The mean aneurysm neck–width diameter was 2.33 mm (1–4 mm); the dome–height diameter was 2.62 (1–6); and the dome–width diameter was 3.32 (1.5–15.8). The mean diameters of the proximal and distal parent arteries were 2.56 mm (1.5–3.6 mm) and 2.17 mm (1.2–4.7 mm), respectively.

Four patients (nos. 9, 10, 12, and 26) had acute subarachnoid hemorrhage (aSAH). Surpass Evolve was used to treat one MCA aneurysm and three ACA aneurysms that had ruptured. Thirty-seven patients had unruptured aneurysms.

Patient demographics and aneurysm features were summarized in Table I.

Table I: Demographics of Patients and Aneurysms

No	Age	Sex	Presentation	Location	Aneurysm Number	Aneurysm Morphology	SAH
1	73	F	Headache	Left Mca	1	Fusiform	-
2	69	F	Previous Sah (Right Mca)	Left Mca	1	Saccular	-
3	66	F	Headache	Left Mca	1	Saccular	-
4	65	F	Headache	Left Mca	1	Saccular	-
5	50	M	Headache	Right Aca	1	Saccular	-
6	37	F	Residual filling after clipping	Right Aca	1	Saccular	-
7	60	F	Disartria	Right Mca	2	Saccular	-
8	41	F	Headache	Right Mca	1	Saccular	-
9	74	F	Headache	Right Aca	1	Saccular	+
9	74	F	Headache	Left Mca	1	Saccular	-
10	78	F	Headache	Left Mca	1	Dissecting	-
10	78	F	Headache	Left Aca	1	Saccular	+
11	64	F	Headache	Left Mca	1	Saccular	-
12	42	F	Headache	Left Aca	1	Saccular	+
13	64	F	Vision Blurring	Left Mca	1	Saccular	-
13	64	F	Vision Blurring	Left Aca	1	Saccular	-
14	61	F	Headache	Right Aca	1	Saccular	-

Table I: Cont.

No	Age	Sex	Presentation	Location	Aneurysm Number	Aneurysm Morphology	SAH
15	68	F	Incidentally	Left Mca	2	Saccular	-
15	68	F	Incidentally	Right Aca	1	Dissecting	-
16	41	M	Headache	Left Mca	1	Saccular	-
17	45	F	Headache	Left Mca	1	Saccular	-
18	53	F	Vertigo	Right Mca	1	Saccular	-
19	60	M	Headache	Right Pca	1	Fusiform	-
20	66	F	Headache	Left Mca	1	Saccular	-
21	48	M	Headache	Left Aca	1	Saccular	-
22	40	F	Residual filling after clipping	Right Mca	1	Saccular	-
23	61	M	Headache	Left Mca	1	Dissecting	-
24	55	F	Vertigo	Left Mca	1	Saccular	-
25	61	M	Hemiparesis	Right Mca	1	Saccular	-
26	53	M	Headache	Left Mca	1	Saccular	+
27	48	F	Syncope	Left Mca	1	Saccular	-
28	62	M	Headache	Left Mca	1	Saccular	-
28	62	M	Headache	Right Aca (A3)	1	Saccular	-
29	67	M	Headache	Left Aca	1	Saccular	-
30	58	F	Residual filling after clipping	Left Aca	1	Saccular	-
31	45	F	Residual filling after clipping	Right Mca	2	Saccular	-
32	41	F	Vision blurring	Left Mca	1	Saccular	-
33	64	M	Headache	Right Mca	1	Saccular	-
34	57	F	Vertigo	Right Pca	4	Saccular	-
35	62	F	Previous Sah (Right Mca)	Left Mca	1	Saccular	-
36	23	F	Headache	Right Mca	1	Saccular	-
37	64	F	Headache	Right Mca	1	Saccular	-
38	49	F	Headache	Left Mca	1	Dissecting	-
39	54	M	Epistaxis	Acom	1	Saccular	-
40	72	F	Headache	Left Mca	1	Dissecting	-
41	47	F	Previous Sah (Right Mca)	Left Aca	1	Saccular	-

