Review Article

FLOW DIVERTER TECHNOLOGY FOR THE TREATMENT OF INTRACRANIAL ANEURYSMS: A REVIEW

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Abstract:

The treatment of Intracranial aneurysms has evolved substantially over the past two decades, transitioning from open skull surgery to less invasive endovascular techniques. The rapid advancement of various endovascular procedures is the main impetus driving this evolution.

The flow-diverting devices are less invasive and cost-effective than endovascular approaches like clipping, platinum coiling, and stent-assisted coiling. Flow diverters are endovascular devices inserted into the brain artery to restrict blood flow to an aneurysm, promoting gradual thrombus formation within an aneurysm sac. While using the current generation flow diverters in treating diverse aneurysms appears to be efficient, each device is different in design, material composition, occlusion rate and deployment system. At times, it becomes challenging to determine the most appropriate device best suited for every patient because of these distinguished factors.

To address this, the present review aims to provide a comprehensive overview of ten flow-diverting devices. It explains their design specifications, material compositions, six-month and one-year occlusion rates, and their respective advantages and limitations. By offering a detailed analysis of these devices, this review seeks to empower researchers and neurosurgeons alike. Researchers can stay abreast of the latest advancements in flow-diverting technology, while neurosurgeons can make informed decisions when selecting the most appropriate device for each patient's specific needs.

Keywords

Intracranial aneurysm, flow diverter, occlusion rate, nitinol, chromium cobalt, braiding, endothelialisation, subarachnoid haemorrhage, surface modification

1. Introduction

1.1. Epidemiology of Intracranial Aneurysms:

Intracranial Aneurysms (IAs) are abnormal dilations formed on the walls of weakened parent arteries within the arterial circulation of the brain. Symptoms of unruptured aneurysms rarely occur, unlike ruptured aneurysms, involving complications like extreme headache, seizure, vomiting, cardiac arrest, double vision, sensitivity to light and subarachnoid haemorrhage or turn fatal depending on the volume and pressure of blood inside the aneurysm and its morphology and location. Based on formation, IAs are categorised as saccular, mycotic, blister, fusiform and bifurcation aneurysms ranging from 11 mm to 25 mm in diameter and categorised as small, medium and giant aneurysms [1,2]. The prevalence of IA in the general population is estimated to be 2-3.2%, and the annual risk of rupture in females is 0.49-1.8% [3]. According to a study by Thompson et al., it is reported that the presence of these aneurysms is possible in about 3% of the general population [4]. A study reported by Harada et al. revealed that the prevalence of unruptured aneurysms is 3.2% of 8696 asymptomatic Japanese adults, and increasing significantly with age, particularly among women. The highest prevalence was 14.5% in the 60-69 age group [5]. According to Deepak Sharma, the fatality rates for aneurysmal subarachnoid haemorrhage (SAH) range from 32% to 67%, and one-third of survivors require ongoing care despite treatment advancements. About 7 to 20% of individuals with aneurysmal SAH have a first- or second-degree relative with an incidence of intracranial aneurysm [6].

1.2. Treatment of aneurysms

Conventional treatment methods entail major Open Skull surgery (Craniotomy) in which a small portion of the cranium is removed, and a clip-like device is positioned at the aneurysm's neck to disrupt the blood flow from the aneurysm sac, leading to gradual endothelialisation. Though there are a few advantages, like immediate occlusion and minimal post-operative management, this invasive procedure is associated with complications like rebleeding rate due to surgical complexity and anatomy of the aneurysm [2]. To overcome these challenges, minimally invasive endovascular techniques like coil embolization and stent-assisted coiling are employed where an aneurysm sac is filled with platinum/titanium coils. In some cases, like wide-necked, large and fusiform aneurysms, coiling alone is inadequate, and an additional stent is required to conserve the placement of coils[7,8]. As large and giant aneurysms require more coils to cover the aneurysm sac completely, the procedure is more expensive. Repeated retreatments and follow-up sessions are needed to ensure that the coils are in place and that the flow of the aneurysm sac is disrupted efficiently. According to a meta-analysis, treating aneurysms with coil embolization is unsatisfactory due to a high recurrence rate of 20% and a 10% retreatment rate [9]. With the advent of flow-diverting technology, Neuro interventional surgeons are contemplating the possibility that flow diverters are safer and more effective than coil embolization and craniotomy in treating patients with aneurysms [10].

