

Impact of catheter-induced flow compromise on the presence of multiple ischemic lesions in endovascular treatment of posterior circulation aneurysms: a two-center retrospective study

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Abstract

Purpose

Catheter-induced flow compromise (CFC) occasionally occurs during endovascular treatment of posterior circulation aneurysms. The precise embolism risk, particularly when differentiating incomplete flow stasis from complete wedge, remains insufficiently characterized. The aim of this study was to provide a clear angiographic definition of CFC and evaluate the association between CFC (including subtype-specific effects) and multiple new ischemic lesions (MNIL) on postoperative diffusion-weighted imaging (DWI).

Methods

We retrospectively reviewed 108 patients who underwent endovascular treatment for posterior circulation aneurysms at two institutions. CFC was angiographically defined as the presence of flow stasis or wedge. Independent predictors of the primary outcome, which was the occurrence of multiple (≥ 3) new ischemic lesions on postoperative DWI, were identified using multivariate logistic regression analysis. Inter-rater reliability for CFC was assessed.

Results

CFC occurred in 56.5% procedures, and MNIL were observed in 33.3% patients. Aneurysm rupture and CFC were identified as independent predictors of MNIL. Both subtypes (flow stasis and wedge) were significantly associated with the ischemic outcome. Excluding patients managed using intraprocedural risk-avoidance strategies further accentuated the CFC risk. Tortuosity at the vertebral artery origin was the primary CFC predictor. Inter-rater agreement for CFC detection was high.

Conclusion

CFC was a strong, independent predictor of MNIL occurring in posterior circulation aneurysm embolization, driven primarily by anatomical tortuosity. Incomplete flow stasis carried a substantial risk of embolism, justifying the need for clinical vigilance equivalent to that for wedge. Routine preoperative anatomical assessment and intraprocedural risk-avoidance strategies are essential to minimize the ischemic burden.

INTRODUCTION

Endovascular treatment has become a standard approach for treating cerebral aneurysms, particularly those in the posterior circulation, for which open surgery is challenging [1]. However, postoperative ischemic complications remain a concern, with silent lesions that are visible on diffusion-weighted

imaging (DWI) observed in up to 60% of patients [2]. The incidence of these lesions is notably higher in aneurysms of the posterior circulation than in those of the anterior circulation [3]. Known risk factors include older age and device complexity [4]; however, traditional procedural factors often cannot fully explain the ischemic complications specific to the vertebrobasilar system [5]. Hemodynamic changes induced by placement of the guiding catheter have received insufficient attention; although complete arrest of antegrade vertebral artery flow during catheter placement is recognized as a potential cause of thromboembolic events [6, 7], the embolic risk of incomplete flow stagnation remains poorly characterized. We defined a broader clinical entity encompassing both wedge and incomplete flow stasis as catheter-induced flow compromise (CFC). Accordingly, we hypothesized that CFC—including its incomplete form (flow stasis)—leads to thrombus formation and embolic complications through hemodynamics specific to the vertebrobasilar system. The aim of this study was to provide a clear angiographic definition of CFC and evaluate the association between CFC (including its subtypes: flow stasis and wedge) and the occurrence of multiple new ischemic lesions on postoperative DWI, hereafter referred to as MNIL. This study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

METHODS

Study design

This retrospective observational cohort study was conducted at two tertiary referral centers in Japan, to evaluate risk factors for postoperative thromboembolic complications following endovascular treatment of posterior circulation aneurysms. Follow-up was limited to the immediate perioperative period; long-term clinical or neurocognitive follow-up was not performed. The primary outcome was the association between CFC during placement of the guiding system and the postoperative occurrence of MNIL. Secondary outcomes included the following: (1) predictive factors for CFC occurrence, including vertebral artery diameter, tortuosity at the origin of the vertebral artery, and outer diameter of the guiding catheter; (2) incidence of ipsilateral infarction in the territory of the posterior inferior cerebellar artery (PICA) in patients who developed CFC; and (3) exploratory analysis of other risk factors for MNIL, including patient demographics, clinical background, aneurysm characteristics, antiplatelet therapy, and device selection. When the operating physician intraoperatively recognized CFC, contralateral vertebral artery angiography was performed at the operator's discretion as a risk-avoidance measure. Whether intraprocedural contralateral angiography was performed (yes/no) was recorded for each procedure; the angiographic findings were not analyzed.

Patient population

Consecutive patients aged ≥ 20 years who underwent endovascular treatment for ruptured or unruptured posterior circulation aneurysms at the two institutions between April 1, 2018, and March 31, 2025, were included. Patients who (1) declined permission for their medical records to be used for research, (2)

underwent parent artery occlusion, or (3) did not undergo a brain magnetic resonance imaging (MRI) examination within 24 h postoperatively were excluded. This two-center study was conducted in accordance with the Declaration of Helsinki and approved by the institutional review boards of the two institutions. The requirement for written informed consent was waived by the respective ethics committees. Instead, patients were provided the opportunity to opt out of the study through public notifications at each participating institution. Figure 1 shows the patient selection process.

