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PRECISION ENDOVASCULAR RECONSTRUCTION OF INTRACRANIAL ANEURYSMS: FLOW DIVERSION, INTRASACCULAR FLOW DISRUPTION, SURFACE-MODIFIED DEVICES, AND PATIENT-SPECIFIC DEVICE SELECTION

Abstract

Background. Endovascular management of intracranial aneurysms has shifted from mechanical filling of the aneurysm sac toward biological reconstruction of the parent artery and controlled modification of intra-aneurysmal hemodynamics. Flow-diverting stents and intrasaccular flow-disruption devices have expanded treatment options for large, giant, fusiform, recurrent, and wide-neck bifurcation aneurysms that are technically challenging for conventional coiling or microsurgical clipping. Contemporary practice increasingly requires selection between parent-vessel flow diversion and intrasaccular treatment rather than universal use of a single implant.

Materials and Methods. A structured narrative review was performed using prospective pivotal trials, randomized studies, multicenter registries, long-term device studies, and contemporary clinical investigations available through August 2026. Pipeline, Surpass, FRED/FRED X, Pipeline Shield, Pipeline Vantage, Woven EndoBridge, Contour, and emerging intrasaccular technologies were evaluated. Particular attention was directed toward aneurysm morphology, vessel reconstruction, branch preservation, delayed occlusion, antiplatelet therapy, surface modification, incomplete occlusion, retreatment, ruptured aneurysms, posterior circulation lesions, and device-specific treatment geometry.

Results. Flow diversion provides progressive aneurysm exclusion through reduction of inflow, intra-aneurysmal thrombosis, and endothelial reconstruction across the aneurysm neck. Long-term studies demonstrate progressive occlusion after Pipeline and Surpass treatment, although efficacy and complication profiles vary substantially according to aneurysm location and morphology. Small and medium unruptured aneurysms can be treated with high effectiveness in appropriately selected patients, but flow diversion requires a parent artery suitable for implantation and usually mandates antiplatelet therapy. Intrasaccular devices provide a fundamentally different strategy by disrupting flow at or within the aneurysm neck without reconstructing the parent artery. The WEB has demonstrated durable five-year safety and effectiveness for wide-neck bifurcation aneurysms, and prospective data support its use in selected ruptured aneurysms. Newer neck-bridging intrasaccular systems such as Contour and Artisse further expand this concept. Surface-modified flow diverters may reduce device thrombogenicity and facilitate simplified antiplatelet strategies, although routine single-antiplatelet treatment has not yet become a universal standard.

Conclusion. Intracranial aneurysm therapy is evolving toward precision device selection based on aneurysm geometry, parent-vessel anatomy, bifurcation architecture, rupture status, branch incorporation, expected healing mechanism, and antiplatelet tolerance. The future objective is not to select the most technologically advanced implant, but to choose the device whose biological mechanism best matches the individual aneurysm.

Keywords: intracranial aneurysm; flow diversion; Pipeline; Surpass; FRED; Woven EndoBridge; WEB; Contour; intrasaccular flow disruption; antiplatelet therapy; wide-neck aneurysm.

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ПРЕЦИЗИОННАЯ ЭНДОВАСКУЛЯРНАЯ РЕКОНСТРУКЦИЯ ВНУТРИЧЕРЕПНЫХ АНЕВРИЗМ: FLOW DIVERSION, ИНТРАСАККУЛЯРНОЕ НАРУШЕНИЕ КРОВОТОКА, МОДИФИЦИРОВАННЫЕ ПОКРЫТИЯ И ПЕРСОНАЛИЗИРОВАННЫЙ ВЫБОР УСТРОЙСТВА

Аннотация

Актуальность. Эндоваскулярное лечение внутричерепных аневризм постепенно перешло от механического заполнения аневризматического мешка к биологической реконструкции несущей артерии и контролируемому изменению внутрисаккулярной гемодинамики. Flow-diverter-стенты и интрасаккулярные flow-disruption-системы существенно расширили возможности лечения крупных, гигантских, фузиформных, рецидивных и широкошейных бифуркационных аневризм.

Материалы и методы. Проведен структурированный нарративный обзор проспективных pivotal-исследований, рандомизированных работ, многоцентровых регистров и долгосрочных исследований, доступных до августа 2026 года. Анализировались системы Pipeline, Surpass, FRED/FRED X, Pipeline Shield, Pipeline Vantage, Woven EndoBridge, Contour и современные интрасаккулярные устройства. Особое внимание уделено морфологии аневризм, реконструкции несущей артерии, сохранению боковых ветвей, отсроченной окклюзии, антитромбоцитарной терапии, неполной окклюзии и повторному лечению.

Результаты. Flow diversion обеспечивает постепенное выключение аневризмы вследствие уменьшения входящего кровотока, формирования внутрисаккулярного тромбоза и эндотелизации устройства. Эффективность метода зависит от локализации, геометрии аневризмы и анатомии несущей артерии. Интрасаккулярные системы реализуют другой механизм, создавая нарушение потока непосредственно в области шейки без необходимости реконструкции всей несущей артерии. WEB продемонстрировал устойчивые долгосрочные результаты при широкошейных бифуркационных аневризмах и может применяться у отдельных пациентов с разорвавшимися аневризмами. Современные поверхностно-модифицированные flow-diverter-системы потенциально снижают тромбогенность импланта, однако оптимальная антитромбоцитарная стратегия остается предметом исследований.

Заключение. Современный выбор эндоваскулярного устройства должен основываться на геометрии аневризмы, анатомии несущей артерии и бифуркации, включении боковых ветвей, статусе разрыва и возможности проведения антитромбоцитарной терапии.

Ключевые слова: внутричерепная аневризма; flow diversion; Pipeline; Surpass; FRED; WEB; Contour; интрасаккулярное лечение; широкошейная аневризма.