1.3. Mechanism of Flow Diverters

Flow diverters (FDs) are advanced endovascular stent-like devices deployed into the parent artery through a guided microcatheter to treat ruptured and unruptured IAs [11]. The detailed schematic of the flow diverter and deployment into a saccular aneurysm through a microcatheter is shown in Fig. 1A [12]. After implantation, FDs redirect the blood flow from the aneurysmal sac to the parent artery, facilitating thrombus formation and subsequent endothelialisation. Many investigations have emphasised porosity, pore density, and metal coverage rate as significant parameters in determining the efficacy of FDs. Based on the aneurysmal morphology, FD with optimal metal coverage area is selected for maximum flow diversion effect and complete occlusion and accelerates occlusion rate [13,14]. Based on research findings, FDs provide a viable and effective treatment option for unruptured aneurysms. Adequate perioperative care is necessary to forestall complications and minimise morbidity and mortality risks [15].

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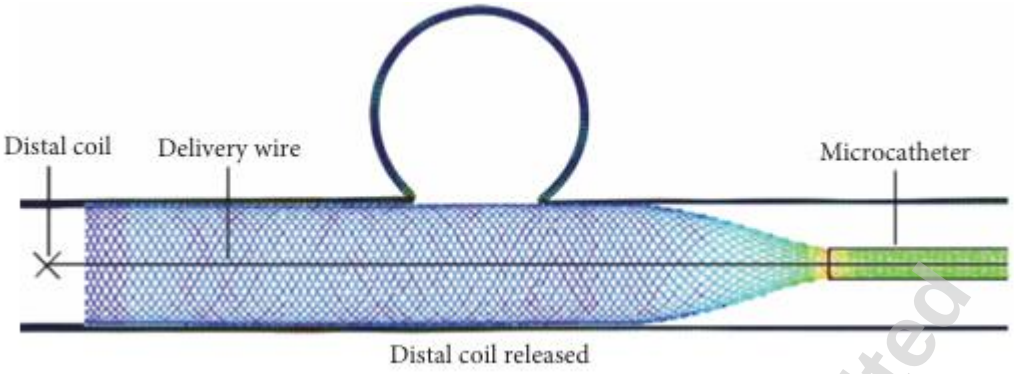

Figure 1A: Saccular aneurysm with flow diverter deployed through microcatheter

1.4. Aneurysm occlusion

FDs occlude blood flow to the aneurysm by facilitating intra-aneurysmal thrombosis inside the sac in both ruptured and unruptured aneurysms without impacting the blood flow to the collateral branches. In contrast to coiling and clipping, FD treatment is a progressive process that requires 6-12 months to achieve complete aneurysmal occlusion, contingent upon the FD design specifications and aneurysm morphology [16]. Therefore, the complete occlusion rate is one of the significant factors in determining the efficacy and approval of FDs for treatment.

Objective:

Nowadays, most neurosurgeons consider FDs as the first line for treating IAs due to their advantage of being minimally invasive and having a high occlusion rate [17]. Although the technology employed in all the commercial flow diverters is the same, design specifications, performance characteristics, and clinical efficacy exhibit significant variability. FD efficacy is assessed based on factors like occlusion rate, post-implantation morbidity and mortality rates. Aneurysmal occlusion rates are estimated according to the Raymond-Roy occlusion classification (RROC) and the O'Kelly-Marotta grading scale [18]. As neurosurgeons and Interventional neurologists analyse the rate of occlusion during the decision-making of selection of appropriate FD, this paper presents a comprehensive overview of various commercially approved flow diverters, including their material composition, design specifications, occlusion rates, and delivery catheter characteristics.

Search strategy:

Full-text screening was conducted after determining the suitability of the titles and abstracts of the articles from PubMed, Web of Science, Science Direct, and Google Scholar. Studies that investigated FDs in the management of cerebral aneurysms, both prospective and retrospective, were chosen. Studies were excluded if all authors declared that they did not meet the inclusion criteria. Disagreements were resolved through discussion. Both research and review articles on currently active FDs are considered for this review, keywords used are Flow Diverters, Treatment of Intracranial aneurysms, Pipeline Embolization Device (PED), Pipeline flex, Pipeline flex with shield technology, Surpass Streamline, Surpass Evolve, Silk, P64, Flow Redirectional Endoluminal Device (FRED), Derivo, Tunbridge in combination with Boolean operators “and” and “or”.