Endovascular procedure

All procedures were performed under digital subtraction angiography using either the Azurion 7 B20/15 or the Allura Clarity FD20/20 system (Philips Medical Systems, Best, The Netherlands). At each institution, the procedures were performed by board-certified neuroendovascular specialists or non-specialists under the guidance of a supervising physician.

Vertebral artery access was achieved using either a guiding catheter or a guiding sheath, hereafter collectively referred to as the guiding device (GD). In most procedures, a guiding catheter alone was advanced into the vertebral artery; in select cases, a guiding sheath was used instead. The type and size of GD were selected on the basis of the case anatomy and the attending physician's judgment.

Embolization devices included flow diverters (Pipeline Embolization Device, Medtronic, Dublin, Ireland; and FRED, MicroVention, Aliso Viejo, CA, USA); the WEB Aneurysm Embolization System (MicroVention); and conventional coil embolization with or without stent assistance.

Anticoagulation treatment was administered during the procedure to maintain an activated clotting time of 250–300 s. For patients with unruptured aneurysms, dual antiplatelet therapy was administered from 1 week before the procedure until ≥ 6 months if they underwent stent-assisted coiling or tapered and discontinued as per institutional protocol if they underwent balloon-assisted or simple coiling. During the perioperative period, adequate antiplatelet activity was ensured for all patients through the protocol-driven administration of loading doses or maintenance therapy.

The following data were retrospectively collected from electronic medical records: patient demographics (sex, age, diagnosis, clinical outcome), clinical background factors (hypertension, diabetes mellitus, hyperlipidemia), aneurysm characteristics (location, size, rupture status), preoperative and postoperative laboratory data (coagulation and fibrinolysis markers), type of antiplatelet therapy administered, size of GD, number of coaxial catheters used within GD, treatment strategy, vertebral artery perfusion status after GD placement, intraprocedural contralateral vertebral artery angiography (yes/no), procedure time, and the number and distribution of ischemic lesions visible on postoperative DWI. Sex was defined as biological sex, as documented in the electronic medical records, in accordance with the Sex and Gender Equity in Research guidelines.

Imaging assessment

Postoperative MRI including DWI was performed within 24 h after the procedure. DWI was selected because of its high sensitivity to acute ischemic changes through detection of cytotoxic edema and its established role as the standard imaging modality for the evaluation of periprocedural ischemic complications after neurointerventional procedures. Postoperative MRI findings were classified according to the number of DWI-positive lesions (0–2 vs. ≥ 3), on the basis of previous literature linking this threshold to cognitive outcomes [2] and their distribution: PICA territory only, multiple lesions including the PICA territory, or lesions outside the PICA territory.

Angiographic assessment of CFC

Perfusion status after GD placement was assessed using vertebral artery angiography, based on the relationship between GD tip and residual contrast agent in the venous phase. The venous phase was defined as the time point at which either of the internal jugular veins first became visible on anteroposterior vertebral artery angiography. Wedge was defined as persistent stagnation of the contrast agent in the vertebral artery that was continuous with the GD, whereas flow stasis was defined as residual contrast agent in the ipsilateral vertebral artery that was not continuous with the GD. CFC was defined as the presence of either wedge or flow stasis (Fig. 2). All vertebral artery angiograms were performed using a power injector with a standardized protocol (flow rate: 2.0–3.0 mL/s, total volume: 4.0–6.0 mL, total duration: 2.0–2.5 s) to ensure consistent opacification.

Tortuosity at the origin of the vertebral artery, evaluated using anteroposterior vertebral artery angiography, was defined as the presence of angulation of $< 90^\circ$ at the V1 portion proximal to the site at which the GD was placed.

At each participating center, three neurointerventionists independently assessed the presence of CFC using angiography: one was a board-certified instructor and two were specialists. These reviewers were blinded to all clinical demographics and postoperative MRI findings to ensure an unbiased assessment. In cases of disagreement between the two initial reviewers, a final decision was made by a senior instructor.

Outcome definitions

The primary outcome was the occurrence of MNIL, defined as ≥ 3 new ischemic lesions on postoperative DWI relative to the number on preoperative imaging. Among patients with unruptured aneurysms, poor functional outcome was defined as a modified Rankin Scale (mRS) score of 3–6 at discharge. Postoperative neurological deterioration was defined as any worsening of the mRS score at discharge relative to the preoperative baseline score.