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INTRAKRANIAL ANEVRIZMALARNI PRETSIZION ENDOVASKULYAR REKONSTRUKSIYA QILISH: FLOW DIVERSION, INTRASAKKULYAR OQIMNI BUZISH, MODIFIKATSIYALANGAN QOPLAMALAR VA SHAXSIYLASHTIRILGAN QURILMA TANLOVI

Annotatsiya

Dolzarblik. Intrakranial anevrizmalarni endovaskulyar davolash konsepsiyasi anevrizma xaltasini mexanik ravishda coil bilan to‘ldirishdan, ota arteriyani biologik rekonstruksiya qilish va anevrizma ichidagi gemodinamikani nazoratli o‘zgartirishga o‘tmoqda. Flow-diverter stentlar va intrasakkulyar oqimni buzuvchi qurilmalar katta, gigant, fuziform, qaytalangan va keng bo‘yinli bifurkatsion anevrizmalarni davolash imkoniyatlarini kengaytirdi.

Material va usullar. 2026-yil avgustigacha mavjud prospektiv pivotal tadqiqotlar, randomizatsiyalangan klinik ishlar, ko‘p markazli registrlar va uzoq muddatli kuzatuvlar tahlil qilindi. Pipeline, Surpass, FRED/FRED X, Pipeline Shield, Pipeline Vantage, Woven EndoBridge, Contour hamda yangi intrasakkulyar qurilmalar o‘rganildi. Anevrizma morfologiyasi, ota arteriya rekonstruksiyasi, yon shoxlarni saqlash, kechiktirilgan okklyuziya, antitrombotsitar terapiya va qayta davolash masalalariga alohida e’tibor qaratildi.

Natijalar. Flow diversion anevrizma ichiga qon oqimini kamaytirish, tromboz va qurilma ustidan endoteliyning rivojlanishi orqali anevrizmani asta-sekin qon aylanishidan chiqaradi. Intrasakkulyar qurilmalar esa bifurkatsiyani to‘liq stentlashsiz anevrizma bo‘yinida oqimni buzadi. WEB keng bo‘yinli bifurkatsion anevrizmalarda uzoq muddatli samaradorlik va xavfsizlikni ko‘rsatdi. Surface-modified flow diverterlar implant trombogenligini kamaytirishga qaratilgan bo‘lib, antitrombotsitar terapiyani soddalashtirish uchun istiqbolli yo‘nalish hisoblanadi.

Xulosa. Zamonaviy endovaskulyar davolashda qurilma tanlovi anevrizma geometriyasi, ota arteriya va bifurkatsiya anatomiyasi, yon shoxlarning jalb qilinishi, yorilish holati va antitrombotsitar terapiyani qo‘llash imkoniyatiga moslashtirilishi kerak.

Kalit so‘zlar: intrakranial anevrizma; flow diversion; Pipeline; Surpass; FRED; WEB; Contour; intrasakkulyar flow disruption; keng bo‘yinli anevrizma.

Introduction. Intracranial aneurysm treatment has undergone one of the most significant conceptual transformations in modern cerebrovascular medicine. Conventional microsurgical clipping and endosaccular coiling are based primarily on anatomical exclusion of the aneurysm from the cerebral circulation. Flow diversion introduced a fundamentally different therapeutic paradigm: instead of filling or directly closing the aneurysm sac, a high-metal-coverage endoluminal scaffold is implanted across the aneurysm neck to reconstruct the diseased parent artery, reduce intra-aneurysmal inflow, promote progressive thrombosis, and provide a substrate for neointimal endothelialization [5–8]. Intrasaccular flow disruption subsequently introduced a second reconstructive principle, in which a flow-disrupting implant is positioned within the aneurysm itself, particularly at a wide-neck

bifurcation, thereby modifying aneurysmal inflow without requiring a conventional stent across the parent vessel [20–24].

This technological expansion has occurred simultaneously with a growing recognition that treatment decisions should not be based on aneurysm diameter alone. The natural rupture risk of an unruptured intracranial aneurysm depends on patient age, hypertension, previous subarachnoid hemorrhage, geographical population, aneurysm size, anatomical site, and morphological characteristics. The UCAS Japan investigation demonstrated substantial location- and size-dependent heterogeneity of rupture risk [1]. The PHASES score subsequently integrated population, hypertension, age, aneurysm size, earlier subarachnoid hemorrhage, and aneurysm site into a clinically applicable risk model [2]. UIATS expanded decision-making by incorporating a broader set of patient-, aneurysm-, and treatment-related variables [3], while ELAPSS provided a model for predicting aneurysm growth during surveillance [4]. These risk systems are imperfect at the individual-patient level, but collectively they establish that the procedural risk of a sophisticated endovascular implant must be justified by a meaningful natural-history risk [1–4]. Flow diversion initially developed for aneurysms that were large, giant, wide-necked, fusiform, previously treated, or otherwise unsuitable for conventional coiling. The early Pipeline experience demonstrated high technical feasibility and established the principle that aneurysm occlusion could occur progressively after the intervention rather than immediately [5]. The PUFS prospective trial subsequently evaluated Pipeline treatment for large or giant wide-neck internal carotid artery aneurysms and demonstrated high angiographic occlusion rates with acceptable morbidity in this difficult population [6]. Long-term PUFS follow-up confirmed progressive occlusion and durable aneurysm exclusion over several years [7, 8]. These studies established vessel reconstruction as a clinically viable alternative to direct sac obliteration [5–8]. The clinical indications then expanded toward smaller aneurysms. The PREMIER prospective multicenter trial evaluated unruptured wide-neck aneurysms measuring 12 mm or less in the internal carotid or vertebral arterial territories. The one-year primary safety event rate was low, and high rates of complete aneurysm occlusion without significant parent-artery stenosis supported use of the Pipeline device beyond the original large-aneurysm population [9]. Three-year follow-up demonstrated continued durability, progressive occlusion, and absence of delayed aneurysm rupture in the study population [10]. Subsequent analysis identified aneurysm- and treatment-related factors associated with incomplete occlusion, reinforcing the concept that technical deployment alone does not ensure biological healing [31].

