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Original Research

Treatment of intracranial aneurysms using the Tubridge flow diverter

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Abstract

Objective: The Tubridge flow diverter (TFD) was recently developed to treat intracranial aneurysm (IA). In this study, we aimed to assess the safety and efficacy of this novel device.
Methods: A retrospective cohort of consecutive patients with IA was recruited between June 2017 and February 2022. The studied outcomes were perioperative complications, clinical quality of life, and angiographic IA occlusion. Multivariate logistic regression was performed to explore the potential predictors of perioperative stroke events and IA occlusion. A comprehensive literature review was conducted across five databases for evidence synthesis.
Results: Among the patients with IA in our cohort, 144 underwent successful TFD implantation. Postoperative stroke was observed in 11 (7.6%) patients, and 130 (90.3%) patients were discharged with modified Rankin scales (mRS) of ≤2. In the last clinical follow-up (mean, 16.9 months), 96.6% of the patients reported a satisfactory quality of life (mRS ≤2). IA occlusion was observed in 84.6% of the patients at the last angiographic follow-up (mean, 10.4 months). Aneurysmal subarachnoid hemorrhage [odds ratio (OR), 6.98; 95% confidence interval (CI), 1.11–43.91] and giant IA (OR, 5.63; 95% CI, 1.15–27.48) were associated with perioperative stroke events. The evidence synthesis found high rates of satisfactory quality of life (rate, 98.8%; 95% CI, 97.1–99.9%) and IA obliteration (rate, 78.5%; 95% CI, 74.0–82.7%) after TFD treatment. The pooled complication rate was 13.6% (95% CI, 10.9–16.5%).
Conclusions: This study identified a high rate of IA occlusion in patients who received TFD treatment. These patients also reported a satisfactory quality of life. Further studies in larger prospective cohorts with longer follow-up periods are warranted to verify our findings.

Key messages:

What is already known on this topic

- Flow diverter (FD) devices are an optimal tool to modify hemodynamics and treat intracranial aneurysms (IAs). However, the safety and efficacy of a novel self-expanding FD, namely the Tubridge flow diverter (TFD), remain to be fully established owing to the short-term follow-up periods and limited sample size of existing studies.

What this study adds

- In our cohort of patients who received TFD treatment, 96.6% of patients reported satisfactory quality of life at the last clinical follow-up (mean, 16.9 months); and 84.6% of IAs were successfully occluded at the last angiographic follow-up (mean, 10.4 months).
- Our comprehensive review and evidence synthesis of existing studies on TFD found high rates of satisfactory quality of life (98.8%; 97.1–99.9%) and IA obliteration (78.5%; 74.0–82.7%).

How this study might affect research, practice or policy

- TFD demonstrated satisfactory performance in the treatment of IAs in our cohort. Studies with larger prospective cohorts and longer follow-up periods are warranted to further investigate this promising novel approach.

Keywords: intracranial aneurysm; treatment; flow diverter; Tubridge; outcome

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Introduction

Intracranial aneurysm (IA) is a pathological change characterized by weak expansion of the cerebral artery. Advances in imaging technique and increased health awareness have enabled clear detection of IAs through computerized tomography (CTA), magnetic resonance angiography (MRA), or digital subtraction angiography (DSA). Silently rupture of IA can lead to aneurysmal subarachnoid hemorrhage (aSAH). Early intervention and treatment of IA, particularly before rupture occurs, can significantly reduce the high disease-specific burden [1].

Microsurgical clipping is an effective and permanent treatment for IAs, however, craniotomy involved in this procedure can cause large trauma and carry multiple risks [1, 2]. Therefore, endovascular techniques and intervention materials have continued to advance. Recently, flow diverter (FD) devices have emerged as an optimal treatment for IA. These devices are known for their ability to modify hemodynamics and facilitate endoluminal reconstruction, provoking a conceptual shift in the management of IA [2]. The higher metal coverage of FDs reduces the amount of the blood flow entering the IA, significantly lowering shear stress in the IA and accelerating thrombosis and occlusion [3]. However, this characteristic also limits the plasticity of FDs.

The Tubridge flow diverter (TFD; MicroPort NeuroTech, Shanghai, China), a novel self-expanding FD, displays the physical properties of nitinol, including superelasticity and shape memory to enhance functionality [4]. A recent meta-analysis [5] reported on the safety and efficacy of TFD for IA treatment. However, this study did not include all relevant studies and most of the included studies reported only short-term outcomes with limited sample sizes. In response, our study aimed to conduct medium- and long-term follow-up assessments in a patient cohort. We then comprehensively synthesized the existing evidence to robustly evaluate the effectiveness of TFD in treating IAs, and investigated the potential risks associated with TFD-related stroke and IA occlusion.

Materials and methods

Ethics

Study approval was passed by the Medical Ethics Committee of XiangYa School of Public Health, Central South University (XYGW-2020-90), and informed consent was obtained from all included patients. The results were reported in accordance with the STROBE and PRISMA guidelines [6, 7].