Statistical analysis

Continuous variables are presented as mean $\pm$ standard deviation and median with interquartile range, as appropriate. Categorical variables are expressed as numbers and percentages. There were no missing

data for any of the analyzed variables. Univariate logistic regression analysis was performed to identify factors associated with the primary outcome (MNIL).

Three pre-specified multivariate logistic regression models were then constructed. All models were adjusted for ruptured aneurysm status and the use of a double-catheter system, factors selected on the basis of clinical relevance and the results of univariate analysis ($p < 0.10$). In Model A (primary analysis), the entire cohort ($n = 108$) was analyzed using CFC as a binary variable (presence vs. absence) for the identification of independent predictors of MNIL. In Model C (subtype analysis), the entire cohort ($n = 108$) was analyzed using CFC disaggregated into its two subtypes—flow stasis and wedge—to examine whether the severity of flow compromise differentially influenced the risk of MNIL. In Model B (sensitivity analysis), the analysis was repeated in a refined cohort ($n = 100$) after exclusion of patients managed using intraprocedural risk-avoidance strategies (i.e., contralateral vertebral artery angiography, $n = 8$) for assessment of the robustness of the association between CFC and MNIL, independent of procedural countermeasures.

Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated for each model.

Two pre-specified sub-analyses were also performed as follows: (1) factors associated with the occurrence of CFC, evaluated using univariate and multivariate logistic regression analyses in the entire cohort (Online Resource 2); and (2) the incidence of ipsilateral PICA territory infarction in patients who developed CFC (Online Resource 3).

Inter-rater agreement for CFC assessment was evaluated using Cohen's kappa coefficient, with values interpreted according to Landis and Koch (0.61–0.80, substantial; 0.81–1.00, almost perfect) [8]. A two-sided p -value of < 0.05 was considered statistically significant. All statistical analyses were performed using R software (version 4.3.0.; R Foundation for Statistical Computing, Vienna, Austria).

Use of generative AI

The authors used Claude (Anthropic, San Francisco, CA, USA) to assist with language editing and refinement of phrasing during manuscript preparation. The AI tool was not used to generate scientific content, interpret data, or formulate conclusions. All text was reviewed and verified by the authors, who take full responsibility for the integrity and accuracy of the work.

RESULTS

Baseline characteristics

In total, 108 patients (mean age, 63.2 ± 15.4 years; 40.7% men) with posterior circulation aneurysms treated using an endovascular approach were included. The baseline clinical and procedural characteristics are summarized in Table 1. Of the total cohort, 13.9% had ruptured aneurysms; a double-

catheter system was utilized for 58.3% patients, and CFC was observed in 56.5%. The mean procedure time was 193.3 ± 70.3 min. Eight patients (7.4%) underwent intra-procedural contralateral vertebral artery angiography as a risk-avoidance strategy in response to recognized flow compromise. Angiographic assessment of CFC was feasible in all patients, with almost perfect inter-rater agreement (percentage agreement: 93.0% at Center A and 91.9% at Center B; Cohen's kappa = 0.89 and 0.88, respectively).

Table 1

Baseline characteristics of patients with posterior circulation aneurysms treated by an endovascular approach (n = 108)

Variable	n (%)
Patient characteristics	
Age, years	63.2 ± 15.4 (median 67.0)
Male sex	44 (40.7%)
Comorbidities	
Hypertension	74 (68.5%)
Diabetes mellitus	15 (13.9%)
Hyperlipidemia	30 (27.8%)
Aneurysm characteristics	
Ruptured aneurysm	15 (13.9%)
Aneurysm size, mm	8.7 ± 5.5 (median 7.2)
≤ 10 mm	82 (75.9%)
> 10 mm	26 (24.1%)
Aneurysm location	
Vertebral artery (VA)	
VA dissection aneurysm	19 (17.6%)
Saccular VA aneurysm	12 (11.1%)
Fusiform VA aneurysm	10 (9.3%)
VA–PICA aneurysm	9 (8.3%)
Basilar artery (BA)	
BA tip	36 (33.4%)
BA trunk	6 (5.6%)
BA–SCA	8 (7.4%)
BA–AICA	4 (3.7%)
Other	4 (3.7%)
Abbreviations: CFC, catheter-induced flow compromise; DWI, diffusion-weighted imaging; PICA, posterior inferior cerebellar artery; BA, basilar artery; VA, vertebral artery; SCA, superior cerebellar artery; AICA, anterior inferior cerebellar artery; WEB, Woven EndoBridge	