Parallel development produced multiple alternative flow-diversion platforms. The Surpass system was designed to provide consistent mesh density across varying vessel diameters and demonstrated high technical deployment success in early prospective evaluation [12]. The SCENT pivotal trial subsequently confirmed safety and effectiveness for large and giant wide-neck internal carotid aneurysms [13]. Five-year SCENT results published in 2025 demonstrated persistent long-term effectiveness, emphasizing that aneurysm occlusion after flow diversion represents a progressive vascular-healing process rather than merely an immediate procedural endpoint [14]. The FRED platform introduced a dual-layer flow-diverter design with a central high-mesh-density working segment. Initial multicenter investigations demonstrated technically feasible deployment and progressive aneurysm occlusion [15]. The SAFE study subsequently provided prospective safety and

efficacy data [16]. Newer FRED X devices incorporate surface modification intended to reduce platelet adhesion and thrombogenicity, with multicenter data showing favorable one-year and longer-term outcomes [17]. These developments illustrate a broader movement in device design away from pure mechanical flow alteration toward simultaneous control of both hemodynamics and blood–implant biological interaction [15–17]. Surface modification has become particularly important because conventional flow diversion requires antiplatelet therapy. A high-metal-coverage construct within an intracranial artery creates an acute thrombogenic interface before endothelialization occurs. Dual antiplatelet therapy using aspirin combined with a P2Y12 inhibitor has therefore become conventional practice for elective flow-diverter implantation. However, patient response to clopidogrel is variable, hemorrhagic complications may be clinically important, and dual therapy complicates treatment of ruptured aneurysms. Pipeline Shield and hydrophilic polymer-coated flow diverters were developed partly to reduce this thrombotic burden [11, 29, 30]. The SHIELD prospective study supported the safety of Pipeline Shield [11], while more recent multicenter investigations have explored surface-modified devices under single-antiplatelet strategies, including use in selected ruptured aneurysms [29]. Pipeline Shield has also been associated with a lower burden of diffusion-weighted imaging lesions in contemporary comparative data [30]. These findings are encouraging but do not establish that routine dual antiplatelet therapy can safely be abandoned for all flow-diverter procedures [11, 29, 30].

The increasing efficacy of flow diversion must be balanced against evidence showing that new technology should not automatically replace established therapies. The FIAT randomized trial was deliberately designed to evaluate flow diversion under conditions of clinical uncertainty. Early results showed that flow diversion did not initially achieve the anticipated superiority over standard treatment and demonstrated the importance of randomized evaluation of novel devices [18]. Longer-term analysis later suggested greater effectiveness of flow diversion in the predominantly large anterior-circulation aneurysm population, illustrating how conclusions can evolve with longer follow-up because flow-diverter treatment depends on delayed healing [19]. References [18, 19] remain critical reminders that high occlusion percentages in single-arm device trials do not substitute for comparative clinical evidence. Wide-neck bifurcation aneurysms represent a different geometrical problem. A flow diverter implanted across an MCA bifurcation, anterior communicating artery complex, ICA terminus, or basilar apex may cover one or more normal arterial branches whose preservation is essential. Conventional stent-assisted coiling can maintain branch patency but requires intraluminal implants and antiplatelet treatment. These anatomical limitations provided the rationale for intrasaccular flow disruption [20–24].

The Woven EndoBridge was developed as a self-expanding braided device placed completely within the aneurysm sac. Early clinical experience demonstrated feasibility in wide-neck bifurcation aneurysms [20]. The pivotal WEB-IT prospective trial included 150 patients and demonstrated a very low primary safety-event rate; at one year, complete aneurysm occlusion was present in approximately 54% and adequate occlusion in approximately 85% [21]. Five-year follow-up subsequently demonstrated durable safety and effectiveness with no new major device-related safety signal, establishing the WEB as one of the most extensively studied intrasaccular devices [22]. Long-term European WEBCAST and WEBCAST-2 experience similarly supports durable aneurysm protection

and a relatively low retreatment burden in properly selected wide-neck bifurcation aneurysms [23]. The clinical significance of the intrasaccular concept becomes particularly evident in ruptured aneurysms. Because the WEB is contained within the aneurysm rather than deployed as a stent across the parent artery, treatment can potentially avoid the antiplatelet requirements associated with conventional stent-assisted techniques. The prospective CLARYS study evaluated recently ruptured bifurcation aneurysms and reported no target-aneurysm rebleeding during the first year after treatment, with subsequent angiographic follow-up demonstrating clinically meaningful occlusion [24, 25]. The success of WEB has stimulated development of other intrasaccular strategies. The Contour Neurovascular System is designed to sit at the aneurysm neck and produce a flow-disrupting interface with less dependence on complete filling of the aneurysm volume. Contemporary multicenter and national cohorts have demonstrated promising technical and angiographic results, particularly in wide-neck bifurcation anatomy [26, 27]. A 2025 systematic review confirmed growing clinical experience while emphasizing the need for additional prospective evidence [28]. The Artisse device represents another newer intrasaccular flow-diversion concept, with early clinical results reported in 2025 [34]. These technologies may eventually permit increasingly morphology-specific treatment within the broad category of "intrasaccular therapy."