Inclusion and exclusion criteria

Data from consecutive patients with IA at XiangYa Hospital, Central South University, from June 2017 to February 2022 were retrospectively reviewed. IA diagnosis was confirmed by at least two experienced physicians (a radiologist and a neurosurgeon/neurologist) using CTA, MRA, DSA. Surgical indications for TFD treatment included: (i) age ≥ 20 years; (ii) large or giant IA (maximum diameter ≥ 10 mm) with a wide neck (≥4 mm); (iii) small or medium-sized IA with a wide neck (≥4 mm), or aspect/dome-to-neck ratio < 2; (iv) multiple small or medium-sized IAs within the same artery (distance ≤25 mm). The patients received endovascular treatment using TFD, with or without coiling. Patients who underwent clipping microsurgery or endovascular intervention without TFD implantation were excluded from the study.

Baseline data collection

Three trained recorders collected patient baseline, treatment, and follow-up information from the medical record system. Baseline data included sex, age, lifestyle habits (smoking and alcohol consumption), underlying diseases (hypertension, diabetes, hypercholesterolemia, coronary artery disease, cerebrovascular stroke, and cerebrovascular/pre-cerebrovascular atherosclerosis), diagnoses, and imaging characteristics of IAs (rupture status, location, shape, and size).

Treatment procedure

For unruptured IAs, patients were prescribed dual antiplatelet drugs (aspirin 100 mg/day plus clopidogrel 75 mg/day or ticagrelor 90 mg twice per day) for at least 3 days. Patients with aSAH received a loading dose of aspirin (300 mg) and clopidogrel (300 mg) prior to general anesthesia surgery.

During the procedure, heparin 100 u/kg was administered once the arterial sheath was placed to maintain the activated clotting time at 250–300 seconds. An appropriate guiding catheter was positioned in the distal internal carotid or vertebral artery. Each TFD was implanted to cover the neck of the IA alone, either alone or in combination with coils. After placement, the guiding catheter was retracted to the proximal part of the ICA or V4 segment of the vertebral artery, and tirofiban (10 μg/kg) was administered through the catheter within 3–5 min. Tirofiban was maintained intravenously at 0.15 μg/(kg•min) until the initiation of oral dual-antiplatelet therapy.

The treatment procedure was thoroughly documented, including characteristics of IAs and parent arteries, as well as immediate postoperative outcomes. Postoperatively, dual antiplatelet therapy was maintained for at least 3 months, followed by lifelong aspirin at 100 mg/day.

Clinical and angiographic outcomes

We evaluated the postoperative complications and quality of life at discharge. Postoperative complications included surgery-related stroke, such as aSAH, intracerebral hemorrhage (ICH), in-stent stenosis, and complications in puncture site, including hematoma and pseudoaneurysm. The modified Rankin Scale (mRS) was used to assess quality of life. Clinical follow-up assessments, including telephone interviews and outpatient visits, were scheduled for 3, 6, 12, and 24 months post-implantation, or according to patient preference. Quality of life was documented, as well as detailed information regarding adverse events including symptoms, event duration, attribution, resolution, and outcomes.

Angiographic follow-up was recommended at 3 months following the initiation of treatment, using noninvasive angiography (CTA or MRA), and at 6 and 12 months using DSA. Patients could opt for additional follow-up after the last DSA if desired. The evaluated parameters included IA occlusion, TFD apposition, and in-stent stenosis. IA occlusion was assessed using the Raymond-Roy occlusion classification [8]. Class I was defined as complete obliteration, whereas classes II and III were defined as residual neck and aneurysm, respectively. To assess the patency of the parent arteries, the thrombolysis in myocardial infarction (TIMI) flow grading system was used: no blood perfusion (grade 0), penetration without perfusion (grade 1), partial perfusion (grade 2), and complete perfusion (grade 3) [9]. A TIMI grade of ≤2 was defined as in-stent stenosis.

Comprehensive review and evidence synthesis

Five databases were searched for potentially relevant literature (in English or Chinese) regarding the treatment of IA using TFD. These included NCBI PubMed, Web of Science, Embase, China National Knowledge Infrastructure (CNKI), and Wanfang Database. The retrieved articles were published between January 2010 and October 2023. The research terms used were "intracranial aneurysm" and "Tubridge." A further evidence synthesis was conducted to assess the clinical or angiographic outcomes of patients with IA who underwent endovascular treatment using a TFD. The number of patients in each study was ≥10.

Statistical analysis

IBM SPSS Statistics (version 23.0) was used for statistical analysis of our cohort data. Quantitative data are presented as means ± standard deviations (SDs), and categorical data by frequencies and percentages. Odds ratios (ORs), 95% confidence intervals (CIs), and *P* values were calculated using χ^2 or Fisher's exact tests to identify the potential risk factors affecting the outcomes of perioperative stroke events, as well as IA occlusion at the last follow-up. Multivariate logistic regression was employed to adjust for multiple hypothesis testing.

Evidence synthesis was performed using the meta-package (version 6.5-0) and R software (version 4.1.2). To obtain more conservative pooling results, a random-effects meta-analysis and the variance-stabilizing Freeman-Tukey transformation were used to estimate the incidence rates of the outcomes, including quality of life satisfaction (mRS score ≤ 2), complication rate (TFD-related stroke), disability rate, mortality rate, and IA obliteration rate. Heterogeneity was evaluated using Cochran's Q test, tau (τ), and Higgins' I^2 statistic. Sensitivity analysis was conducted by excluding each study individually and assessing the remaining studies, and Egger's test and funnel plots were used to evaluate publication bias. Statistical significance was set at a two-sided *P*-value < 0.05.