Periprocedural Outcomes and Complications

Except for one patient, the preoperative Glasgow Coma Scale (GCS) score was 15, and the postoperative GCS score was 15. A 2.5-mm-diameter Surpass Evolve was successfully deployed across the aneurysm neck in all procedures, and the technical success rate was 100%. In this study group, no additional devices were used. Preprocedural, procedural, and follow-up angiograms in ACA and MCA aneurysms are shown in Figures 1 and 2. We used a single stent to treat two adjacent aneurysms in patients 7, 15, and 31. Four aneurysms in the right PCA were treated with a single 2.5-mm Surpass Evolve in patient 34 (Figure 3). According to OKM classification, we found significant stasis in 12 aneurysms, moderate stasis in 39 aneurysms, and no stasis in one aneurysm after stent deployment.

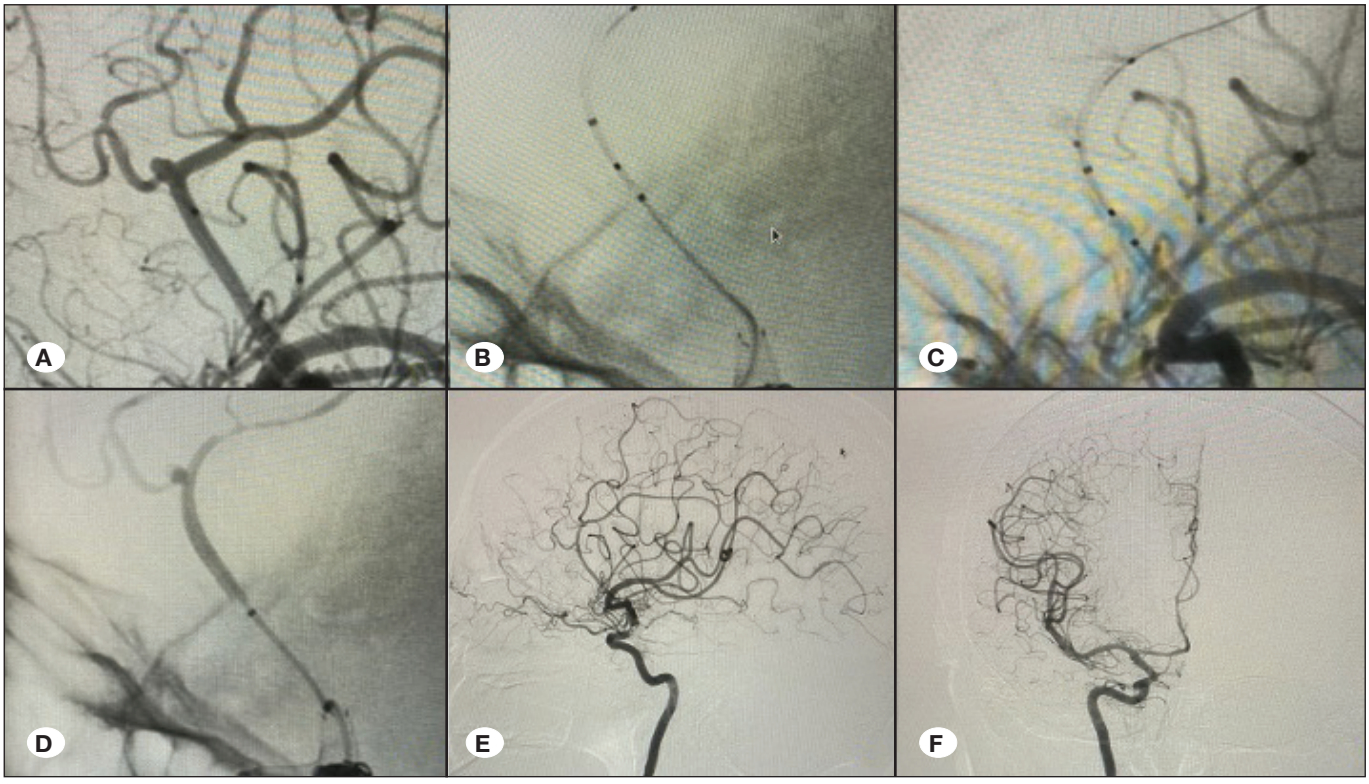

Figure 1: Right A2 and A3 junctional aneurysm: **A)** Preoperative subtraction images; **B-D)** intraoperative images of deploying a 2.5 × 12-mm Surpass Evolve flow diverter to aneurysm neck; **E-F)** FU DSA images revealed total occlusion of aneurysm with OKM grade D.