This expansion creates a new clinical problem: several technically feasible devices may exist for the same aneurysm. A 7-mm wide-neck MCA bifurcation aneurysm may potentially be treated with balloon-assisted coiling, stent-assisted coiling, WEB, Contour, selected flow diversion, or microsurgical clipping. The optimal choice depends not only on technical feasibility but on branch incorporation, bifurcation geometry, patient age, rupture status, antiplatelet tolerance, likelihood of complete occlusion, retreatment probability, and availability of a surgical option.

Materials and Methods. A structured narrative review was performed using prospective pivotal device trials, randomized controlled investigations, prospective multicenter registries, large retrospective cohorts, and long-term follow-up studies available through August 2026. The analysis focused on modern intracranial flow-diversion and intrasaccular flow-disruption systems. Pipeline, Pipeline Flex, Pipeline Shield, Pipeline Vantage, Surpass Streamline, Surpass Evolve, FRED, FRED X, WEB, Contour, and emerging intrasaccular devices were considered. The evidence was organized around aneurysm geometry, biological mechanism of occlusion, technical deployment, parent-vessel reconstruction, side-branch incorporation, angiographic occlusion, retreatment, ischemic complications, hemorrhagic complications, antiplatelet therapy, ruptured aneurysms, and long-term durability. Because device trials differed in aneurysm location, size, morphology, occlusion scales, antiplatelet regimens, and follow-up schedules, direct quantitative pooling was not attempted. The conceptual endpoint was defined as precision endovascular reconstruction, meaning selection of the device whose mechanism of aneurysm healing provides the highest expected probability of durable aneurysm exclusion with the lowest cumulative risk to the parent artery, incorporated branches, and patient.

Results.

Mechanism of Flow Diversion. A flow diverter does not primarily occlude the aneurysm at the moment of deployment. The device is positioned across the aneurysm neck within the parent artery. Its braided high-metal-coverage structure modifies the relationship between longitudinal parent-artery

flow and the aneurysm inflow jet. Entry velocity and intra-aneurysmal circulation progressively decrease. Blood stasis promotes thrombus formation within the aneurysm. Simultaneously, endothelial and neointimal growth progressively covers the device across the aneurysm neck, reconstructing the lumen of the parent vessel and excluding the pathological sac from circulation. This distinction explains why immediate angiography often shows persistent aneurysm opacification despite a technically successful procedure. Complete occlusion can evolve over six months, one year, and even several years. Therefore, immediate angiographic filling should not automatically be interpreted as procedural failure.

Device Deployment and Metal Coverage. Flow-diverter performance depends substantially on deployed geometry. Braided devices change their porosity and metal coverage according to vessel diameter, curvature, foreshortening, and deployment technique. An oversized device can produce reduced metal density across the aneurysm neck. An undersized device may generate stronger flow diversion but can create deployment, wall-apposition, or migration concerns. Vessel curvature can produce asymmetric braid opening, with differences between the inner and outer curvature. Poor wall apposition can facilitate thrombus formation or persistent endoleak-like inflow around the device. This means that the nominal device specification does not necessarily equal the biologically effective configuration after deployment. Three-dimensional cone-beam CT and high-resolution fluoroscopic imaging are consequently increasingly used to assess device expansion and wall apposition.

Aneurysm Geometry and Delayed Occlusion. The probability of complete healing after flow diversion is influenced by aneurysm size, branch incorporation, parent-vessel anatomy, neck geometry, previous stents, device apposition, smoking, antiplatelet regimen, and possibly patient-specific endothelial response. Aneurysms from which an important branch originates may remain patent because continuing branch flow sustains circulation through the aneurysm neck. This phenomenon is particularly relevant for posterior communicating artery aneurysms with fetal-type posterior cerebral circulation. In such cases, persistent physiological demand across the aneurysm can counteract the low-flow environment required for thrombosis. Similarly, bifurcation aneurysms may behave differently from sidewall ICA aneurysms because the device must preserve downstream branch flow.

Table 1. Factors influencing success after flow diversion

Factor	Potential effect
Small sidewall aneurysm	Generally favorable healing geometry
Large or giant aneurysm	Longer thrombosis interval and delayed rupture concern
Incorporated branch	Can sustain residual aneurysm flow
Fetal PCom anatomy	May reduce occlusion probability
Good device wall apposition	Supports safe endothelialization
Device oversizing	May reduce effective metal coverage
Multiple overlapping devices	Greater flow disruption but increased metal burden
Previous stent	Can impair FD expansion and wall apposition
Smoking	Potential negative biological effect on healing
Inadequate platelet inhibition	Increased thromboembolic risk
Excessive platelet inhibition	Increased hemorrhagic risk

Pipeline and the Evolution From Large to Small Aneurysms. Pipeline was initially adopted for large and giant ICA aneurysms that were poorly suited to coiling. Long-term follow-up demonstrated progressive occlusion, with the proportion of completely occluded aneurysms increasing over time. This delayed biological healing distinguishes flow diversion from coil embolization. PREMIER extended the concept to smaller unruptured aneurysms and demonstrated that flow diversion can be performed with relatively low morbidity in carefully selected anatomy.

However, this does not imply that every small aneurysm should be treated with a flow diverter.

A small aneurysm with a very low lifetime rupture risk may gain little benefit from a device that requires antiplatelet therapy and introduces a small but nonzero risk of ischemic or hemorrhagic complications. The indication must therefore begin with rupture-risk assessment rather than device availability.

Surpass and FRED Platforms. Surpass was designed to provide predictable mesh density with relatively limited need for overlapping constructs. SCENT validated the device for complex large and giant ICA aneurysms. Long-term results indicate durable vascular remodeling. Surpass Evolve subsequently introduced a lower-profile delivery platform and has expanded real-world use toward smaller and more distal vessels. FRED uses a dual-layer configuration in which the central working segment provides the principal flow-diversion effect while proximal and distal portions support deployment. FRED X incorporates surface treatment intended to reduce thrombotic interaction. The relevant clinical question is not whether one contemporary platform is universally superior. Differences in deliverability, radial force, foreshortening, wire count, mesh configuration, surface coating, radiopacity, and available diameter range can make different devices preferable for different vessel anatomies.