Variable	n (%)
VA origin tortuosity	24 (22.2%)
Procedural characteristics	
Coaxial catheter configuration	
Single	45 (41.7%)
Double	63 (58.3%)
Guiding device size, Fr	
≤ 6 Fr	66 (61.1%)
≥ 7 Fr	42 (38.9%)
Intraprocedural contralateral injection	8 (7.4%)
Treatment modality	
Simple coiling	18 (16.7%)
Stent-assisted coiling	52 (48.1%)
Balloon-assisted coiling	10 (9.2%)
Flow diverter	16 (14.8%)
WEB device	10 (9.2%)
Other	2 (1.9%)
Catheter-induced flow compromise (CFC)	61 (56.5%)
Flow stasis	34 (31.5%)
Wedge	27 (25.0%)
Procedure time, min	193.3 ± 70.3
Postoperative D-dimer, µg/mL (n = 72)	
< 1.0	27 (37.5%)
≥ 1.0	45 (62.5%)
Postoperative DWI lesions	
0	43 (39.8%)
1–2	29 (26.9%)
Abbreviations: CFC, catheter-induced flow compromise; DWI, diffusion-weighted imaging; PICA, posterior inferior cerebellar artery; BA, basilar artery; VA, vertebral artery; SCA, superior cerebellar artery; AICA, anterior inferior cerebellar artery; WEB, Woven EndoBridge	

Variable	n (%)
≥ 3	36 (33.3%)
Distribution of ischemic lesions (n = 65)	
PICA territory only	22 (33.8%)
Multiple territories including PICA	21 (32.3%)
Without PICA territory	22 (33.8%)
Antiplatelet therapy	
Single antiplatelet	10 (9.3%)
Dual antiplatelet	89 (82.4%)
Triple antiplatelet	2 (1.9%)
None	7 (6.4%)
Abbreviations: CFC, catheter-induced flow compromise; DWI, diffusion-weighted imaging; PICA, posterior inferior cerebellar artery; BA, basilar artery; VA, vertebral artery; SCA, superior cerebellar artery; AICA, anterior inferior cerebellar artery; WEB, Woven EndoBridge	

Predictors of MNIL

The results of the univariate analysis are shown in Table 2. Older age ($p = 0.017$) and the presence of a ruptured aneurysm ($p = 0.006$) were significantly associated with MNIL. Among the procedural factors, the presence of CFC was a significant risk factor for MNIL, although the use of a Flow Diverter or WEB device was associated with a significantly lower risk. A procedure time of ≥ 180 min was not significantly associated with the presence of ischemic lesions. In terms of postoperative laboratory findings, elevated D-dimer levels (≥ 1.0 $\mu\text{g/mL}$; data available for 74 patients), were significantly associated with the occurrence of MNIL. In a sub-analysis wherein we evaluated the components of CFC, compared with no flow delay, both flow stasis and wedge were independently associated with MNIL.

Table 2

Univariate logistic regression analysis for predictors of multiple new ischemic lesions on postoperative DWI (≥ 3 lesions)

Variable	OR	95% CI	p-value	
Patient and aneurysm factors				
Age (yearly interval)	1.04	1.01–1.07	0.008	**
Male sex	0.43	0.18–1.02	0.055	
Ruptured aneurysm	5.15	1.61–16.52	0.008	**
Aneurysm size ≤ 10 mm	1.92	0.70–5.32	0.208	
Procedural factors				
CFC	2.75	1.16–6.52	0.022	*
Double-catheter system	1.69	0.74–3.90	0.216	
Guiding device size ≥ 7 Fr	1.00	0.44–2.27	1.000	
Contralateral injection	0.27	0.03–2.24	0.223	
Flow diverter or WEB device	0.28	0.09–0.90	0.033	*
Procedure time ≥ 180 min	1.40	0.63–3.12	0.414	
Laboratory Findings				
Postoperative D-dimer ≥ 1.0 $\mu\text{g/mL}$	3.47	1.08–11.09	0.036	*
Abbreviations: OR, odds ratio; CI, confidence interval; CFC, catheter-induced flow compromise; DWI, diffusion-weighted imaging; WEB, Woven EndoBridge				
* $p < 0.05$; ** $p < 0.01$				

Characterization of ischemic patterns: lesion count and distribution

We conducted additional analyses to characterize the ischemic patterns associated with CFC. CFC was significantly associated with MNIL, although no significant association was observed when only one or two lesions were noted. The presence of MNIL was associated with involvement of the PICA territory. Among patients with multiple lesions, 75.0% exhibited infarction in the PICA territory; however, only 22.2% patients with one or two lesions exhibited such infarction.