Exclusion Criteria:

Studies carried out on animals, in vivo and in vitro models, paediatric patients, and case studies are excluded from the present review. Studies including multiple treatments are also omitted to facilitate the efficacy and performance of FDs.

2. Commercial flow diverters:

Flow diversion has emerged as a preferred endovascular treatment for treating both ruptured and unruptured aneurysms. As a result, a diverse range of flow diverter designs and delivery systems have been developed and continue to evolve. However, the optimal choice of device for a specific aneurysm can be challenging due to factors such as size, morphology, location, and rupture status. Neurosurgeons face a significant challenge in selecting the optimal flow diverter and delivery system to minimise periprocedural complications. The composition of these devices, particularly their material properties, plays a crucial role in preventing thrombogenic events and ensuring smooth deployment. Table 1 provides an overview of the chemical composition of various flow diverter devices. Design specifications and treatment outcomes of all available commercial flow diverters are elaborated.

Table 1: Chemical composition of flow diverters

Device	Braided material	Radio-opaque material	Reference
PED	Cobalt chromium alloy	Platinum	19
Silk	Nickel titanium alloy	4 platinum wires	19
Surpass streamline	Cobalt chromium	12 platinum wires	19
Surpass evolve	Cobalt chromium	12 platinum wires	19
FRED	Nickel-titanium alloy	4 platinum wires	19
P64	Nickel-titanium alloy	2 platinum wires	19
Derivo	Nickel titanium alloy	Platinum core	19
Tubridge	Nickel-titanium alloy	2 Platinum Iridium wires	19

2.1 Pipeline Embolization Device:

PED is the first FD device approved by CE and FDA for clinical usage. It is fabricated with 48 cobalt chromium (75%) and platinum (25%) wires of diameter ranging from 28-33 micrometres aiding radio-opacity during deployment. The mesh is self-expandable up to 2.5 times its minimum length with a metal surface area coverage of 30-35% and porosity of 70-65% [10]. Although PED is not approved for posterior circulation, in a cohort trial of IntrePED, this device resulted in a favourable outcome of approximately 80% occlusion rate [19] According to a study by Nelson et al. it is reported that successful deployment and aneurysm occlusion rates of 87 and 93.3% surpassing the occlusion rates of coil embolization [20]. In large and giant aneurysms where coiling failed, the post-treatment outcome of PED is successful with complete occlusion in 93.4% of cases, and no complications like SAH or Ischemic Stroke are observed in these cases till 3 years post-device implantation [21]. In a meta-analysis conducted by Yiming He et al., it is reported that the vessel diameter is proportional to the occlusion rate. Amongst different arteries in the anterior circulation of the brain, the highest occlusion rate is observed in anterior circulation with no procedure-related morbidities [22]. In a systematic review by Leung et al., it is reported that the overall incidence of procedural morbidity and mortality rates are 6.3 and 1.5% respectively [23].

2.2 Pipeline flex

Pipeline Flex is the upgraded version of PED, often referred to as second-generation PED. Pipeline Flex is differentiated from previous-generation flow diverters by its 0.027-inch catheter delivery system, redesigned for accurate deployment and improved procedural outcomes. A study conducted by Colby et al. reported that the successful implantation rate of PED Flex is 98% in both posterior and anterior circulation IAs, with post-procedural complications seen in 2.3% of total cases [24]. This device is ideal for IAs with a neck diameter of a minimum of 4 mm or a dome-to-neck ratio of less than 2. Still, it can also be used for treating saccular or fusiform IAs originating from a parent vessel with a diameter ranging from 2.0 to 5.0 mm [25]. In a comparative study conducted on a cohort of 171(53 PED and 118 PED Flex) patients, the procedural outcome of PED and PED Flex is investigated. A comparative study between PED and PED Flex reported that a morbidity rate of 9.4% is observed in the PED group and 2.5% in the PED Flex group, demonstrating PED Flex to be more efficient than FD, according to this study [26].