Surface Modification and Antiplatelet Therapy. Thromboembolic events remain one of the major limitations of flow diversion. Before endothelialization, metal struts remain exposed directly to circulating blood. Platelet adhesion and activation can generate acute or delayed in-stent thrombosis. DAPT reduces this risk but simultaneously increases hemorrhagic risk. Surface modification aims to shift this balance. Pipeline Shield uses phosphorylcholine-based surface modification, while other systems use hydrophilic polymer coating or related antithrombogenic technologies. The ultimate objective is not simply a less thrombogenic device. The larger clinical objective is to reduce antiplatelet burden sufficiently that flow diversion becomes safer in patients with recent hemorrhage, anticipated surgery, ventriculostomy requirements, or elevated bleeding risk. Current evidence is promising, but the degree to which single-antiplatelet therapy can replace DAPT depends on the specific device, clinical context, platelet agent, and rupture status.

Flow Diversion in Ruptured Aneurysms. The major challenge in subarachnoid hemorrhage is that definitive aneurysm protection is needed immediately. Flow diversion can be useful for blister, dissecting, fusiform, or otherwise unclippable and uncoilable aneurysms. However, several problems remain. First, the aneurysm may continue to fill immediately after device implantation because thrombosis is delayed. Second, antiplatelet therapy increases the bleeding risk associated with external ventricular drainage, decompressive surgery, or other invasive procedures. Third, acutely ruptured lesions may have unstable walls. Surface-modified flow diverters under reduced antiplatelet regimens

are therefore particularly attractive in this setting, but their use requires specialized neurovascular expertise and careful patient selection.

Posterior Circulation Flow Diversion. Posterior circulation aneurysms represent one of the most challenging applications of flow diversion. Basilar and vertebrobasilar arteries give rise to numerous perforators supplying the brainstem. A high-metal-coverage construct across these vessels can potentially produce perforator ischemia. Fusiform basilar aneurysms also frequently reflect diffuse parent-artery pathology rather than a focal neck defect. Consequently, excellent technical deployment does not guarantee a favorable biological result. Posterior circulation flow diversion should therefore be considered separately from routine ICA sidewall aneurysm treatment. Distal posterior circulation and carefully selected vertebral lesions can be reasonable targets, but giant fusiform basilar aneurysms remain among the highest-risk aneurysm phenotypes.

WEB and Intrasaccular Flow Disruption. WEB provides a distinct mechanism of treatment. Instead of reconstructing the parent artery, the device sits inside the aneurysm and creates a dense mesh at the aneurysm neck. The resulting reduction in inflow promotes intra-aneurysmal thrombosis. Because no parent-artery stent is required in the standard configuration, the approach is particularly attractive for wide-neck bifurcation aneurysms. Branch arteries originating around the aneurysm neck can remain untouched by an intraluminal scaffold. The trade-off is that device sizing is critical. An undersized WEB may leave persistent inflow around the device. An oversized device may protrude into the parent artery or compress longitudinally over time. The final implant configuration is therefore strongly dependent on accurate three-dimensional measurement of aneurysm width and height.

Long-Term WEB Healing. WEB treatment introduced a new angiographic issue: complete occlusion is not the only clinically acceptable endpoint. A small residual proximal recess can remain while the actual aneurysm dome is effectively excluded. Therefore, adequate occlusion commonly combines complete occlusion with a limited neck remnant. Long-term studies suggest that many WEB-treated aneurysms remain stable over years, although device compression or shape modification can occur. Retreatment remains necessary in a minority of patients. The possibility of retreatment should therefore be incorporated into initial counseling, especially in young patients.

Table 2. Parent-vessel flow diversion versus intrasaccular flow disruption

Feature	Parent-vessel flow diverter	Intrasaccular flow disruptor
Implant location	Parent artery	Aneurysm sac/neck
Primary mechanism	Vessel reconstruction	Inflow disruption
Best-established anatomy	Sidewall and complex ICA aneurysms	Wide-neck bifurcation aneurysms
Parent-vessel metal	High	Minimal or absent
Branch coverage	Often unavoidable	Usually avoided
DAPT requirement	Common	Often unnecessary if device fully intrasaccular
Immediate complete occlusion	Uncommon	Variable
Delayed healing	Expected	Expected

Ruptured aneurysm suitability	Selected cases	Particularly attractive in some bifurcation lesions
Main technical determinant	Wall apposition and neck coverage	Accurate device sizing and neck interface

WEB in Ruptured Aneurysms. Wide-neck bifurcation aneurysms are particularly difficult to treat in acute subarachnoid hemorrhage because conventional stent assistance requires antiplatelet therapy. WEB offers a solution when the aneurysm morphology can accommodate a stable intrasaccular device. The CLARYS prospective study provides important evidence that selected ruptured aneurysms can achieve effective early protection against rebleeding. This does not imply that WEB is appropriate for every ruptured aneurysm. Irregular morphology, very small sacs, unfavorable dimensions, intraprocedural instability, or anatomy unsuitable for secure device positioning may still favor coiling or microsurgical clipping.

Contour and Neck-Focused Intrasaccular Therapy. Contour differs conceptually from devices designed to occupy most of the aneurysm sac. Its disk-like braided configuration is deployed across the aneurysm neck from within the sac. The objective is to create a dense flow-disrupting interface at the inflow zone while allowing less dependence on filling the entire aneurysm volume. This may be particularly useful in irregular sacs where conventional volume-filling intrasaccular sizing is difficult. Early and intermediate data are encouraging, but the evidence base remains smaller than for WEB. Long-term multicenter prospective evaluation will be necessary before equivalent durability can be assumed.