Multivariate analysis

Using multivariate logistic regression analysis, we identified significant independent predictors of MNIL in the total cohort (Table 3). In Model A, both ruptured aneurysm status and the presence of CFC emerged as independent risk factors. The use of a double-catheter system showed a strong trend

toward increased risk. To further investigate whether the severity of flow compromise influenced the risk of embolism, we performed a sub-analysis (Model C) with CFC categorized into flow stasis and wedge. Both flow stasis and wedge remained significant independent predictors; this confirmed that even incomplete stagnation of flow carries a substantial risk of ischemic complications. In this model, the use of a double-catheter system also demonstrated statistical significance. Finally, we evaluated the robustness of these findings in a refined analysis (Model B) excluding eight patients (7.4%) who were managed using intraprocedural contralateral angiography as a risk-avoidance strategy. In this cohort of 100 patients, the association between CFC and MNIL was further accentuated. This result indicated that the observed risk of CFC is a valid hemodynamic effect, with no confounding by procedural countermeasures.

Table 3

Multivariate logistic regression analysis for multiple new ischemic lesions on postoperative DWI

Variable	Model A	Model C	Model B
	Total cohort (n = 108)	CFC subtype (n = 108)	Refined cohort (n = 100)
	OR (95% CI); p-value	OR (95% CI); p-value	OR (95% CI); p-value
Ruptured aneurysm	8.56 (2.33–31.44); 0.001**	8.94 (2.37–32.46); 0.001**	7.95 (2.14–29.55); 0.002**
Double-catheter system	2.56 (0.99–6.62); 0.053	2.61 (1.01–6.85); 0.049*	2.38 (0.87–6.47); 0.090
CFC (overall)	4.13 (1.53–11.11); 0.005**	—	4.35 (1.61–11.76); 0.004**
Flow stasis	—	3.56 (1.16–10.94); 0.023*	—
Wedge	—	5.10 (1.56–16.65); 0.007**	—
Model A (primary analysis): entire cohort (n = 108), CFC as a binary variable. Model C (subtype analysis): entire cohort (n = 108), CFC disaggregated into flow stasis and wedge. Model B (sensitivity analysis): refined cohort (n = 100) excluding patients managed with intraprocedural contralateral angiography.			
All models were adjusted for ruptured aneurysm status and double-catheter system use.			
Abbreviations: OR, odds ratio; CI, confidence interval; CFC, catheter-induced flow compromise			
* p < 0.05; ** p < 0.01			

Factors associated with CFC

A pre-specified sub-analysis was performed to identify factors associated with CFC (Online Resource 2). Tortuosity at the origin of the vertebral artery was significantly associated with a higher incidence of CFC (79.2% vs. 50.0%; OR, 3.80; 95% CI: 1.30–11.12; p = 0.015). The incidence of CFC was higher when the

diameter of the guiding catheter was ≥ 7 French (64.3% vs. 51.5%), although the association was not statistically significant.

Clinical impact of ischemic lesions in unruptured aneurysms

We evaluated the clinical impact of the presence of ischemic lesions in 93 patients with unruptured aneurysms in order to assess procedural safety without the confounding effect of subarachnoid hemorrhage. In this subgroup, the presence of MNIL was not statistically associated with a poor outcome (i.e., deterioration in mRS score from baseline to discharge) at discharge or with neurological deterioration (Online Resource 3). Clinically, most lesions were silent.

DISCUSSION

Main findings

In the present study involving the endovascular treatment of posterior circulation aneurysms, CFC was a potent and independent predictor of MNIL. When we excluded cases in which intraprocedural risk-avoidance strategies were utilized, OR for CFC as a predictor of MNIL reached 4.35 (95% CI: 1.61–11.76; $p = 0.004$), thus confirming its critical impact on procedural safety.

Mechanism of CFC: flow stasis-induced thrombus and hemodynamics

CFC was a potent and independent predictor of multiple ischemic lesions in the embolization of posterior circulation aneurysms. The underlying mechanism likely involves the formation of fragile thrombi under the combined influence of flow stagnation and the hemodynamics specific to the posterior circulation.

Histological evidence suggests that under low-flow or stasis conditions (low shear stress), thrombi become predominantly erythrocyte- and fibrin-rich, unlike the platelet-rich white clots typical of high-shear arterial flow [9, 10]. These fibrin-rich thrombi are histologically unstable and highly prone to fragmentation [11]. During intraprocedural maneuvers or upon restoration of flow, these friable thrombi can easily dislodge and migrate distally, leading to the scattered pattern of DWI lesions observed in the present study.

Hemodynamically, the reduction in antegrade flow creates a pressure gradient along which contralateral vertebral artery flow effectively washes these proximal thrombi preferentially into the ipsilateral PICA. This low-resistance outlet effect explains why 75% of the multiple lesions were concentrated in the PICA territory. Although the difference did not reach statistical significance because of the limited sample size, wedge was numerically more frequent in PICA-only cases (50.0%) than in those with multi-territory involvement including the PICA territory (33.3%). This finding suggested that a well-developed ipsilateral

PICA may serve as a preferential embolic outlet when CFC occurs. Accordingly, operators should exercise particular vigilance for CFC in patients with a prominent PICA.