2.3 Pipeline flex with shield technology

Pipeline Flex with shield technology is the third-generation flow diverter of PED approved for treating intracranial aneurysms in Europe in 2015. The design specifications of Pipeline Shield are similar to those of the previous generation Pipeline Flex but with an additional layer of phosphorylcholine polymer surrounding the metallic mesh. This layer prevents direct contact between the metal and blood cells, reducing the risk of thromboembolic complications. Treating both ruptured and unruptured aneurysms with a PED shield is safe, maintaining a good efficacy profile [21]. In a systematic review, it is reported that postoperative morbidity and mortality rates are 11.1 and 0.7%, respectively, and the additional feature of phosphorylcholine surface coating reduces the potential complications associated with the original PED, facilitating better hemocompatibility [27]

2.4 Silk

Silk is a self-expandable flow diverter with 48 Nitinol and Platinum struts with flared ends available in dimensions ranging from 15-40mm long and 2-5mm wide. The Flow diverter is fabricated as a braided mesh with a pore size of 110-250 micrometres and a strut diameter of 35 micrometres. The design of this FD includes a radiopaque wire for easy deployment and a reinforced catheter. From a Meta-analysis conducted on 14 cohort studies, the reported procedural outcome is 93%, and the mortality rate is 2.84% [28]. According to a study, the average rate of successful deployment of Silk flow diverter varies from 75% to 96%, with an average of 88.6%. It is evident from the published literature that treating IAs, including saccular, fusiform and blister aneurysms, results in a complete occlusion rate of 80%. However, device mitigation might occur due to its less radial force, leading to severe complications in bifurcation aneurysms. Compared with other FDs, the Silk flow diverter possesses desirable features like resheathing and repositioning even after 90% deployment [29]. According to Gabriel et al., procedural complications are prevalent in 33% of anterior IAs. [30] Silk flow diverter from Balt Extrusion was approved for clinical usage in 2008. The updated versions Silk+ and Silk Vista Baby are FDs designed to treat smaller aneurysms ranging from a diameter of 3mm to 5mm through a 0.018-inch diameter catheter, which facilitates much convenient deployment. A prospective study revealed that the treatment outcome of Silk Vista implanted in 27 wide-necked aneurysms is satisfactory, with a complete occlusion rate of 77.7% at 3-month follow-up. More studies, especially comparative studies, are required to analyse the performance of Silk Vista Baby in treating aneurysms [31].

2.5 Surpass Streamline

Surpass Streamline is the first-generation flow diverter from Stryker that is fabricated with various braided strut configurations ranging from 48 to 96 struts. For maintaining high efficacy, a porosity of 70% with a pore density of 21 to 32 pores/mm²is maintained in all devices [32]. Cobalt-chromium alloy, combined with platinum wires, braids the mesh for enhanced radio-opacity [18]. The FDA approves this device for treating large unruptured and fusiform aneurysms with diameters ranging from 2.5 to 5.3 mm [33]. A multi-centre study investigated that

successful implantation is observed in 98% of patients, and morbidity rates were 4% and 7.4% for anterior and posterior circulation aneurysms, respectively. Morbidity rates of complications like Ischemic stroke and Intra intra-parenchymal haemorrhage, and SAH are 3.7%, 2.5% and 1.6%, respectively [34]. It was also analysed that complete occlusion rates are substantially lower for wide-necked and giant aneurysms (38%) than for smaller aneurysms (69%). It is recommended that a Leo stent be implanted before the device is deployed to treat wide-necked aneurysms effectively [32]. According to a study by Rebecca et al., the adequate occlusion rate is seen in both small and large aneurysms, which is more significant in small than large aneurysms by 31% [35]. A single-centre study conducted on 26 patients with large and giant aneurysms reported that the treatment outcome was 80%, including residual neck and complete occlusion [36].

The next generation in Surpass is the Surpass Evolve flow diverter, designed with fewer wires for better deployment in smaller vessels. Still, the efficiency in diverting blood is sustained due to the improved design of braided wires. The FDA approves it for treating saccular aneurysms and fusiform aneurysms sized less than 12mm and parent vessel diameters ranging from 1.75-5.0mm in adult patients [37]. The pore density of the device is 15 to 30 pores/sqm, and porosity ranges from 74-78% [18]. A meta-analysis analysed that the complete occlusion rate observed is 69%, and the occurrence of early complications is 6% [38]. Rania et al.'s systematic review revealed that while Surpass Evolve is a safe and easy procedure for treating aneurysms, its efficacy is marginally unstable [39].