Treatment of Recurrent or Residual Aneurysms. Flow diversion has become particularly important for aneurysms recurring after previous coiling. A residual neck or reopened sac can sometimes be reconstructed with a single parent-vessel device rather than repeated coil packing. However, previous stents can interfere with complete wall apposition of the new flow diverter. WEB-treated aneurysms can also require retreatment. Options include additional intrasaccular treatment, stent-assisted coiling, flow diversion, or microsurgical clipping depending on device configuration and residual anatomy. Microsurgical retreatment after previous intrasaccular therapy is technically possible but requires detailed understanding of the relationship between the implant, aneurysm neck, and branches.

Precision Device Selection. The existence of multiple effective devices means that technical possibility alone should no longer define treatment choice. A sidewall cavernous ICA aneurysm and an MCA bifurcation aneurysm may have identical maximal diameters but require completely different reconstructive strategies. The first is fundamentally a diseased-parent-artery problem. The second is a bifurcation-preservation problem. Flow diversion is naturally suited to reconstruction of the first lesion. Intrasaccular therapy or microsurgical clipping may be more anatomically logical for the second.

Table 3. Proposed precision endovascular phenotypes

Aneurysm phenotype	Primary anatomical problem	Preferred conceptual strategy
Large ICA sidewall aneurysm	Diseased parent artery + wide neck	Flow diversion
Fusiform ICA aneurysm	Parent-vessel pathology	Flow diversion

Recurrent coiled sidewall aneurysm	Persistent neck + coil compaction	Flow diversion
Small wide-neck MCA bifurcation	Branch preservation	WEB/Contour or clipping
Basilar apex wide-neck aneurysm	Multiple branch origins	Intrasaccular therapy in selected anatomy
Ruptured wide-neck bifurcation aneurysm	Need for immediate protection without DAPT	WEB when anatomically suitable
Blister aneurysm	Fragile non-saccular wall	Flow diversion ± adjunctive strategy
Giant fusiform basilar aneurysm	Diffuse perforator-bearing artery disease	Extremely selective individualized treatment
Patient unable to tolerate DAPT	Antiplatelet limitation	Intrasaccular device when anatomy permits
Distal small-vessel aneurysm	Limited parent-vessel diameter	Low-profile reconstructive or alternative technique

Discussion. The major change in intracranial aneurysm treatment is not the introduction of a specific brand of flow diverter or intrasaccular implant. It is the transition from sac-centered occlusion to mechanism-centered reconstruction. The foundational natural-history studies remain critical because the existence of a technically elegant device does not establish an indication for prophylactic treatment. UCAS demonstrated that rupture risk differs significantly by aneurysm location and size [1]. PHASES translated several major clinical predictors into a practical rupture-risk model [2]. UIATS attempted to combine natural history with procedural considerations [3], while ELAPSS emphasized the importance of aneurysm growth during follow-up [4]. These studies [1–4] should precede, rather than follow, discussion of device selection. A low-risk incidental aneurysm should not be converted into a high-tech intervention merely because flow diversion has become technically feasible. The Pipeline literature [5–11] demonstrates why long-term evaluation is essential for reconstructive endovascular therapy. Initial studies established technical feasibility [5], PUFS demonstrated effectiveness in complex large and giant carotid aneurysms [6], and later follow-up documented progressively increasing occlusion rates [7, 8]. PREMIER then expanded the indication toward small and medium wide-neck aneurysms [9], with three-year data confirming durability [10]. Pipeline Shield introduced the additional concept that thromboresistant surface chemistry can become part of device efficacy and safety [11]. Taken together, references [5–11] show a progression from mechanical design toward biological device–blood interaction.

A similar progression is observed with Surpass. Early prospective experience demonstrated deployment feasibility [12]. SCENT established pivotal effectiveness and safety in large and giant aneurysms [13]. The five-year SCENT results now demonstrate durable long-term reconstruction, an important finding because delayed aneurysm reopening or device-related complications could theoretically emerge long after implantation [14]. References [12–14] therefore support the concept that parent-artery reconstruction can produce lasting aneurysm exclusion when lesion geometry and device deployment are favorable. FRED provides a complementary example. The early European

experience [15] and prospective SAFE data [16] showed progressive aneurysm occlusion using the dual-layer platform. FRED X extends the concept through surface treatment and has demonstrated favorable multicenter long-term results [17]. The broader significance of references [15–17] lies in the recognition that future flow diverters will likely be judged not only by porosity and radial force but also by thromboresistance, deliverability through smaller catheters, branch interaction, and compatibility with simplified antiplatelet regimens. At the same time, the FIAT randomized experience remains one of the most important methodological counterweights to uncontrolled technological enthusiasm [18, 19]. Early results showed that flow diversion did not immediately outperform standard therapy by the expected margin [18]. Later analysis provided a more favorable view in selected large anterior-circulation aneurysms [19]. This temporal change illustrates a fundamental problem in flow-diverter trial design: the device produces delayed biological healing, while conventional coiling or clipping can provide immediate anatomical exclusion. Endpoints assessed too early may underestimate the effectiveness of flow diversion; endpoints limited to angiographic occlusion may overestimate its clinical value. References [18, 19] therefore support both continued use and continued critical evaluation of the technology.