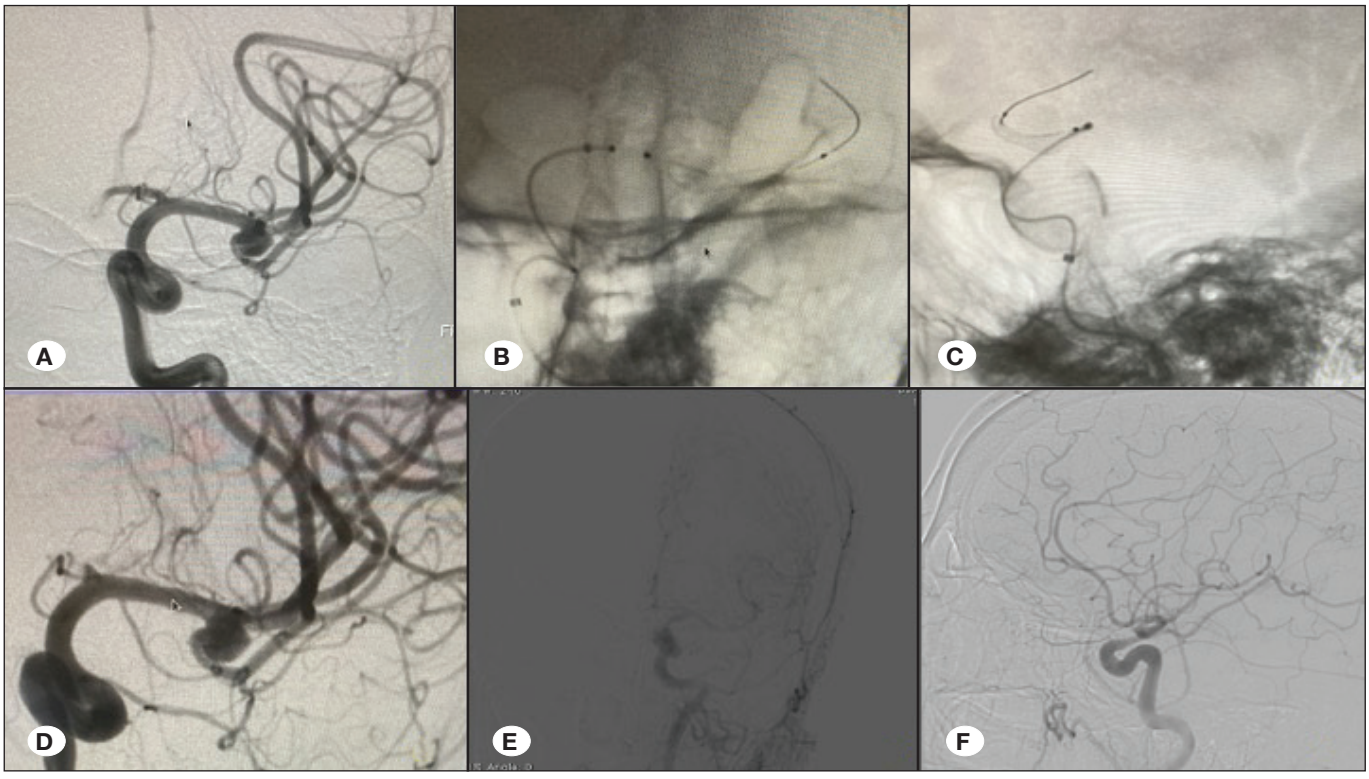

Figure 2: Left middle cerebral artery bifurcation aneurysm: **A)** preoperative subtraction images; **B-D)** intraoperative images of a 2.5 × 12-mm Surpass flow diverter; **E)** FU DSA images revealed total occlusion of aneurysms with OKM grade D.