Mechanism of CFC: anatomy versus catheter size

A key finding of this study was the strong association between the tortuosity at the origin of the vertebral artery and the occurrence of CFC [12]. Although Matsubara et al. initially hypothesized that large-bore guiding catheters would more readily impair antegrade flow [6], catheter size was not identified as a statistically significant predictor in our cohort; instead, tortuosity at the origin of the vertebral artery emerged as the primary associated factor. In tortuous vessels, the inherent tendency of the guiding catheter to straighten deforms the vessel, causing the catheter tip to deviate eccentrically and press against the vessel wall, thereby directly compromising antegrade flow. Therefore, preoperative assessment of vascular tortuosity is of paramount importance. Operators must remain vigilant for CFC in patients with severe tortuosity, regardless of the catheter size selected.

Validity of the definition of CFC

In this study, CFC was defined as the presence of either wedge or flow stasis. Sub-analysis revealed that flow stasis alone was independently and significantly associated with MNIL. Although the analyses showed that the association with wedge was even stronger, the significant risk conferred by flow stasis indicated that even incomplete flow stagnation is sufficient to activate the coagulation cascade. These findings indicate that flow stasis carries a substantial embolic risk, warranting the same degree of clinical vigilance as wedge. Furthermore, potential concerns regarding the subjectivity of this angiographic definition were mitigated by the high rates of inter-rater agreement observed across both institutions.

Clinical relevance: silent but not benign

A critical question regarding DWI lesions is their clinical significance. In our sub-analysis of unruptured aneurysms, MNIL was not significantly associated with immediate neurological deterioration or poor modified Rankin Scale scores at discharge. These silent brain infarctions are not benign; however, they are established predictors of long-term cognitive decline and future stroke. We utilized the threshold of ≥ 3 DWI lesions based on existing evidence linking this specific lesion burden to cognitive outcomes in endovascular and transcatheter aortic valve implantation populations [2, 4]. Recent studies have confirmed that infarctions of the posterior circulation carry significant cognitive risks that are comparable to those of supratentorial strokes [13, 14]. Cognitive impairment occurs in up to 73% patients with infratentorial infarcts [13], with cerebellar lesions frequently manifesting as disturbances in attention and executive function, mimicking frontal lobe dysfunction [14]. Given that MNIL in this study were predominantly located in the PICA territory, mitigating CFC is essential for preserving comprehensive long-term brain health, not merely for preventing acute morbidity.

Procedural complexity and hypercoagulability

The use of a double-catheter system was identified as an independent predictor of MNIL across multiple models, likely reflecting the complexity of treating wide-necked aneurysms. Conversely, the use of WEB devices was associated with a lower risk of ischemia; this finding aligned with those of recent meta-analyses, which found that the use of WEB devices resulted in fewer thromboembolic complications than did the use of conventional stent-assisted coiling [15, 16]. Interestingly, although prolonged procedure time was not a significant predictor, elevated postoperative D-dimer levels were significantly associated with ischemic lesions. This suggests that a hypercoagulable state—potentially aggravated by local flow stagnation—plays a more critical role than does the duration of the procedure itself.

Impact of risk-avoidance strategies

The observation that using intraprocedural contralateral angiography reduced the incidence of MNIL offers a crucial clinical insight, namely, that CFC is a manageable risk rather than an irreversible event. Notably, because these countermeasures act to reduce ischemic events in patients with recognized CFC, their inclusion would be expected to attenuate—rather than inflate—the observed CFC–MNIL association. Consistent with this, exclusion of these eight patients strengthened the association (OR, 4.35; 95% CI, 1.61–11.76), indicating that the relationship reflects a genuine hemodynamic effect of CFC rather than an artifact of procedural management. Prompt recognition of flow compromise followed by timely countermeasures—such as securing collateral flow via contralateral injection or repositioning the catheter—can effectively mitigate ischemic complications. To proactively minimize CFC, particularly in patients with severe vascular tortuosity, operators should consider utilizing lower-profile systems or advancing the guiding catheter to the subclavian artery only. Moreover, use of alternative access routes such as the transradial approach has proven highly effective in overcoming challenging angle geometries at vertebral artery origin while ensuring catheter stability [7, 17–19].

Limitations

Several limitations of this study should be acknowledged. First, this was a retrospective, two-center study with a relatively small sample size. Second, CFC was assessed on the basis of a review of the angiographic findings, which may be subject to inter-observer variability; however, the high inter-rater agreement rates observed at both institutions suggest that such variability was minimal in this study. Third, postoperative D-dimer levels were not routinely measured in all patients, limiting the statistical power of this specific variable. Finally, long-term cognitive outcomes were not assessed. Given the ongoing debate regarding the cognitive impact of cerebellar lesions compared to that of cerebral hemispheric lesions, prospective studies with comprehensive long-term neurocognitive assessment are warranted to evaluate the clinical significance of MNIL.