Results

Population and baseline characteristics

The selection and distribution of the participants is shown in Fig. 1. Between June 2017 and February 2023, 2846 patients with IA were identified in the medical record system, with 144 of them undergoing endovascular treatment using TFD. Of these patients, 43 (29.9%) were males, and the average age when receiving the treatment was 53.0 (SD, 12.7) years. In total, 156 IAs were treated with TFD, and aSAH caused by IA rupture occurred in 14 patients. The IAs were located in the anterior circulation in 128 patients (82.1%) and in the posterior circulation in 28 patients (17.9%). Saccular IAs represented 88.5% ($n = 138$) of the IAs, and large or giant IAs (maximum diameter > 10 mm) represented 43.6% ($n = 68$) of the IAs. Detailed information is summarized in Table 1.

Perioperative characteristics and outcomes

All 152 TFDs were successfully implanted in the cohort patients (eight patients were implanted with two TFDs), and 75 (52.8%) of the 144 patients received additional coiling alongside TFD treatment (Table 1).

The perioperative outcomes are shown in Table 2. Postoperative complications (7 days after the treatment) were identified in 23 (16.0%) patients. Seven (4.9%) had hemorrhagic stroke, with an IA rupture (aSAH) in one patient and ICH in all other patients. Two of them died within 1 month after surgery. Another six (4.2%) patients had in-stent thrombosis. The complication was observed during the surgery in five patients, who received intra-arterial thrombolysis successfully. Of these, four patients were asymptomatic post-surgery, the remaining one had symptomatic ischemic stroke after anesthesia resuscitation and died 2 months later due to acute pulmonary embolism. One patient experienced delayed in-stent thrombosis and subsequent symptomatic ischemic stroke 4 days after treatment. Moreover, four (2.8%) patients had ischemic stroke (including the two patients with in-stent thrombosis), and eight (5.6%) patients had complications at the puncture site (hematoma at the puncture site were observed in seven patients and one patient had a pseudoaneurysm of the iliac artery). At discharge, 130 (90.3%) patients had an mRS of ≤2.

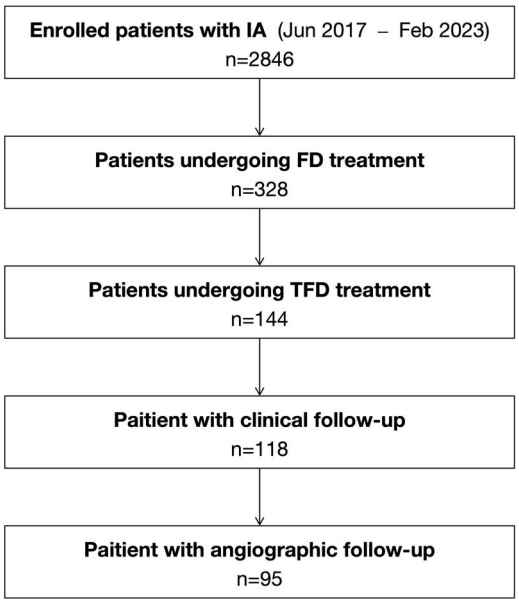

Figure 1 Flow diagram of the participant selection

Outcomes in clinical and angiographic follow-up assessments

We identified 118 patients who underwent clinical follow-up assessments via telephone interviews or during outpatient visits, with an average period of 16.9 ± 10.1 months (ranges, 3–43 months). At the last follow-up, 114 (96.6%) patients reported satisfaction with their quality of life (mRS ≤2). Late-onset complications occurred in two patients with ischemic stroke (mRS scores of 3 at the last follow-up).

Angiographic follow-up data were obtained for 95 patients. The mean follow-up period was 10.4 ± 8.7 months (range, 3–43 months). Complete occlusion (Raymond-Roy occlusion classification class I) was identified in 88 (84.6%) patients, whereas class II and III occlusions were identified in 10 (9.6%) and 6 (5.8%) patients, respectively. Only four (4.2%) patients had asymptomatic intra-stent stenosis at the parent artery with a TIMI grade 2. Further details are provided in Table 2.

Potential predictors of perioperative stroke events and IA occlusion

Multiple potential risk factors were included to explore the outcomes associated with perioperative stroke events (Table 3) and IA occlusion at the final follow-up (Table S1). Univariate regression analysis revealed that giant IA was significantly associated with an increased risk of perioperative stroke events (OR, 3.07; 95% CI, 1.04–9.09). After adjustment via multivariate regression, aSAH (6.98, 1.11–43.91) and giant IA (5.63, 1.15–27.48)

Table 1. Baseline and perioperative characteristics of participants with IA.