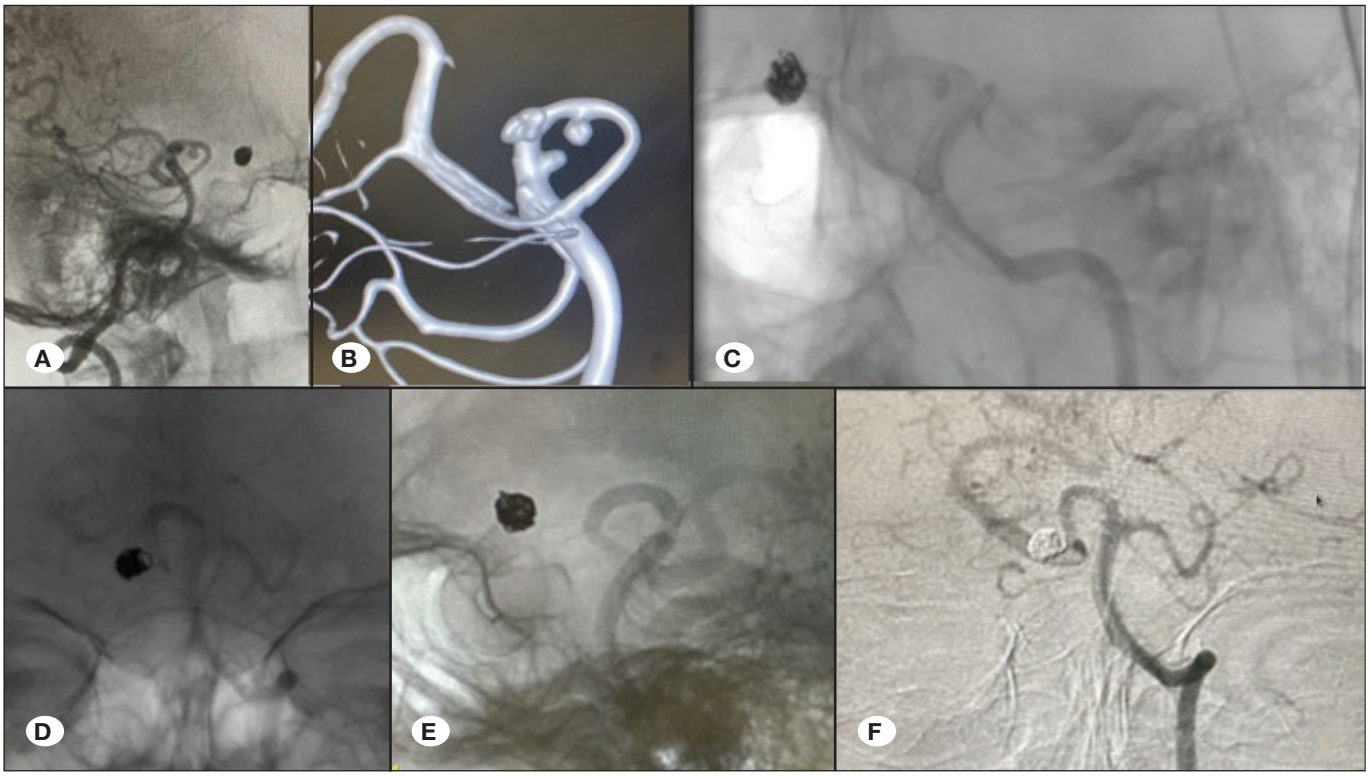

Figure 3: Right posterior cerebral artery tandem aneurysms: **A)** preoperative subtraction images; **B-D)** four PCA aneurysms were treated with a single 2.5 × 20-mm Surpass Evolve flow diverter deployment; **E-F)** FU DSA images revealed total occlusion of aneurysms with OKM grade D.

Two aneurysms in different locations were treated with 2.5-mm Surpass Evolve in separate sessions in five patients (nos. 9, 10, 13, 15, and 28).