The WEB evidence base represents a different type of evolution. Early work established feasibility for aneurysms that had historically required balloon remodeling or stent-assisted coiling [20]. WEB-IT then provided prospective pivotal evidence with extremely low major morbidity and adequate one-year occlusion in the majority of treated patients [21]. Five-year WEB-IT follow-up demonstrated durability without a late device-related safety signal [22]. European WEBCAST experience independently reinforced this long-term profile [23]. Thus, references [20–23] provide a comparatively mature body of evidence for intrasaccular treatment. The CLARYS trial adds a particularly important dimension because it evaluated ruptured aneurysms [24, 25]. Conventional wide-neck bifurcation treatment in acute SAH frequently requires a compromise between coil stability and antiplatelet burden. The absence of target-aneurysm rebleeding reported in CLARYS supports the concept that an intrasaccular implant can provide early protection without the same need for a parent-vessel stent [24]. One-year angiographic follow-up demonstrated that this immediate clinical protection can coexist with acceptable longer-term aneurysm occlusion [25]. These findings [24, 25] explain why intrasaccular therapy may be especially transformative in ruptured bifurcation aneurysms. The Contour literature [26–28] represents the next stage in device specialization. Rather than treating all wide-neck bifurcation aneurysms with a volume-filling implant, Contour focuses on the neck plane. Early series and the large UK experience have shown promising occlusion and safety profiles [26, 27], while systematic review demonstrates increasingly consistent multicenter experience but also highlights limitations of the current evidence [28]. References [26–28] therefore support Contour as a promising technique, not yet as a universally equivalent alternative to the more extensively studied WEB.

Artisse represents a further variation of the intrasaccular flow-diversion principle [34]. The proliferation of these devices suggests that the future category will not simply be “WEB-like devices.” Different aneurysm morphologies may favor different radial profiles, neck coverage, conformability, and retrievability characteristics. Reference [34] is therefore important not because it proves superiority of a new platform, but because it illustrates a rapidly diversifying therapeutic class.

Antiplatelet therapy remains one of the most consequential distinctions between parent-vessel and intrasaccular treatment. The SHIELD study [11], multicenter experience with hydrophilic polymer-coated flow diverters under single antiplatelet therapy [29], and comparative diffusion-weighted MRI data for Pipeline Shield [30] all suggest that surface engineering can meaningfully alter thrombogenicity. However, device coating does not eliminate the fundamental biological reality that a braided metallic scaffold remains in contact with arterial blood until endothelialization occurs. References [11, 29, 30] therefore support antiplatelet simplification as an evolving research direction rather than an established universal practice. This issue is particularly important in ruptured aneurysms. In an elective unruptured case, platelet inhibition can be established before implantation, response can be assessed, and elective surgery can be postponed if necessary. In SAH, ventriculostomy, decompressive craniectomy, tracheostomy, shunt placement, or other procedures may become necessary unexpectedly. Any strategy requiring potent prolonged platelet inhibition complicates the entire neurocritical-care pathway.

This is one reason why intrasaccular devices are more than simply another method of producing aneurysm occlusion. They may alter the management of the entire ruptured-aneurysm patient by reducing the need for an intraluminal implant. The problem of incomplete flow-diverter occlusion deserves equally careful attention. PREMIER analyses demonstrated that failure of complete occlusion is not random [31]. Branch incorporation, aneurysm geometry, device factors, and biological healing can contribute. Reference [31] suggests that future treatment planning should include a preprocedural probability of complete endothelial closure rather than assuming that all successfully deployed devices will ultimately cure the aneurysm. Long-term multi-device experience reported in 2026 similarly supports overall durability of contemporary flow-diversion platforms while demonstrating that residual filling, retreatment, ischemic events, and delayed device-related changes remain clinically relevant [32]. Reference [32] is particularly useful because most historical evidence was dominated by Pipeline, whereas current practice increasingly involves multiple platforms with different mechanical and surface properties. Modern Surpass Evolve investigations add further support to the move toward lower-profile and more deliverable flow diverters [33]. The ability to deliver a device through smaller microcatheters can expand access to distal and tortuous anatomy, but broader technical reach does not necessarily mean broader appropriate indication. Small distal parent arteries contain proportionally more important branch and perforator anatomy, making safety margins narrower. Reference [33] therefore illustrates the tension between increasing device deliverability and the need for increasingly disciplined selection.

The posterior circulation provides perhaps the clearest example of this tension. Flow diversion can reconstruct aneurysms previously considered almost untreatable, but perforator-rich basilar anatomy creates a qualitatively different risk profile from cavernous or paraophthalmic ICA treatment. Contemporary Pipeline Vantage experience similarly demonstrates that bifurcation and posterior circulation aneurysms can have lower occlusion rates and greater complication risks than straightforward anterior circulation sidewall lesions [35]. Thus, references [13, 14, 32, 35] should not be generalized across vascular territories. A central implication is that aneurysm location should be interpreted mechanistically. A paraophthalmic sidewall aneurysm is primarily an inflow-and-parent-vessel reconstruction problem. An MCA bifurcation aneurysm is primarily a branch-preservation and

neck-control problem. A basilar apex aneurysm is a branch- and perforator-preservation problem. A blister aneurysm is a diseased-wall reconstruction problem. A giant fusiform basilar aneurysm is a diffuse parent-artery pathology problem. These are all called intracranial aneurysms, but they should not be expected to respond optimally to the same device.

