OPEN ACCESS

Original research

Prospective evaluation to characterize the real-world performance of the EMBOVAC aspiration catheter for neurothrombectomy: a post-market clinical follow-up trial

Mariangela Piano,[1] Olav Jansen,[2] Gaultier Marnat ,[3] Benjamin Gory,[4] Hannes Nordmeyer ,[5,6] Bernd Eckert,[7] Alessandro Pedicelli,[8] Christophe Cognard ,[9] Christian Loehr,[10] Matteo Zanoni ,[11] Axel Schaefer,[12] Antonio Macera,[13] Jens Fiehler,[14,15] Karen Doyle,[16] Kyriakos Lobotesis [17]

► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/jnis-2023-021407).

For numbered affiliations see end of article.

Correspondence to
Dr Kyriakos Lobotesis; k.lobotesis@nhs.net

Received 20 December 2023
Accepted 4 March 2024
Published Online First 12 April 2024

To cite: Piano M, Jansen O, Marnat G, *et al*. *J NeuroIntervent Surg* 2025;**17**:254–260.

ABSTRACT

Background A direct aspiration first pass technique (ADAPT) is an effective alternative to stent retriever thrombectomy for patients with large vessel occlusion (LVO). The PERFECT study evaluated direct aspiration with the EMBOVAC large bore aspiration catheter in patients with LVO strokes.

Methods PERFECT was a prospective, post-market, single-arm, multicenter, observational study of patients enrolled across 11 European centers between October 2020 and July 2022. Three direct aspiration passes with EMBOVAC were mandated before switching strategy. The primary endpoint was core-lab assessed successful reperfusion (modified Thrombolysis In Cerebral Infarction (mTICI) ≥2b) post-procedure. Other outcomes included first pass mTICI ≥2c, independent 90-day modified Rankin Scale (mRS) evaluation, and symptomatic intracerebral hemorrhage (sICH) at 24 hours by a clinical events committee.

Results EMBOVAC was used in 100 patients (mean age 70.4±14.0 years, 59.0% (59/100) female). Final mTICI ≥2b was achieved in 98.0% (97/99), final mTICI ≥2b with no change in frontline therapy or thrombolytics use during the procedure was achieved in 87.9% (87/99), final mTICI ≥2c in 86.9% (86/99), and first pass mTICI ≥2c in 53.5% (53/99). sICH at 24 hours was 0%. The 90-day mRS ≤2 rate was 56.6% (56/99) and all-cause mortality was 12.9%. One device-related serious adverse event occurred within 90 days (1.0%).

Conclusions PERFECT demonstrates that EMBOVAC achieves successful reperfusion rates and favorable clinical outcomes when used in the endovascular treatment of acute ischemic stroke (AIS) using a direct aspiration technique as first line therapy in a real-world setting in patients with AIS secondary to large vessel occlusion.

Trial registration www.clinicaltrials.gov Unique identifier: NCT04531904.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Direct aspiration is an alternative to stent retriever thrombectomy in patients with acute ischemic stroke (AIS) secondary to large vessel occlusion. EMBOVAC is a large bore aspiration catheter with an inner diameter of 0.071 inch. The PERFECT study assessed the safety and efficacy of EMBOVAC.

WHAT THIS STUDY ADDS

⇒ In the PERFECT multicenter, post-market observational study, direct aspiration with EMBOVAC as first line therapy resulted in high rates of successful mTICI ≥2b revascularization, fewer device passes, good clinical outcomes, and low complication rates.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The PERFECT study demonstrates the safety and effectiveness of EMBOVAC when used as first line therapy in a real-world, post-market European setting.

INTRODUCTION

A direct aspiration first pass technique (ADAPT) with large bore aspiration catheters alone or combined with other mechanical thrombectomy (MT) techniques has been demonstrated to be safe and effective for treating acute ischemic stroke (AIS) secondary to large vessel occlusion (LVO).[1–5] Three randomized controlled trials (RCTs) have compared the safety and effectiveness of direct aspiration versus stent retrievers: ASTER and Penumbra Separator 3D showed similar successful revascularization rates between techniques,[1 3] and COMPASS demonstrated non-inferiority and shorter first pass recanalization time for aspiration compared with stent retrievers,[5] supporting direct aspiration as an alternative to stent retriever as first line therapy.[6]

EMBOVAC (Cerenovus, Johnson & Johnson) is a large bore, single lumen, variable stiffness aspiration catheter with a 0.071 inch inner diameter, designed to aspirate emboli and thrombi in the neurovasculature either alone or in combination with stent retrievers. The Prospective Evaluation to Characterize the Real-World PerFormance of the EMBOVAC Aspiration Catheter for Neurothrombectomy: A Post-Market Clinical Follow-up Trial

(PERFECT) study was conducted in Europe to assess the efficacy of EMBOVAC when used by multiple interventionalists and centers in AIS patients undergoing MT in a real-world clinical setting.