In our series, the complication rate was 2/41 (5%). A procedural hemorrhage occurred in patient 15 with an ACA aneurysm. This patient's postoperative GCS was 7. There were no further interventions planned. She was discharged from the hospital with mRS 4 after receiving supportive treatment. We observed a pseudoaneurysm in the femoral artery in patient 24 due to the vascular intervention. She was treated with a thrombin injection into the pseudoaneurysm.

Procedural details and complications were summarized in Table II.

Clinical and Radiological Follow-Up Outcomes

The study's mean follow-up time was 16.2 ± 6.6 (6–28) months. Forty patients with mRS 0 were followed up. There were no minor or major neurological deficits observed postoperatively. Patient 15 was discharged with mRS 4 after perioperatively developing an intracranial hematoma. At 6-month control, a follow-up MRA revealed minimal neck filling. The patient died 16 months after surgery due to clinical deterioration and infectious complications.

DSA imaging was performed on 37/41 (90%) patients with 46/52 (88%) having aneurysms. On follow-up angiograms, complete occlusion (OKM D) was observed in 38/46 (82%) of the aneurysms, and near complete occlusion (OKM C) was observed in 7/46 (15%). Near complete–complete occlusion (OKM C and D) was found in 45/46 (98%) of the aneurysms. We found subtotal filling (OKM B) in one patient with a dissecting aneurysm at the third and sixth postoperative follow-up.

Five aneurysms (patients 10, 15, 32, 40, and 41) had only MRA. No residual filling or in-stent stenosis was found in the follow-up MRAs of these patients.

Angiographic and clinical follow-up outcomes were summarized in Table III.

DISCUSSION

The Surpass Evolve (Stryker Neurovascular, Kalamazoo, MI) is a self-expandable FD that was recently introduced. The increased mesh density (pores per mm^2) and braid angle improve trackability and navigability even in highly tortuous vessels. Surpass Evolve FD research on efficacy and safety is limited (14,20,22,25). A recent in vitro study comparing intra-geometry flow diverting parameters of Evolve and Pipeline FDs found Evolve to be superior (25).

Peripheral small vessel aneurysms with a diameter of <3 mm have recently been treated with low-profile FDs thanks to innovative endovascular technology (6,8,21,26). However, cases reporting the efficacy and safety of 2.5-mm-diameter Surpass Evolve in peripheral intracerebral arteries are rare. In a recent study, Orru et al. summarized their experience in 25 patients with Surpass Evolve FD, and none of the stents

Table II: Procedural Details and Complications

No	Neck width	Dome width	Dome height	Distal PA	Proximal PA	Stent size	Preop/Postop OKM	Complication
1	2	2	2	1.45	2.1	2.5 x 20	A1/C1	-
2	2.5	3	2.5	2.2	2.3	2.5 x 12	A1/B1	-
3	2.5	3	3	2.5	2.6	2.5 x 15	A1/C1	-
4	2	3	2	2.3	3	2.5 x 15	A1/C1	-
5	2	3	2.5	2.3	2.6	2.5 x 12	A1/C1	-
6	4	7	5	2	2.5	2.5 x 20	A1/B1	
7	3.5	4	3	1.8	2.1	2.5 x 15	A1/C1	-
8	3	4	3	1.7	2,2	2.5 x 12	A1/B1	-
9	2	3	2	1.5	1.7	2.5 x 12	A1/C1	-
9	3	4	3	1.2	1.5	2.5 x 15	A1/B1	-
10	2	2	2.5	2.3	2.3	2.5 x 12	A1/B1	-
10	2	4	3	1.7	1.7	2.5 x 15	-	-
11	3	6	3	2.5	2.8	2.5 x 15	A1/A2	-
12	2	3	2.5	2	2.2	2.5 x 12	A1/B1	-
13	1	2	2	2.4	2.5	2.5 x 12	A1/C1	-
13	2	3	3	2	2.1	2.5 x 15	A1/B1	-
14	2.5	3	3	2.2	2.2	2.5 x 12	A1/C1	-
15	1	2	1	1.2	1.4	2.5 x 15	A1/A2	-
15	N/A	3	2	2.2	2.3	2.5 x 12	-	intraprocedural hemorrhage
16	1	2	2	2.1	2.2	2.5 x 12	A1/C1	-
17	3.5	3	3.5	2.3	2.4	2.5 x 15	A1/C1	-
18	1	2	2	2.5	2.7	2.5 x 15	A1/C1	-
19	4	5	3	2.4	2.6	2.5 x 15	A1/C1	-
20	2	2.5	2	2.3	2.4	2.5 x 12	A1/C1	-
21	1.5	2.5	1.5	2.1	2.2	2.5 x 12	A1/C1	-
22	2	2.5	2.5	1.9	2	2.5 x 12	A1/C1	-
23	N/A	4	3	2.7	2.9	2.5 x 15	A1/B1	-
24	3	5	4	2.4	2.7	2.5 x 15	A1/B1	SFA pseudoaneurysm
25	3	3	3	2.6	2.6	2.5 x 15	A1/B1	-
26	2	2	2	2.2	2.5	2.5 x 15	A1/C1	-
27	1	1.5	1.5	2.4	2.5	2.5 x 15	A1/B1	-
28	3.5	3	1.2	1.5	2.4	2.5 x 15	A1/C1	-
28	3	3	1.5	1.5	2.4	2.5 x 15	A1/C1	-
29	2.3	2.4	2	2.5	2.7	2.5 x 12	A1/B1	-
30	2	2	2	1.8	2.2	2.5 x 15	A1/A2	-