CONCLUSION

CFC is a strong, independent predictor of the occurrence of MNIL in posterior circulation aneurysms embolization, and it is primarily driven by anatomical tortuosity at the origin of the vertebral artery. Importantly, incomplete flow stasis carries a substantial risk of multiple ischemic lesions, justifying that

the same degree of clinical vigilance be adopted for both flow stasis and wedge. If flow compromise is identified, risk-avoidance strategies—such as contralateral flow assessment or system downsizing—should be considered to reduce the silent ischemic burden and maximize safety of interventions in the posterior circulation.

Declarations

Author Contribution

N.T. and T.T. contributed to conceptualization and study design. N.T., K.A., and F.O. performed data collection. N.T. conducted data analysis and wrote the original draft. J.S., S.M. and T.S. reviewed and edited the manuscript. T.T. provided supervision. All authors read and approved the final version of the manuscript.

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Figures

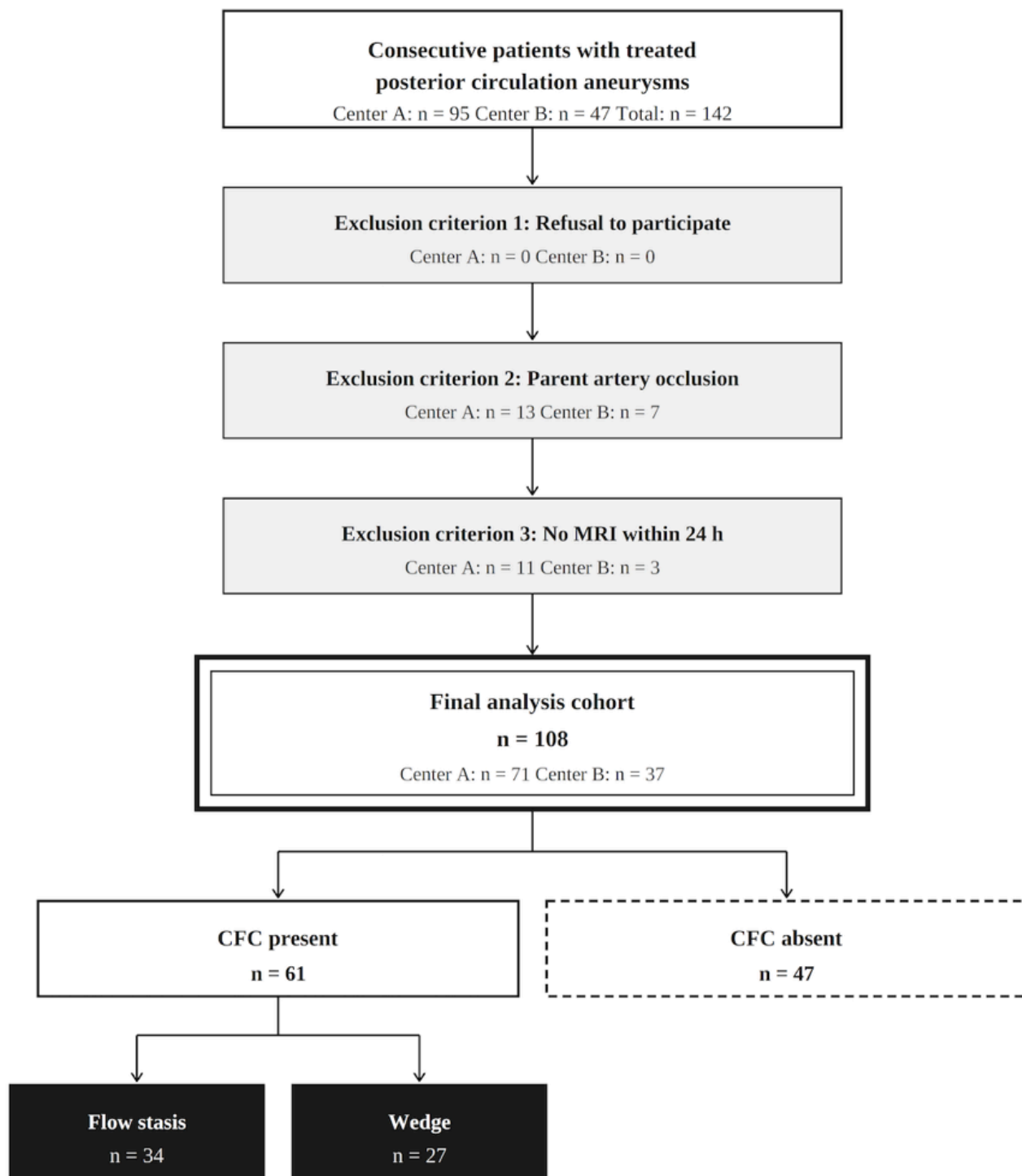


Figure 1

STROBE flowchart of patient selection.