METHODS

Study design

PERFECT was a prospective, multicenter, single-arm, post-market observational study, evaluating the safety and efficacy of endovascular clot removal with first line ADAPT using EMBOVAC for AIS. To minimize bias and variability, independent imaging core lab assessment (Eppdata, Hamburg, Germany), independent 90-day mRS assessment, and a clinical events committee were used.

Patient population

From October 2020 to May 2022, 100 consecutive AIS patients in 11 European sites were treated per investigator's standard of care (SOC), with EMBOVAC mandated for the first three clot removal passes using ADAPT.[4] Investigators enrolled eligible patients based on pre-specified inclusion and exclusion criteria (online supplemental table 1) after obtaining written informed consent.

Device

EMBOVAC is a large bore aspiration catheter with a 0.071 inch inner diameter designed to remove/aspirate neurovascular emboli/thrombi during AIS treatment. It consists of a single lumen, variable stiffness catheter with a braided reinforced shaft for support. A hydrophilic coating reduces friction during use. The catheter includes a distal radiopaque marker for angiographic visualization, a proximal luer hub for flushing and aspiration attachments, a hemostasis valve, and two peelable introducers. EMBOVAC is available in 125 cm and 132 cm usable length sizes.

Intervention

Baseline data included medical history/demographic information, pre-stroke modified Rankin Scale (mRS) score, National Institutes of Health Stroke Scale (NIHSS) score, and CT/MRI data including initial Alberta Stroke Program Early CT Score (ASPECTS). Intravenous thrombolysis was administered according to standard guidelines in the absence of contraindication.

Patients underwent endovascular MT using EMBOVAC for the first three clot removal passes (if needed) for the target intracranial occlusion using ADAPT.[4] Balloon guide catheter (BGC) use, anesthetic management, and any subsequent MT technique after three EMBOVAC passes were allowed at the operator's discretion.

Patients were assessed 24 hours post-procedure for NIHSS, CT/MRI (independent imaging core lab), and reportable adverse events (AEs); 7 days post-procedure or discharge (−1/+7 days, whichever occurred first) for reportable AEs, NIHSS, and mRS scores if performed per SOC; and 90 days post-procedure for mRS scores (independent assessor), reportable AEs, and NIHSS scores if performed per SOC. Health economics data were collected during the procedure and each follow-up visit.

Outcome measures

The primary endpoint was end of procedure successful revascularization, defined as modified Thrombolysis In Cerebral Infarction (mTICI) ≥2b in the target vessel. Secondary efficacy outcomes included: (1) successful revascularization (final mTICI ≥2b) with no change in frontline therapy or use of thrombolytics during the procedure; (2) complete revascularization (final mTICI ≥2c); (3) first pass mTICI ≥2c; (4) first pass mTICI ≥2b; (5) time to recanalization (arterial puncture to mTICI ≥2b); and (6) 90-day mRS ≤2 (≥75 days). Revascularization was measured by the independent imaging core lab and reported using the expanded TICI (eTICI), inclusive of the 2c rating. For purposes of data comparisons, a minimum threshold of mTICI 2b was equal to eTICI 2b50.

Per the study protocol, during the first three passes of EMBOVAC operators were advised not to use rescue therapy, defined as: (1) any change in frontline device therapy to remove the target occlusion in a vessel ≥2 mm, (2) using intracranial stenting during the procedure, or (3) using an intra-arterial thrombolytic agent during the procedure (eg, tissue plasminogen activator (tPA), urokinase, pro-urokinase). Progression in therapy to address thrombus/occlusion that was no longer appropriate for EMBOVAC treatment (eg, using another device to remove distal occlusion in <2 mm vessel) was considered an appropriate evolution in SOC and not considered rescue therapy.