Table II: Cont.

No	Neck width	Dome width	Dome height	Distal PA	Proximal PA	Stent size	Preop/Postop OKM	Complication
31	2	2.5	2	1.9	2.2	2.5 x 12	A1/C1	-
32	2.3	2	2.8	2.9	3.6	2.5 x 12	-	-
33	2.7	3.7	3.6	1.9	2.7	2.5 x 15	A1/B1	-
34	1.8	3.1	3.5	2.1	3.3	2.5 x 20	A1/B1	-
34	2	3.5	3.1	2.1	3.3	2.5 x 20	A1/B1	-
34	1.1	2.5	2.4	2.1	3.3	2.5 x 20	A1/B1	-
34	2	1.8	2.6	2.1	3.3	2.5 x 20	A1/B1	-
35	3.2	7.7	5.6	4.7	5	2.5 x 12	A1/B1	-
36	2.2	2.5	1.9	3.1	3.3	2.5 x 15	A1/B1	-
37	2.5	2.1	2.2	2	2.4	2.5 x 15	A1/C1	-
38	1.6	2.2	2.4	2.4	2.7	2.5 x 12	A1/B1	-
39	1.6	1.9	1.3	1.9	2.6	2.5 x 15	A1/B1	-
40	N/A	15.8	6	2.7	3.2	2.5 x 20	-	-
41	1.5	2.3	2.3	1.8	3.1	2.5 x 12	-	-

Table III: Radiologic and Clinical Follow-Up Outcomes

Patient No	Location	OKM FU (6-12 months)	RROC (MRA)	1/6/12-month mRS	Follow-up /month
1	Left Mca	D	complete occlusion	0/0/0	27
2	Left Mca	D	complete occlusion	0/0/0	28
3	Left Mca	D	complete occlusion	0/0/0	28
4	Left Mca	D	complete occlusion	0/0/0	28
5	Right Aca	D	complete occlusion	0/0/0	23
6	Right Aca	D	complete occlusion	0/0/0	23
7	Right Mca	D (2 aneurysms)	complete occlusion	0/0/0	23
8	Right Mca	D	complete occlusion	0/0/0	24
9	Right Aca	D	complete occlusion	0/0/0	24
9	Left Mca	D	complete occlusion	0/0/0	20
10	Left Mca	D	complete occlusion	0/0/0	24
10	Left Aca	-	complete occlusion	0/0/0	23
11	Left Mca	C	complete occlusion	0/0/0	23
12	Left Aca	D	complete occlusion	0/0/0	20
13	Left Mca	D	complete occlusion	0/0/0	20
13	Left Aca	D	complete occlusion	0/0/0	19
14	Right Aca	D	complete occlusion	0/0/0	19
15	Left Mca	C (2 aneurysms)	2	0/0/0	19

Table III: Cont.