Characteristics	Total ($n = 144$)	Patients with clinical follow-up ($n = 118$)	Patients with angiographic follow-up ($n = 95$)
Male, *n*(%)	43 (29.9)	34 (28.8)	29 (30.5)
Age, mean ± SD	53.0 ± 12.7	52.0 ± 13.0	51.8 ± 13.5
Smoking, *n*(%)	9 (6.3)	7 (5.9)	6 (6.3)
Alcohol consumption, *n*(%)	7 (4.9)	5 (4.2)	5 (5.3)
Medical history			
Hypertension, *n*(%)	53 (37.3)	45 (38.1)	40 (42.1)
Diabetes, *n*(%)	12 (8.5)	12 (10.2)	11 (11.6)
Hypercholesterolemia, *n*(%)	34 (23.9)	27 (22.9)	22 (23.2)
Coronary artery disease, *n*(%)	8 (5.6)	6 (5.1)	5 (5.3)
Cerebrovascular stroke, *n*(%)	9 (6.3)	9 (7.6)	8 (8.4)
Cerebrovascular atherosclerosis, *n*(%)	22 (15.5)	20 (16.9)	12 (12.6)
aSAH, *n* (%)	14 (9.9)	12 (10.2)	10 (10.5)
Aneurysm number, *n*	156	128	104
Aneurysm location			
Anterior circulation, *n*(%)	128 (82.1)	105 (82.0)	77 (81.1)
Posterior circulation, *n*(%)	28 (17.9)	23 (18.0)	18 (17.3)
Aneurysm shape			
Saccular, *n*(%)	138 (88.5)	113 (88.3)	91 (87.5)
Fusiform, *n*(%)	7 (4.5)	6 (4.7)	4 (3.8)
Dissecting, *n*(%)	11 (7.0)	9 (7.0)	9 (8.7)
Aneurysm size			
Small (<5 mm), *n*(%)	49 (31.4)	42 (32.8)	37 (35.6)
Middle (5–10 mm), *n*(%)	39 (25.0)	29 (22.7)	21 (20.2)
Large (10–15 mm), *n*(%)	25 (16.0)	21 (16.4)	18 (17.3)
Giant (>15 mm), *n*(%)	43 (27.6)	36 (28.1)	28 (26.9)
Perioperative characteristics			
N of TFD implantation >1, *n*(%)	8 (5.6)	6 (5.1)	5 (5.3)
Coiling, *n*(%)	82 (56.9)	61 (51.7)	50 (52.6)

SD, standard deviation; aSAH, aneurysmal subarachnoid hemorrhage; TFD, Tubridge flow diverter.

Table 2. Outcome evaluation for the participants with IA.

Outcomes	Events
Perioperative outcomes ($n = 144$)	
Perioperative complications	
Hemorrhagic stroke, *n*(%)	7 (4.9)
In-stent thrombosis, *n*(%)	6 (4.2)
Ischemic stroke, *n*(%)	4 (2.8)
Complications at punctured site, *n*(%)	8 (5.6)
Perioperative deaths, *n*(%)	2 (1.4)
mRS score ≤ 2 at discharge, n(%)	130 (90.3)
Clinical follow-up ($n = 118$)	
Last clinical follow-up, mean month ± SD	16.9 ± 10.1
mRS score ≤ 2 at the last follow-up, *n*(%)	114 (96.6)
Late-onset complications	
Hemorrhagic stroke, *n*(%)	0 (0)
Ischemic stroke, *n*(%)	2 (1.7)
Late-onset complication-related deaths, *n*(%)	1 (0.8)
Angiographic follow-up ($n = 95$)	
Last angiographic follow-up, mean month ± SD	10.4 ± 8.7
Occlusion of IA at the last angiographic follow-up	
Raymond-Roy occlusion classification I, *n*(%)	88 (84.6)
Raymond-Roy occlusion classification II, *n*(%)	10 (9.6)
Raymond-Roy occlusion classification III, *n*(%)	6 (5.8)
Intra-stent stenosis at the last angiographic follow-up, *n*(%)	4 (4.2)

SD, standard deviation; mRS, modified Ranking Score; IA, intracranial aneurysm.

were identified as predictors of perioperative storke events. For IA occlusion, although male sex (0.26, 0.08–0.85) and non-saccular IA (5.07, 1.36–18.87) were associated with IA occlusion, these results became non-significant after adjusting for the risk factors.

Comprehensive review and evidence synthesis

Fourteen studies [4, 10–22] were eligible following a systematic literature search in which 143 recorded studies were screened (Fig. S1). The included studies involved a total of 912 patients who underwent TFD implantation for IA treatment. The summarized characteristics of the studies, along with those of our cohort study, are presented in Table S2. During the clinical follow-up, 98.8% (95% CI, 97.1–99.9%; I^2, 31.3%) of 620 patients with angiographic follow-up reported satisfaction with their quality of life (mRS ≤2). The pooled complication rate of TFD-related stroke was 13.2% (10.6–16.0%; 8.1%) after excluding a study by Lv et al. [11]. The disability and mortality rates were 2.9% (1.6–4.4%; 0.0%) and 0.6% (0–1.8%; 23.6%), respectively. The overall IA obliteration rate was 78.5% (74.0–82.7%; 41.6%) at the final angiographic follow-up. Detailed information is presented in Table 4, Fig. 2, and Figs S2–S4. No publication bias was identified for any of the reported outcomes.

Discussion

As new medical products rapidly emerge in the neuroendovascular field, robust evidence of their safety and efficacy is crucial for both clinicians and patients to guide appropriate clinical decision-making. This study found that a high proportion of patients treated via TFDs achieved IA occlusion (84.6%) and reported a satisfactory quality of life (96.6%). An acceptable (16.0%) rate of perioperative complications was associated

Table 3. Regression analysis for potential risk factors associated with perioperative stroke events.