2.6 P64

The P64 flow diverter is designed with 64 nitinol wires in various models of diameters ranging from 2.5 to 5 mm and lengths from 12 to 36 mm. An essential advantage of the P64 over other flow diverters is its retrievability. If the initial deployment is unsatisfactory, the device can be detached and resheathed, even after full deployment. It is designed with 64 wires, maintaining a 51 to 60% porosity. The permanent morbidity with P64 deployment varies from 1.7% to 2.5%, and mortality of 0.8% [21]. A single-centre retrospective study reported that an occlusion rate of 85.7% is observed in 130 patients. While treating wide-necked aneurysms, locating the device is difficult due to the lack of distal wire. Due to the controlled detachment through the 0.0021 microcatheter, repositioning is possible even after complete deployment, avoiding deployment-related complications [9]. Hellstern et al. reported that in a retrospective study on 102 patients treated with P64 HPC, early follow-up imaging showed promising results, with aneurysm occlusion rates of 72.6% after four months and 83.8% after nine months [40].

Treating smaller distal parent vessels with denser flow diverters can lead to unintended vessel perforation. To address this, a novel flow diverter called the P48MW Flow Modulation device has been designed with 48 struts to implant in parent vessels of diameter ranging from 1.75 to 3mm[41]. A newer P48MW device, known as the P48 HPC, has been developed, incorporating a hydrophilic polymer coating on the outer layer of its struts to reduce the risk of thrombotic events. A comparative study by Hellstern et al. reported that the occlusion rate of aneurysms treated with P 48 MW HPC is highest at 88.9% amongst aneurysms treated with P64 classic and P64 HPC. Furthermore, P64 MW HPC demonstrated the fastest time to complete aneurysm occlusion at around six months [42]. A single-centre study on treating complex bifurcation aneurysms revealed that p48MW/p48MW HPC is safe and effective for flow diversion and potentially provides increased safety [43]. Another multicentre study reported that treating acute SAH with p48 MW HPC or p64 MW HPC was safe and effective, with no post-procedural complications like ischemic stroke [44].

2.7 Flow Redirectional Endoluminal Device

FRED flow diverter is designed with a unique dual-wired mesh pattern, featuring a denser outer layer of 48 wires and a less dense inner layer of 16 wires, comprising a total metal coverage ratio of 33-44% [45]. Approximately 80% of the device's length comprises these dual layers, encouraging higher occlusion at the aneurysm's neck and sac. The FRED device is available in diameters ranging from 3.5 to 5.5 mm and lengths from 10 to 38 mm and is delivered through a 0.0027-inch microcatheter. While effectively occluding the aneurysm neck, this design

restricts side branch vessel perforation. In a retrospective study of 29 patients, FRED and FRED Junior demonstrated complete occlusion rates of 78.3% at 6 months and 91.3% at 1 year, respectively. [46]. FRED X, an upgraded version of FRED, features a modified braided mesh surface to reduce thrombogenicity. High radial force allows for implantation in paraclinoid aneurysms, providing an additional feature [9]. In a retrospective multicentre study that included 184 patients treated with FRED X, it is analysed that a complete occlusion rate of 66% is achieved with morbidity and mortality rates of 1.9 and 1.2%, respectively [47]

FRED Junior, the second-generation device, has received CE and FDA approval for treating smaller-diameter arteries. A cohort study of 25 patients by Bige Siyen et al. demonstrated that FRED Junior is safe and efficient in treating ruptured and challenging aneurysms with a near-complete or complete occlusion rate of 95.2%. Although there were a few complications, like intraoperative thrombosis and haemorrhage, the overall clinical outcome was satisfactory, with 96% of patients achieving a good functional outcome [48].

2.8 Derivo

The Derivo Embolization device is designed with 48 nitinol wires, braided at a 75-degree angle and a 25-degree outward angle, maximising wall apposition force and maintaining porosity of 62-65%. The device's length and diameter range from 15 to 50 mm and 3.5 to 6 mm, respectively. At the nominal diameter, the pore area ranges from 0.042 to 0.053 sq mm, with a pore density of 15 to 19 pores/square mm[49]. To reduce friction between blood vessels and the metallic mesh surface, the mesh is coated with a protective layer of oxides and oxynitrides to minimise thrombogenicity [50]. While Derivo is effective in flow diversion for treating giant aneurysms, coiling is often required to prevent rupture-related morbidities. Limited long-term studies are available to fully evaluate the overall performance and efficacy of Derivo flow diverting devices[49]. A single-centre clinical survey reported that 84.1% of aneurysms were occluded completely, and a remnant neck was observed in 3 aneurysms [51].