Patient No	Location	OKM FU (6-12 months)	RROC (MRA)	1/6/12-month mRS	Follow-up /month
15	Right Aca	-	2	4/4/6	16
16	Left Mca	D	complete occlusion	0/0/0	21
17	Left Mca	D	complete occlusion	0/0/0	19
18	Right Mca	D	complete occlusion	0/0/0	17
19	Right Pca	D	complete occlusion	0/0/0	15
20	Left Mca	D	complete occlusion	0/0/0	15
21	Left Aca	D	complete occlusion	0/0/0	15
22	Right Mca	D	complete occlusion	0/0/0	14
23	Left Mca	D	complete occlusion	0/0/0	14
24	Left Mca	D	complete occlusion	0/0/0	14
25	Right Mca	D	complete occlusion	0/0/0	12
26	Left Mca	D	complete occlusion	0/0/0	12
27	Left Mca	D	complete occlusion	0/0/0	12
28	Left Mca	C	complete occlusion	0/0/0	11
28	Right Aca (A3)	C	complete occlusion	0/0/0	11
29	Left Aca	D	complete occlusion	0/0/0	10
30	Left Aca	C	2	0/0/0	10
31	Right Mca	D (2 aneurysms)	complete occlusion	0/0/0	10
32	Left Mca	-	complete occlusion	0/0/0	10
33	Right Mca	C	complete occlusion	0/0/0	11
34	Right Pca	D (4 aneurysms)	complete occlusion	0/0/0	10
35	Left Mca	D	complete occlusion	0/0	9
36	Right Mca	C	2	0/0	8
37	Right Mca	D	complete occlusion	0/0	8
38	Left Mca	B1	2/1	0/0	7
39	Acom	D	complete occlusion	0/0/-	7
40	Left Mca	-	complete occlusion	0/0/-	6
41	Left Aca	-	complete occlusion	0/0/-	6

OKM: *O'Kelly moratta grading,* ***FU:*** *Follow-up,* ***RROC:*** *Raymond-roy classification.*

in their series were 2.5 mm in diameter (20). Surpass Evolve 2.5 × 12 mm was used in only one elective patient out of 29 and 42 patients in the other two series in the literature (14,22). Therefore, well-conducted studies on the use of low-profile FDs of ruptured and electively treated small artery aneurysms are still needed.

To the best of our knowledge, our study is the largest report demonstrating the efficacy and safety of 2.5-mm Surpass Evolve beyond the Willis circle, involving 41 patients with 52 aneurysms treated with 2.5-mm Surpass Evolve FD. We encountered no technical difficulties during the periprocedural period.

Complications of endovascular FD treatment are ischemic stroke, intraoperative rupture, stent thrombosis, stent restenosis, delayed aneurysm rupture, and intraparenchymal hemorrhage. Endovascular access to the distal circulation is tech-

nically challenging, and the risk of thromboembolic events and dissection is increased. Yao et al. reported the procedure-related neurologic mortality, neurologic morbidity, and ischemic complication rates of 0.87% (0.29–1.74%), 5.22% (3.62–7.1%), and 2.35% (1.31–3.68%), respectively, in a meta-analysis of 10 observational studies in distal intracranial artery aneurysms treated with Silk and Pipeline (29). Möhlenbruch et al. reported 47 FRED Jr-treated aneurysms with a 7% complication rate and a 2% mortality rate (17). Rautio et al. and Sivasankar et al. reported no periprocedural complications and mortality in 15 unruptured aneurysms treated with FRED Jr (22,28). Jesser et al. reported periprocedural, technical, and intra-stent thrombosis rates of 16%, 3%, and 7%, respectively, in 159 aneurysms treated with FRED Jr (11). Orru et al. reported minor transient neurological deficits in 20% of patients in their Surpass Evolve series (20).