Risk factors	Perioperative stroke events ($n = 144$)		Univariate regression analysis		Multivariate regression analysis	
	Events, $n = 15$	Other, $n = 129$	OR (95% CI)	*P*	OR (95% CI)	*P*
Male: Female	4:11	39:90	1.19 (0.36–3.97)	0.775	0.99 (0.18–5.29)	0.988
Age, mean ± SD	53.5 ± 12.0	53.0 ± 12.9	1.00 (0.96–1.05)	0.888	1.02 (0.96–1.07)	0.587
Smoking, *n*(%)	1 (6.7)	8 (6.2)	1.08 (0.13–9.29)	0.944	3.12 (0.19–51.21)	0.426
Alcohol consumption, *n*(%)	0 (0)	7 (5.4)	-	0.999	-	0.999
Medical history						
Hypertension, *n*(%)	4 (26.7)	54 (41.9)	0.44 (0.12–1.63)	0.216	0.25 (0.05–1.35)	0.106
Diabetes, *n*(%)	1 (6.7)	11 (8.5)	0.77 (0.09–6.39)	0.806	1.24 (0.08–18.52)	0.877
Hypercholesterolemia, *n*(%)	4 (26.7)	30 (23.3)	0.48 (0.10–2.23)	0.346	0.59 (0.09–3.82)	0.584
Coronary artery disease, *n*(%)	1 (6.7)	7 (5.4)	1.25 (0.14–10.87)	0.843	1.27 (0.09–18.78)	0.863
Cerebrovascular stroke, *n*(%)	0 (0)	9 (7.0)	-	0.999	-	0.999
Cerebrovascular atherosclerosis, *n*(%)	3 (20.0)	19 (14.7)	1.45 (0.37–5.62)	0.593	1.16 (0.22–6.15)	0.864
aSAH, *n* (%)	3 (20.0)	11 (8.5)	2.68 (0.66–10.96)	0.170	6.98 (1.11–43.91)*	0.038*
Aneurysm number > 1, *n*(%)	1 (6.7)	9 (7.0)	-	0.999	-	0.999
IA in Posterior circulation, *n*(%)	2 (13.3)	26 (20.3)	0.61 (0.13–2.87)	0.531	0.76 (0.08–7.14)	0.812
Non-saccular IA, *n*(%)	2 (13.3)	16 (12.4)	0.47 (0.06–3.81)	0.480	0.35 (0.02–5.36)	0.447
Giant IA (≥15 mm), *n*(%)	8 (53.3)	35 (27.1)	3.07 (1.04–9.09)*	0.043*	5.63 (1.15–27.48)*	0.033*
N of TFD implantation >1, *n*(%)	1 (6.7)	7 (5.4)	1.25 (0.14–10.87)	0.843	2.889 (0.20–41.14)	0.434
Coiling, *n*(%)	12 (80.0)	68 (52.7)	3.59 (0.97–13.32)	0.056	2.46 (0.51–11.83)	0.261

SD, standard deviation; aSAH, aneurysmal subarachnoid hemorrhage; IA, intracranial aneurysm; TFD, Tubridge flow diverter. *, *P*-value < 0.05.

Table 4. Pooling results of outcomes for IA patients with TFD treatment.

Pooled outcomes	N of studies	Total events	Sample size	Rate (95% CI), %	I^2, %	tau	p^Q	Publication bias, *P*
Satisfactory life quality	11	605	620	98.8 (97.1–99.9)	31.3	0.051	0.149	0.774
Complication rate	13	99	712	13.2 (10.6–16.0)	8.1	0.014	0.365	0.826
Morbidity rate	12	25	703	2.9 (1.6–4.4)	0.0	0.000	0.844	0.429
Mortality rate	13	13	817	0.6 (0–1.8)	23.6	0.042	0.206	0.997
IA occlusion rate	15	579	737	78.5 (74.0–82.7)	41.6	0.064	0.046	0.176

OR, odds ratio; 95% CI, 95% confidence interval; p^Q, the *P* value for the Cochran's Q test.

mainly with aSAHs and giant IAs. A comprehensive review and evidence synthesis identified consistent results, demonstrating the satisfactory performance of TFD for treating IAs.

The outcomes of IA treatment using FDs have been systematically reported (Table S3) [23–28]. Chancellor et al. [23] analyzed a number of clinical trials and reported an IA occlusion rate ranging from 66.1 to 93.3% as a long-term outcome. When comparing to the other types of FDs with IA occlusion pooled rates ranging from 64.1 to 88.9% (median, 80.2%), the TFD was found to perform well (84.6% of IA occlusion cases in our cohort and 78.5% in the pooled results) [24–28]. Regarding FD-related complications, the trials reported rates in the range of 0.8–17.1%, with morbidity rates of 2.9–12.2% and mortality rates of 0–4.9% [23, 29]. We found similar morbidity and mortality rates, but noted relatively higher complication rates. This discrepancy may be because the asymptomatic complication of in-stent thrombosis with prompt treatment was categorized as ischemic complications in this study. Combining the data from 14 studies that reported on the complication rate, a pooled result (rate, 12.2%; 95%CI, 8.9–16.0%) was obtained with considerable heterogeneity (I^2, 52.0%; Fig. S2). The sensitivity analysis (Fig. S3B) revealed that the source of this heterogeneity was from a study by Lv et al. [11] that relied solely on follow-up data. Patients with complications and unsatisfactory clinical outcomes, including death, could not attend follow-up visits, leading to an underestimation of complication rates.