Table 4. Proposed precision device-selection framework

Decision domain	Relevant question	Device implication
Natural history	Is treatment justified at all?	Observation may remain optimal
Aneurysm morphology	Saccular, fusiform, blister, dissecting?	Determines reconstructive mechanism
Neck geometry	Sidewall or bifurcation?	FD versus intrasaccular strategy
Parent vessel	Can a stable FD be deployed?	Determines feasibility of flow diversion
Branch incorporation	Does a major branch arise from the sac/neck?	May favor intrasaccular or surgical strategy
Rupture status	Is immediate secure protection required?	Avoid unnecessary DAPT when possible
Antiplatelet tolerance	Can prolonged DAPT be safely administered?	Major determinant of FD suitability
Aneurysm size	Small versus giant	Influences thrombosis and delayed rupture behavior
Location	ICA, MCA, ACom, basilar, distal	Determines branch/perforator risk
Previous treatment	Coil/stent/device already present?	Influences wall apposition and retreatment
Patient age	Long expected follow-up?	Durability becomes increasingly important
Surgical alternative	Is clipping low risk and curative?	Device therapy should be compared with surgery

The next stage of development will likely involve patient-specific computational prediction. Flow diverter effectiveness is strongly dependent on deployed braid geometry, which determines pore density and inflow reduction. Computational fluid dynamics can quantify post-treatment velocity, wall shear stress, turnover time, and inflow concentration. However, computational models remain too slow and heterogeneous for routine intraoperative decision-making in many centers. Machine-learning approaches and angiographic parametric imaging are therefore being explored as faster surrogates. Such models could eventually answer a clinically practical question before implantation: whether the proposed device diameter, length, and landing zone are likely to produce sufficient hemodynamic disruption in this specific aneurysm. A comparable principle can be applied to WEB and Contour sizing. At present, device selection remains largely dependent on three-dimensional angiographic measurement and operator experience. The future could involve automated segmentation of the aneurysm sac, computational simulation of device deployment, estimation of wall contact, prediction of neck coverage, and probability of complete occlusion. The clinical value of such technology would be greatest if it reduced both incomplete occlusion and unnecessary device oversizing. Artificial intelligence should not be used merely to produce an automated device recommendation. It should

quantify the competing consequences of several possible strategies. For example, an algorithm evaluating an MCA bifurcation aneurysm should compare expected WEB occlusion, expected flow-diverter branch risk, predicted stent-assisted coiling recurrence, and estimated microsurgical morbidity. This is the difference between device prediction and clinical decision support.

The growing diversity of technologies also creates a challenge for clinical trials. Traditional pivotal device trials compare outcomes against prespecified performance goals rather than against another modern device. Such studies are essential for regulatory evaluation but provide limited information when the practical question is whether WEB, Contour, clipping, or stent-assisted coiling is preferable for a specific aneurysm. Future trials therefore require morphology-specific comparative designs. One potential study could enroll unruptured 4–10 mm wide-neck bifurcation aneurysms that are technically suitable for both an intrasaccular device and established conventional therapy. The primary endpoint should not be complete occlusion alone. A more meaningful endpoint would combine complete or adequate aneurysm occlusion, no major neurological morbidity, absence of retreatment, branch preservation, and freedom from long-term antiplatelet therapy. For flow diversion, future comparative studies should similarly evaluate device-specific outcomes according to anatomical phenotype rather than combining carotid sidewall, bifurcation, posterior circulation, and fusiform lesions.

Table 5. Proposed prospective precision-endovascular aneurysm registry

Variable	Proposed assessment
Patient factors	Age, hypertension, smoking, previous SAH
Natural-risk model	PHASES + growth history
Aneurysm geometry	Size, neck, aspect ratio, irregularity
Architecture	Sidewall versus bifurcation
Branch anatomy	Incorporated branch/perforator
Parent vessel	Diameter, curvature, landing zones
Rupture status	Ruptured/unruptured
Device strategy	FD, WEB, Contour, coil, stent-coil, clipping
Antiplatelet strategy	DAPT, SAPT, agent and duration
Platelet testing	When clinically indicated
Immediate endpoint	Device deployment and branch patency
Imaging follow-up	6, 12, 24 months and long term
Occlusion scale	Device-appropriate standardized classification
Clinical endpoint	mRS and neurological adverse events
Retreatment	Any additional aneurysm treatment
Primary composite outcome	Durable occlusion without neurological morbidity or retreatment

The key lesson from references [1–35] is that endovascular innovation has not eliminated the need for individualized cerebrovascular judgment. Instead, greater technological choice has made that judgment more important. The correct question is no longer “Can this aneurysm be treated with a flow diverter?” For many aneurysms, the answer is technically yes. The correct question is whether flow diversion provides a superior risk–benefit mechanism compared with an intrasaccular implant, coiling, clipping, or observation. Similarly, the question is not whether WEB or Contour can be deployed

successfully, but whether long-term branch preservation, aneurysm healing, retreatment probability, and antiplatelet burden make that strategy preferable for the individual patient. Precision endovascular reconstruction therefore requires simultaneous assessment of natural history, morphology, vascular architecture, healing biology, antiplatelet risk, and alternative therapy.

Conclusion. Modern intracranial aneurysm therapy has evolved from mechanical aneurysm filling toward biological and hemodynamic reconstruction. Parent-vessel flow diversion and intrasaccular flow disruption represent two fundamentally different mechanisms of aneurysm treatment. Flow diverters are particularly suited to sidewall, fusiform, large, giant, recurrent, and complex aneurysms in which reconstruction of the diseased parent artery is the principal therapeutic objective. Intrasaccular devices are particularly attractive for wide-neck bifurcation aneurysms because they modify aneurysm inflow while minimizing the need for a permanent parent-vessel scaffold. The WEB currently has the most mature long-term evidence among intrasaccular flow-disruption systems, while newer technologies such as Contour and Artisse expand the range of available geometrical solutions. Surface-modified flow diverters represent an important evolution aimed at reducing thrombogenicity and potentially simplifying antiplatelet therapy, particularly in patients with an elevated bleeding risk. However, no device should be selected solely because it is technologically newer or technically deployable. The optimal strategy depends on aneurysm rupture risk, parent-vessel anatomy, sidewall versus bifurcation configuration, branch incorporation, rupture status, antiplatelet tolerance, probability of durable occlusion, and the safety of available surgical or conventional endovascular alternatives. The future of aneurysm therapy therefore lies in precision endovascular reconstruction, in which the biological mechanism of the selected device is matched to the anatomical and clinical phenotype of the individual aneurysm.

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