In our series, we had an acceptable complication rate of 2/41 (4.8%), which was comparable with the relevant reports. There was no major or minor stroke, intra-stent thrombosis, arterial dissection, arterial occlusion, or stent shortening. Only one patient had a vascular access complication (femoral artery pseudoaneurysm). Another patient (2.4%) experienced intraoperative aneurysm rupture and intracranial hematoma. The intracerebral hemorrhage rate was reported to be 1.42% (0.64%–2.49%) within the Pipeline and Silk series (6). Complications, such as hemorrhage and thromboembolic events, are more common in treating ruptured aneurysms. There are few periprocedural outcomes in the literature for acute ruptured small artery aneurysms treated with low-profile FD. There was no case of a ruptured distal aneurysm treated with the 2.5-mm-diameter Surpass Evolve. In the Surpass Evolve series of 29 patients reported by Rautio et al., larger sizes of Surpass Evolve were used for four vertebrobasilar system aneurysms presenting with acute SAH (22). This study included four acute ruptured aneurysms treated with 2.5-mm Surpass Evolve. We had no major technical issues or complications with ruptured aneurysms located beyond the Willis circle treated with 2.5-mm Surpass Evolve. Although the number of ruptured aneurysms is insufficient to determine feasibility in this cohort, it would add to the body of knowledge.

Parent vessel occlusion has been reported with coil embolization if an aneurysm is located in a distal parent artery, such as the PICA, AICA, and PCA (7,27). In our study, five aneurysms were found in the proximal part of the PCA. Parent artery occlusion was not feasible.

In our study, the mean follow-up period was quite long (16.2 ± 6.6 months), and the follow-up rate with DSA was high, with 37/41 (90%) patients having 46/52 (88%) aneurysms. At follow-up angiograms, 45/46 (98%) aneurysms had favorable aneurysm occlusion (OKM C and D). Follow-up DSA revealed complete aneurysm occlusion in four acutely ruptured patients. Our findings suggest that data on the efficacy of 2.5-mm Surpass Evolve in acute and elective patients should be added to the published literature. Complete–near complete occlusion (OKM C and D) rates of other 2.5-mm-diameter FDs were reported to be between 68% and 100% in the first year of FRED Jr FD in the literature (11,17,22,28). Previous research has shown that aneurysms with larger necks and side branches have a longer occlusion time (17).

Only MRA was used to monitor four aneurysms, and no residual filling found in the control MRA. Studies indicate that MRA is a reliable modality for monitoring aneurysms treated with endovascular techniques (1). An article comparing TOF–MRA and DSA imaging as a follow-up tool to evaluate aneurysm occlusion of FDs was recently published. Nitinol FDs appear beneficial for TOF–MRA follow-up to avoid missing small aneurysm remnants or clinically relevant parent artery stenosis. In the study, we found a high rate of artifacts in chromium–cobalt FDs such as Surpass Evolve (2). Therefore, one should be aware of the limitations of follow-up MRA in chromium–cobalt FDs.

CONCLUSION

Endovascular treatment of aneurysms beyond the Willis circle with 2.5-mm Surpass Evolve is a safe and effective method that allows for high aneurysm occlusion rates with low periprocedural complications. To the best of our knowledge, this is the most extensive study of low-profile Surpass Evolve 2.5 outcomes. The major strengths of the study is its long-term follow-up and high rate of DSA control. Aneurysm occlusion rate was high, with an acceptable complication rate. Our findings show promising technical success and favorable radiological outcomes. Larger studies with long-term follow-up are required to draw conclusions about the safety and efficacy of these stents, particularly in the treatment of acute ruptured aneurysms with Surpass Evolve.

Limitations of the Study

Our study had limitations because it was a single-center series and not a population-based study. The data were examined retrospectively. Additionally, the imaging outcome was evaluated by operators and rather than independently. A neurosurgeon provided clinical follow-up but was not blinded to the procedure, and the angiographic results were not evaluated externally. The radiologic follow-up process was not standardized.

AUTHORSHIP CONTRIBUTION

Study conception and design: BS, BD
Data collection: ED, YCS
Analysis and interpretation of results: BS, YCS, AK
Draft manuscript preparation: BS
Other (study supervision, fundings, materials, etc...): BS, BD, YCS, IA, AK, ED, ADB
All authors (BS, BD, YCS, IA, AK, ED, ADB) reviewed the results and approved the final version of the manuscript.

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