Moreover, several studies have investigated the predictors of satisfactory outcomes to refine indications for FDs in the treatment of IAs [30, 31]. Kallmes et al., analyzing data from 793 patients with 906 IAs from 17 medical centers, concluded that small IA treated with pipeline embolization devices (PEDs) generally had lower complication rates. Whereas IA in the posterior circulation and giant IA were associated with higher procedure-related complications and deaths [30]. We also investigated the role of giant IA as a risk factor for perioperative stroke events. It is more difficult to establish a TFD delivery system to target locations when treating giant IAs than when treating smaller ones. Moreover, intra-aneurysm thromboses in giant IAs may break down, resulting in ischemic events [32]. Another study reported that hypertension and IA locations in the posterior circulation represented risk factors for PED-related ischemic stroke events [30]. Consistent results were not obtained in this study because we defined both the complications related to stroke and those in puncture site as post-operative complications. The safety of FDs in treating vertebrobasilar IAs remains unclear because FDs may alter local hemodynamics and cause the occlusion of branches supplying the brainstem [2]. Considering the potential risk of ischemic stroke, only a small number of patients with posterior-circulation IA were included in this cohort.

This study had some limitations. First, the TFD was launched on the market only 10 years ago, which limits the sample size and follow-up duration in our retrospective cohort. Therefore, we

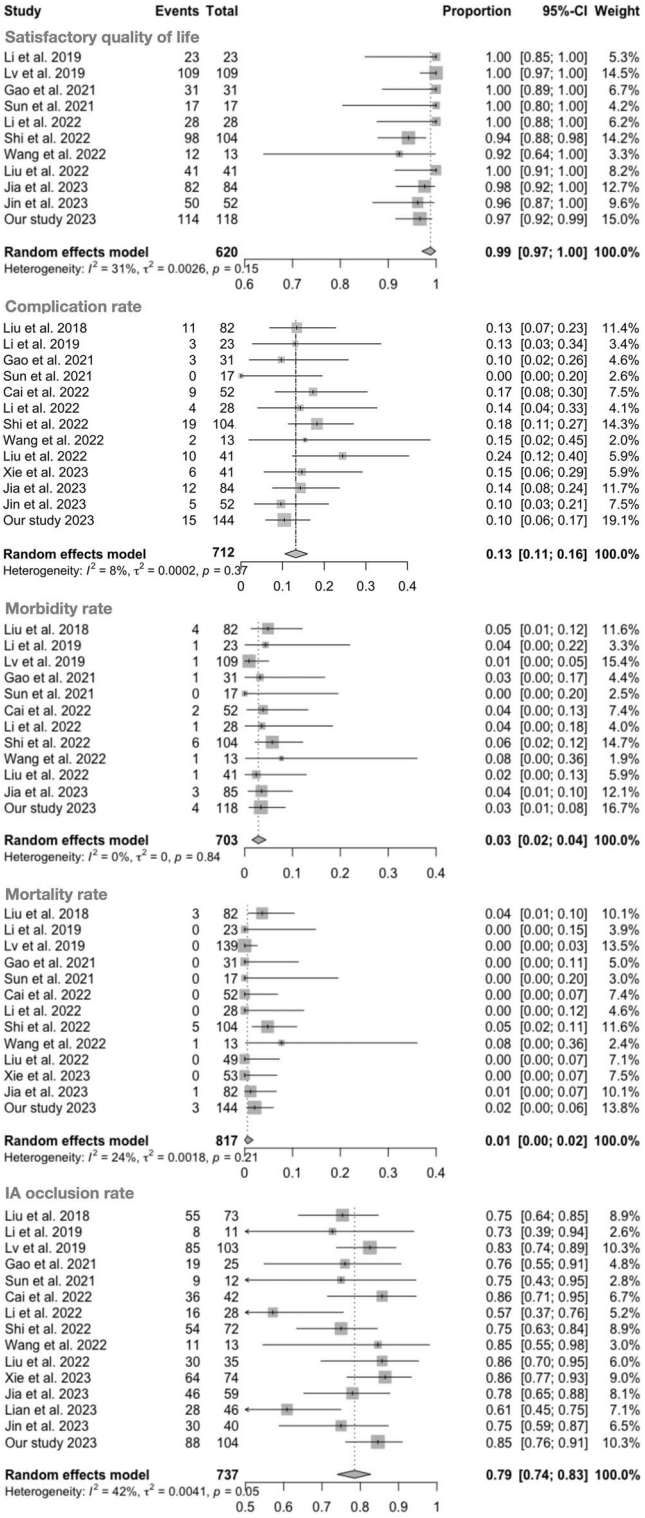

Figure 2 Forest plots of satisfactory quality of life, complication rate, morbidity rate, mortality rate, and IA occlusion rate in included studies

conducted a complementary comprehensive review and evidence synthesis, which corroborated our findings and provided higher statistical power. However, there was heterogeneity among the included studies because of different definitions for the outcomes of interest. In addition, considering the low incidences of complications and occluded IAs, our regression analysis showed a relatively wide CI. Only a limited number of patients with IAs in the posterior circulation were enrolled in this study; thus, more evidence is needed to explore the safety of TFD in treating vertebrobasilar IAs.