Derivo 2 Heal is the recent fibrin and heparin coating upgrade to reduce periprocedural thromboembolic events. A retrospective multicentre study found that successful deployment is observed in 99% of cases, and adequate occlusion is achieved in 80.7%. There is no procedure-related mortality and morbidity of 1.2% [52]. Another study revealed that an adequate occlusion rate of 88.2% is achieved 6 months after the procedure [53]..According to a small study on 32 patients this device exhibits higher occlusion rate and less periprocedural outcomes compared to Derivo device[54]. However, as Derivo 2 Heal is a relatively new device, limited studies are available to provide more comprehensive information on its performance and long-term complications

2.9 Pipeline vantage flow diverter:

Pipeline Vantage Embolization Device with Shield Technology is a 4th generation flow diverter developed with either 48 or 64 cobalt chromium wires coated with platinum on the inside for radiopacity and improved visualisation. The deployment of this flow diverter is feasible with both 21 and 27-inch microcatheters, enabling interventional neurosurgeons to choose the appropriate catheter according to the diameter of the blood vessel. Compared to its predecessor, the Pipeline Flex, the diameter of the braided wires is lower in Vantage. This device comes with phosphorylcholine surface treatment, which aids in reducing thrombogenic events occurring in the parent artery walls. Higher pore density in the Vantage embolisation device facilitates reduced inflow and faster & complete occlusion compared to previous models [55]. A multicentre retrospective study on ruptured, unruptured, and SAH cases evaluated that adequate occlusion was accomplished in 83% of the imaged patients at 6-month follow-up. However, the major complication rates in unruptured and SAH cases are 6.4% and 40%, respectively [56]. Another study on 32 patients' clinical outcomes of Vantage, examined after a mean imaging follow-up of 9.9 months, demonstrated that the rates of complete aneurysm occlusion were 65.6% and 75%, respectively [57]. In a meta-analysis of 392 patients, at a mean follow-up of 7 months, 75.7% (ranging from 70.7%

to 80.6%) of patients achieved complete occlusion. Additionally, 8.1% (ranging from 4.5% to 11.8%) developed instant stenosis [58].

2.10 Tubridge flow diverter:

Tubridge flow diverter is the only flow diverter developed by MicroPort Medical Company (Shanghai, China) and approved by the Chinese Food and Drug Administration for treating intracranial aneurysms in the posterior location of the brain. It is designed in two variations, one with 48 and the other with 64 wire struts. The first variant comprises 46 nickel-titanium (nitinol) wires and two platinum-iridium wires for facilitating radio-opacity, and the other one with 62 nitinol and two platinum-iridium wires [24]. The flared ends design provides better wall apposition to avoid displacement after deployment. A single-centre study reported that a tubridge flow diverter is safe and efficient in treating aneurysms ranging from 11.3mm to 44 mm [25]. In a single-centre study by Li Li et al., the treatment outcome of Tubridge demonstrated a complete occlusion rate observed in 83.6% of cases, with thrombogenic events occurring in 3.5% of cases, revealing that Tubridge is safe and effective in treating both small and large aneurysms.[59]

Each flow diverter possesses distinct design features and deployment catheters. To facilitate a comprehensive comparison of design specifications and occlusion rates, Table 2 presents detailed design specifications, while Table 3 outlines occlusion rates at 6 and 12-month follow-up in both ruptured and unruptured aneurysms.

Table 2: Design specifications of flow diverter devices

Device	Length in mm	Stent diameter in mm	Number of wires	Wire diameter in mm	Pore size in sq-mm	Pore density in pore/sq-mm	Porosity in%	Catheter diameter in inches	References
PED	10-35	2.5-5.0	48	28-33	0.02-0.05	-	65-70	0.027	9,21
Silk	15–40	2-5	48	35	110-250	-	45-60	0.025	21,24
Surpass	12–50	2.0–5.3	48-96	25-36	-	21-32	70	0.014	21,29
Surpass evolve	15-40	2.5-5	48-64	28	-	15-30	74-78	0.027	21
FRED	10-38	3.5-5.5	48	-	-	-	65-70	0.027	45
P64	12-36	2.5-5	64	-	-	-	51-60	0.027	21
Derivo	15- 50	3.5-6	48	35	0.042-0.053	15-17	62-65	0.027	21
Tubridge	12-45	2.5-6.5	48-64	-	0.040-0.050	-	65-70	0.029	21