Safety outcomes included: (1) 90-day device-related serious adverse events (SAEs); (2) 24-hour symptomatic intracerebral hemorrhage (sICH) specified according to the Heidelberg Bleeding Classification,[7] (3) 24-hour post-procedure NIHSS; and (4) 90-day all-cause mortality. SAEs were any adverse event that led to: (1) death; (2) serious deterioration in the health of the subject resulting in either a life-threatening illness or injury, permanent impairment of a body structure or function, including chronic diseases, in-patient or prolonged hospitalization, or medical/surgical intervention to prevent life threatening illness/injury or permanent impairment to a body structure or function; or (3) fetal distress, fetal death, or a congenital abnormality or birth defect.

Health economic-related endpoints included hospitalization length of stay (LOS) for the index procedure and unscheduled rehospitalizations and healthcare resource utilization for the index procedure. LOS in hospitalizations (days) was calculated as date of discharge−date of admission+1.

Statistical analysis

Descriptive summary statistics are presented for all endpoints. The number and percentage of subjects are summarized for categorical variables. Unless specified otherwise, percentages are based on subjects with non-missing values. Descriptive statistics for continuous variables include: number of subjects, mean, standard deviation (SD), median, first quartile (Q1), and third quartile (Q3). All statistical analyses were performed using SAS Studio, version 9.4.

Kaplan-Meier analysis (using product limit estimates) was applied to device-related SAEs and all-cause mortality. Kaplan-Meier event rate and its associated two-sided 95% confidence intervals (95% CI) using log-log transformation were reported. The estimate of standard error was computed using Greenwood's formula. Subjects without events were censored at the date of last contact.

The modified intent-to-treat (mITT) analysis set included all enrolled subjects who received ≥1 EMBOVAC pass (defined as aspiration use followed by evaluation of revascularization with angiography). The mITT analysis set was used to analyze effectiveness endpoints. The safety analysis set included all enrolled subjects in whom treatment was attempted. The safety analysis set was used to analyze safety endpoints.

Subgroup analyses

The primary endpoint was analyzed by: (1) age at consent, (2) vascular location, (3) ASPECTS, (4) baseline NIHSS, (5) aspiration device position when aspiration started in pass 1, and (6) the system approach of using EMBOVAC in combination with CEREBASE using the mITT analysis set. Descriptive statistics for each subgroup were presented when there was a minimum of 10 subjects in all subgroup levels. Confidence intervals were not provided due to limited sample size.

A separate systems approach was used to assess the primary endpoint, and secondary effectiveness and safety endpoints of the mITT analysis set when treated with EMBOVAC in combination with the CEREBASE distal access guide sheath (CEREBASE, Cerenovus, Johnson & Johnson) in any pass, or with EMBOVAC in combination with a non-CEREBASE long sheath in any pass. CEREBASE was designed for use with EMBOVAC and is indicated for the introduction of interventional devices into the neurovasculature. It was designed for atraumatic vessel interaction with soft, compliant, and rounded distal edges and a highly flexible dexterous tip to minimize direct vessel wall contact. Descriptive statistics were presented based on observed data. Confidence intervals were not presented due to limited sample size.

RESULTS

Patient demographics and baseline characteristics

A total of 108 patients consented and 102 were enrolled. Online supplemental figure 1 shows the patient disposition flow chart. Demographic characteristics for the mITT and safety analysis sets are summarized in table 1. Mean age in the mITT group was 70.4±14.0 years, with over half of patients being female (59.0% (59/100)). The most common comorbidities were hypertension (65.0% (65/100)) and atrial fibrillation (43.0% (43/100)). Pre-stroke, most patients had an mRS of 0 (79.0% (79/100)) and an NIHSS ≥8 (86.0% (86/100)). A total of 72.0% (72/100) patients had a witnessed stroke with known onset date and time. Approximately half of patients received intravenous tPA at baseline (51.0% (51/100)). Baseline ASPECTS was 6–10 in 85.0% (85/100). Most occlusions were located in the middle cerebral artery-M1 segment 1 (71.0% (71/100)) and the internal carotid artery/carotid T (21.0% (21/100)). Demographic and baseline characteristics were similar in the safety analysis set.