Conclusion

Our findings demonstrate the satisfactory performance of TFD in the treatment of IAs. We observed an acceptably low level of postoperative adverse complications. Giant IAs and aSAHs are the major potential risk factors for perioperative stroke events that should be considered when treating IAs using TFD. Future prospective studies with large numbers of patients from multiple medical centers and long follow-up periods are necessary to confirm our results.

Abbreviations

TFD, Tubridge flow diverter; IA, intracranial aneurysm; CTA, computerized tomography; MRA, magnetic resonance angiography; DSA, digital subtraction angiography; mRS, modified Rankin score; aSAH, aneurysmal subarachnoid hemorrhage; ICH, intracerebral hemorrhage; FD, flow diverter; PEDs, pipeline embolization devices.

Supplementary data

Supplementary data are available at *Postgraduate Medical Journal* online.

Conflict of interest statement: None declared.

Authors' contributions

D.Y.: data curation, statistical analysis, validation, resources and software, writing for original draft; N.Z., Y.G., F.C.: data curation, resources and software; W.J.: methodology, funding acquisition; J.L., Y.L.: project administration and supervision, methodology, validation, writing for original draft & review & editing; J.Y.: project administration and supervision, methodology, funding acquisition, statistical analysis, writing for original draft & review & editing.

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Data availability

The data are available from the corresponding author on reasonable request.

References

1. Etminan N, Chang HS, Hackenberg K. *et al.* Worldwide incidence of aneurysmal subarachnoid hemorrhage according to region, time period, blood pressure, and smoking prevalence in the population: a systematic review and meta-analysis. *JAMA Neurol* 2019;**76**:588–97. https://doi.org/10.1001/jamaneurol.2019.0006.
2. Liu J, Cao F, Zhenmei N. *et al.* Flow-diverter stents in intracranial aneurysm treatment: impact on covered cerebral artery