Table 3. Occlusion rates of flow diverters in 6 months and 1 year

Serial. No.	Flow Diverter type	Company Location	Approval	% of aneurysms completely occluded at 6 months	%of aneurysms completely occluded at 12 months	References
1	PED	USA	FDA approval 2011[18]	91.5 76.92 93.3 74.8 (7.8 months) 93 (5.9 months)	95.7 87.74 95 83 (13 months)	60 61 62 21 21 21
2	PED shield	USA	CE Approval 2015[18]	 78.1 79.7 82.7 73.9	88 (15 months) 81.8% 85.3 83.2 80.9 80.4	2 2 63 64 65 27 66
3	Pipeline flex	USA	CE Approval in 2014 and FDA approval 2015[18]	80.8 (9.25 mean) 77 75.7		67 68 69
4	Silk	France	CE Approval 2008[18]	 68	83.1 84.5 82.2 93.9 78.1	29 70 71 18 18
5	Surpass Streamline	California	CE Approval in 2010 and FDA approval 2018[18]	62.8 66 75		72 73 19
6	Surpass Evolve	Canada	CE Approval 2019[10] and FDA approval 2020[18]	78 75		74 75
7	P64	Germany	CE Approval in 2012[18]	 76.3 80.2	85.7 in 16.5 months 85 in 9.5 months 91.4 83.7	19 19 76 77 78
8	FRED	USA		73	 73.3	79 19

			CE Approval in 2012 and the FDA approval in 2019[19]	87.2	100 91.3 84.6	19 49 80
9	Derivo	Germany	CE Approval in 2012[19]	87.9 87 78.9 77.8 in 9 months	89.2 87.8	19 81 65 19
10	Tubridge	China	Chinese FDA in 2018 [19]	72	84.6% (mean 10.4 months)	82 83
11	Pipeline Vantage	USA	CE Approval in 2022 [85]	78(5.8 months) 77.9 (mean 7.1 months) 75 88	100	56 84 85 86

Discussion:

Compared to other therapeutic approaches like stent-assisted coiling, the AOR is noticeably higher with flow diverters [29]. The evolution of flow diverter devices has led to several advancements aimed at improving performance and reducing complications. Pipeline, the first FDA-approved flow diverter, has been extensively studied in short-term and long-term case series and cohort studies to assess its safety and efficacy. While effective in occluding large and small aneurysms, some concerns regarding hemocompatibility and deployment challenges have been reported [23]. The Flex device, for instance, offers enhanced deployment through a smaller microcatheter. Shield Technology, incorporated into newer PEDs, employs a phosphorylcholine polymer coating to minimise thromboembolic events. Dual-catheter deployment systems have also been introduced to facilitate navigation in complex anatomies. While these advancements have shown promise, challenges remain. Devices like Silk and Silk+ have demonstrated efficacy in achieving adequate occlusion, but long-term follow-up is needed to assess potential complications. The Surpass Streamline and Surpass Evolve devices, with their 12 platinum wires, offer improved radiopacity for precise placement. These devices are designed to treat giant aneurysms with low procedural complications. The P64 flow diverter's 64-wire design and retrievability feature provides flexibility during deployment. P48 movable wire design enables the repositioning of the microcatheter into the target segment, allowing the implantation of another P48 flow diverter. The P48 movable wire flow diverter's hydrophilic coating prevents platelet adhesion, making it less thrombogenic. These devices reduce the intake of platelet-inhibitory medications [43]. The FRED device's dual-mesh design can be placed precisely, protecting adjacent critical branches and modified surfaces to enhance occlusion and minimise thrombosis. This device can also safely treat unruptured vertebral artery dissecting aneurysms. Derivo and Derivo 2 Heal devices, with their flared ends and heparin/fibrin coating, offer improved stability and hemocompatibility, thereby reducing thromboembolic complications. Finally, the Tubridge device, developed in China, has shown potential for treating smaller aneurysms, although US FDA approval is still unavailable. As the field of endovascular neurointervention continues to evolve, ongoing research and clinical trials are essential to optimise flow diverter design, improve patient outcomes, and address potential long-term complications.

Conclusion:

Treatment of unruptured and ruptured intracranial aneurysms using flow diverters is analysed in relation to the design of the devices. Designs evolve from generation to generation. These devices' safety and efficacy depend not only on the design aspects but also on other parameters such as delivery system, deployment status, tortuosity of the parent artery, etc. Each of these devices has specific advantages and disadvantages. One cannot suggest a particular device for all patients. However, these devices simplify the treatment of intracranial aneurysms. It is the call of neuro-interventional radiologists to select a specific device based on the patient's requirements and past experiences.

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