Of 142 consecutive patients with posterior circulation aneurysms treated at two institutions, 34 were excluded as follows: 0 refused to participate, 20 had parent artery occlusion (Center A: n = 13; Center B: n = 7), and 14 did not undergo MRI within 24 hours of the procedure (Center A: n = 11; Center B: n = 3).

The final analysis cohort comprised 108 patients (Center A: n = 71; Center B: n = 37); CFC was present in 61 of these patients (flow stasis: n = 34; wedge: n = 27) and absent in 47.

CFC, catheter-induced flow compromise; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.

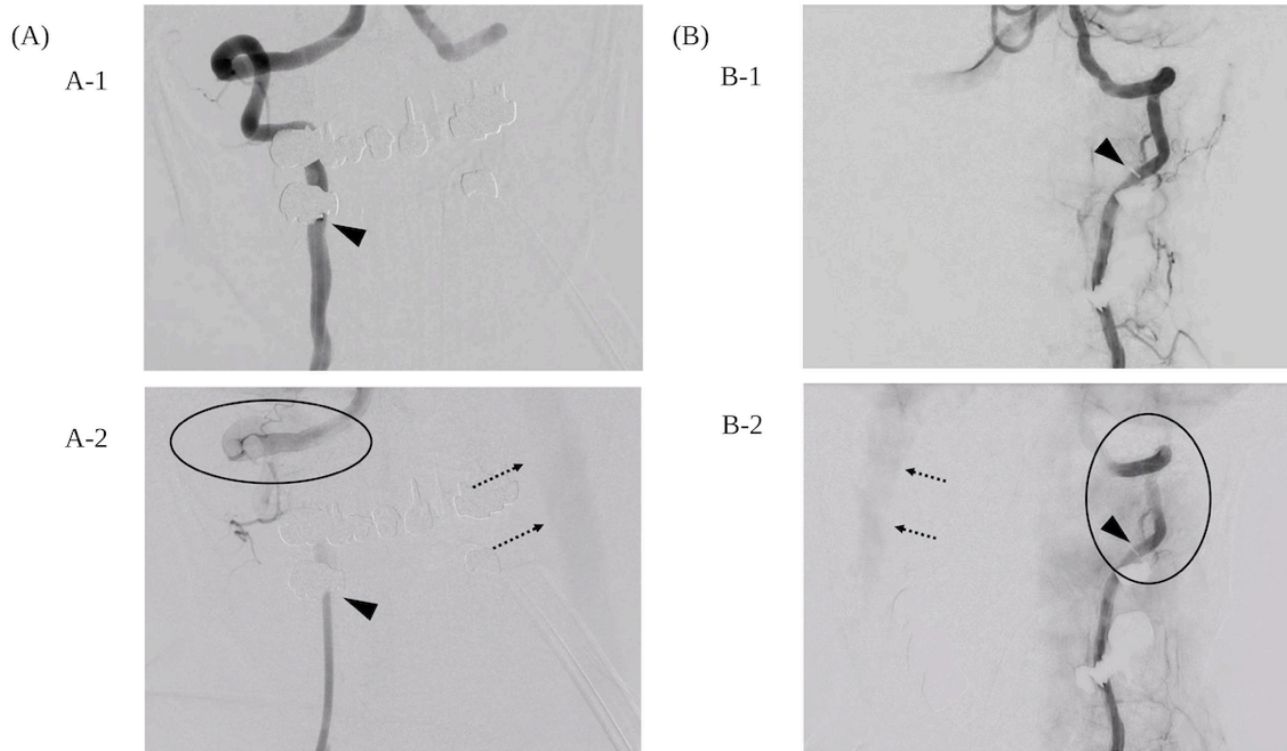


Figure 2

Representative angiographic findings of catheter-induced flow compromise (CFC)

(A) Flow stasis. A-1, arterial phase; A-2, venous phase

Anteroposterior view of vertebral artery (VA) angiography. During the venous phase—defined as the time point at which any of the internal jugular veins (dotted arrows) is first opacified—stagnant contrast medium (circled in black) is observed within the VA. A key diagnostic feature of flow stasis is that the retained contrast is clearly separated from the tip of the guiding catheter (arrowheads), indicating residual but impaired antegrade flow

(B) Wedge. B-1, arterial phase; B-2, venous phase

Angiography obtained under the same venous-phase conditions (dotted arrows) demonstrate complete arrest of antegrade flow. In the wedge configuration, the stagnant contrast (circled in black) is continuous with the tip of the guiding catheter (arrowheads), reflecting total obstruction of antegrade flow at the catheter tip