branches. *Int J Surg* 2023;**110**:53–65. https://doi.org/10.1097/JS9.0000000000000762.
3. Oliver AA, Carlson KD, Bilgin C. *et al.* Bioresorbable flow diverters for the treatment of intracranial aneurysms: review of current literature and future directions. *J Neurointerv Surg.* 2023;**15**:178–82. https://doi.org/10.1136/neurintsurg-2022-018941.
4. Liu JM, Zhou Y, Li Y. *et al.* Parent artery reconstruction for large or giant cerebral aneurysms using the Tubridge flow diverter: a multicenter, randomized, controlled clinical trial (PARAT). *AJNR Am J Neuroradiol* 2018;**39**:807–16. https://doi.org/10.3174/ajnr.A5619.
5. Fan Y, Lei J, Fei F. *et al.* A novel flow diverter device (Tubridge) for the treatment of intracranial aneurysms: a systematic review and meta-analysis. *Neurosurg Rev* 2023;**46**:198. https://doi.org/10.1007/s10143-023-02100-6.
6. Ghaferi AA, Schwartz TA, Pawlik TM. STROBE reporting guidelines for observational studies. *JAMA Surg* 2021;**156**:577–8. https://doi.org/10.1001/jamasurg.2021.0528.
7. Sohrabi C, Franchi T, Mathew G. *et al.* PRISMA 2020 statement: what's new and the importance of reporting guidelines. *Int J Surg* 2021;**88**:105918. https://doi.org/10.1016/j.ijsu.2021.105918.
8. Mascitelli JR, Moyle H, Oermann EK. *et al.* An update to the Raymond-Roy Occlusion Classification of intracranial aneurysms treated with coil embolization. *J Neurointerv Surg* 2015;**7**:496–502. https://doi.org/10.1136/neurintsurg-2014-011258.
9. White HD, Van de Werf FJ. Thrombolysis for acute myocardial infarction. *Circulation* 1998;**97**:1632–46. https://doi.org/10.1161/01.cir.97.16.1632.
10. Li L, Li T, Shao Q. *et al.* Application of domestic Tubridge flow diverter in the treatment of unruptured intracranial aneurysms. *Chin Neurosurg J* 2019;**35**:909–13. https://doi.org/10.3760/cma.j.issn.1001-2346.2019.09.009.
11. Lv N, Zhou Y, Zhao R. *et al.* Treatment of intracranial aneurysms with Tubridge flow diverter: a single-center experience. *Chin Neurosurg J* 2019;**35**:900–3. https://doi.org/10.3760/cma.j.issn.1001-2346.2019.09.007.
12. Gao G, Zhu H, Zhang Y. *et al.* Flow diverter device Tubridge in intracranial complex aneurysms: an efficacy and safety analysis. *Chin J Neuromed* 2021;**20**:771–5. https://doi.org/10.3760/cma.j.cn115354-20210224-00125.
13. Sun S, Li T, Li L. *et al.* Preliminary application of domestic Tubridge flow diverter in the treatment of vertebral artery dissecting aneurysm. *Chin J Inter Rad (Electronic Edition)* 2021;**9**:160–4. https://doi.org/10.3877/cma.j.issn.2095-5782.2021.02.008.
14. Cai H, Yang F, Xu Y. *et al.* A multicenter retrospective controlled study of the Pipeline™ and Tubridge™ flow diverter devices for intracranial wide-necked aneurysms. *Front Neurol* 2022;**13**:1014596. https://doi.org/10.3389/fneur.2022.1014596.
15. Li S, Lu Z, Tang H. *et al.* Flow diversion for aneurysms beyond the circle of Willis: a preliminary experience. *J Clin Neurosci* 2022;**95**:63–9. https://doi.org/10.1016/j.jocn.2021.11.030.
16. Shi M, Feng Y, Zhang CD. *et al.* Tubridge flow diverter alone vs. Tubridge flow diverter and coils for the treatment of intracranial aneurysms: a propensity score matching analysis. *Front Neurol* 2022;**13**:974354. https://doi.org/10.3389/fneur.2022.974354.
17. Wang C, Zhu D, Xu X. *et al.* Use of flow diverter device in basilar artery for aneurysm treatment: case series and literature review. *Front Neurol* 2022;**13**:990308. https://doi.org/10.3389/fneur.2022.990308.
18. Liu X, Huang C. *The Retrospective Analysis of Domestic Flow Diverter Tubridge in the Treatment of Intracranial Aneurysms [D]*. The People's Republic of China:Southwest Medical University, 2021
19. Xie D, Yang H, Zhao L. *et al.* Tubridge flow diverter for the treatment of small and medium aneurysms. *Front Neurol* 2023;**14**:1054631. https://doi.org/10.3389/fneur.2023.1054631.
20. Jia L, Lv M. Analysis of therapeutic effect of Tubridge flow diverter in the treatment of intracranial aneurysms. *Chin Neurosurg J* 2023;**39**:112–6. https://doi.org/10.3760/cma.j.cn112050-20220406-00181.
21. Lian W, Yao J, Wu Z. *et al.* Flow-diverters in treating unruptured intracranial aneurysms: a study of efficacy and influencing factors. *Chinese J Cerebrovasc Dis (Electronic Edition)* 2023;**17**:31–6. https://doi.org/10.11817/j.issn.1673-9248.2023.01.006.
22. Jin H, Lv J, Meng X. *et al.* Pipeline versus Tubridge in the treatment of unruptured posterior circulation aneurysms. *Chin Neurosurg J* 2023;**9**:22. https://doi.org/10.1186/s41016-023-00337-0.
23. Chancellor B, Raz E, Shapiro M. *et al.* Flow diversion for intracranial aneurysm treatment: trials involving flow diverters and long-term outcomes. *Neurosurgery* 2020;**86**:S36–45. https://doi.org/10.1093/neuros/nyz345.
24. Beydoun HA, Azarbaijani Y, Cheng H. *et al.* Predicting successful treatment of intracranial aneurysms with the pipeline embolization device through meta-regression. *World Neurosurg* 2018;**114**:e938–58. https://doi.org/10.1016/j.wneu.2018.03.120.
25. Florez WA, Garcia-Ballestas E, Quiñones-Ossa GA. *et al.* Silk® flow diverter device for intracranial aneurysm treatment: a systematic review and meta-analysis. *Neurointervention* 2021;**16**:222–31. https://doi.org/10.5469/neuroint.2021.00234.
26. Issa R, Al-Homedi Z, Syed DH. *et al.* Surpass evolve flow diverter for the treatment of intracranial aneurysm: a systematic review. *Brain Sci* 2022;**12**:810. https://doi.org/10.3390/brainsci12060810.
27. Monteiro A, Burke SM, Baig AA. *et al.* A systematic review and meta-analysis of the Derivo Embolization Device: a novel surface-modified flow diverter for intracranial aneurysm treatment. *J Neurointerv Surg* 2022;**14**:1125–9. https://doi.org/10.1136/neurintsurg-2021-018390.
28. Bilgin C, Senol YC, Kobeissi H. *et al.* Phenox HPC and Phenox flow modulation devices for the endovascular treatment of intracranial aneurysms: a systematic review and meta-analysis. *J Neurointerv Surg.* 2023;**16**:706–14. https://doi.org/10.1136/jnis-2023-020514.
29. Lv X, Yang H, Liu P. *et al.* Flow-diverter devices in the treatment of intracranial aneurysms: a meta-analysis and systematic review. *Neuroradiol J* 2016;**29**:66–71. https://doi.org/10.1177/1971400915621321.
30. Kallmes DF, Hanel R, Lopes D. *et al.* International retrospective study of the pipeline embolization device: a multicenter aneurysm treatment study. *AJNR Am J Neuroradiol* 2015;**36**:108–15. https://doi.org/10.3174/ajnr.A4111.
31. Kang H, Luo B, Liu J. *et al.* Postoperative occlusion degree after flow-diverter placement with adjunctive coiling: analysis of complications. *J Neurointerv Surg* 2022;**14**:371–5. https://doi.org/10.1136/neurintsurg-2021-017445.
32. Gu Y, Miao C, Li A. *et al.* High-resolution magnetic resonance imaging (HR-MRI) evaluation of the distribution and characteristics of intra-aneurysm thrombosis to improve clinical diagnosis of thrombotic intracranial aneurysm. *Med Sci Monit* 2022;e935613-1–e935613-10. https://doi.org/10.12659/MSM.935613.

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https://doi.org/10.1093/postmj/qgae109
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