Procedural characteristics

Procedural characteristics for both mITT and safety analysis sets are summarized in table 2. A total of 59.0% (59/100) mITT patients had general anesthesia. Mean time from symptoms onset to first aspiration attempt was 396.1±357.0 min, with 78.7% (74/94) patients having aspiration attempted ≤8 hours post-stroke. At least one stent retriever was used in 35.0% (35/100) and BGCs were used in 5.0% (5/100) patients. Mean number of total procedural passes was 2.4±2.2 (median (IQR) 1.0 (1.0–3.0)) and the maximum number of procedural passes for any subject was 11 (n=1). A total of 17.0% (17/100) patients were treated with another thrombectomy device at any pass (including a stent retriever combined with EMBOVAC). Within the first three passes of EMBOVAC, 10.0% (10/100) patients underwent either a change in frontline device therapy (7/10) and/or use of stenting (5/10) during the procedure. Procedural characteristics were similar for the safety analysis set. EMBOVAC use was unsuccessful in two patients due to vessel tortuosity.

Table 1 Patient demographics and baseline characteristics

Category	mITT analysis set N=100	Safety analysis set N=102
Age at consent, years (mean±SD)	70.4±14.0	70.6±13.9
Female, n/N (%)	59/100 (59.0%)	61/102 (59.8%)
Medical history, n/N (%)		
Hypertension	65/100 (65.0%)	65/102 (63.7%)
Atrial fibrillation	43/100 (43.0%)	43/102 (42.2%)
Hyperlipidemia	25/100 (25.0%)	25/102 (24.5%)
Diabetes	13/100 (13.0%)	13/102 (12.7%)
History of ischemic stroke	12/100 (12.0%)	12/102 (11.8%)
Smoking (active)	12/100 (12.0%)	12/102 (11.8%)
CAD	8/100 (8.0%)	8/102 (7.8%)
Smoking (previous)	8/100 (8.0%)	8/102 (7.8%)
Myocardial Infarction	7/100 (7.0%)	7/102 (6.9%)
Congestive heart failure	6/100 (6.0%)	6/102 (5.9%)
Previous CABG	5/100 (5.0%)	5/102 (4.9%)
Previous coronary intervention	5/100 (5.0%)	5/102 (4.9%)
DVT	4/100 (4.0%)	4/102 (3.9%)
COPD	3/100 (3.0%)	3/102 (2.9%)
History of TIA	3/100 (3.0%)	3/102 (2.9%)
History of hemorrhagic stroke	2/100 (2.0%)	2/102 (2.0%)
Current drug abuse (cocaine, amphetamine)	1/100 (1.0%)	1/102 (1.0%)
Previous CEA	1/100 (1.0%)	1/102 (1.0%)
Pre-stroke mRS, n/N (%)		
0	79/100 (79.0%)	80/102 (78.4%)
1	19/100 (19.0%)	20/102 (19.6%)
2	1/100 (1.0%)	1/102 (1.0%)
4	1/100 (1.0%)	1/102 (1.0%)
Baseline NIHSS total score, n/N (%)		
<8	14/100 (14.0%)	15/102 (14.7%)
≥8	86/100 (86.0%)	87/102 (85.3%)
Baseline NIHSS total score		
Mean±SD	14.9±6.4	14.8±6.4
Median (IQR)	16.0 (10.5–19.5)	16.0 (9.0–19.0)
Baseline stroke, n/N (%)		
Witnessed stroke with onset date/time known	72/100 (72.0%)	74/102 (72.5%)
Wake-up stroke	9/100 (9.0%)	9/102 (8.8%)
Unwitnessed non-wake up stroke	19/100 (19.0%)	19/102 (18.6%)
Use of IV-tPA for baseline stroke, n/N (%)	51/100 (51.0%)	53/102 (52.0%)
Baseline ASPECT score* n/N (%)		
0	0/100 (0.0%)	0/102 (0.0%)
1	1/100 (1.0%)	1/102 (1.0%)
2	2/100 (2.0%)	2/102 (2.0%)
3	3/100 (3.0%)	3/102 (2.9%)
4	2/100 (2.0%)	2/102 (2.0%)
5	7/100 (7.0%)	7/102 (6.9%)
6	10/100 (10.0%)	10/102 (9.8%)
7	15/100 (15.0%)	15/102 (14.7%)
8	22/100 (22.0%)	23/102 (22.5%)
9	16/100 (16.0%)	17/102 (16.7%)
10	22/100 (22.0%)	22/102 (21.6%)

Continued

Table 1 Continued

Category	mITT analysis set N=100	Safety analysis set N=102
Baseline (pre-procedure) anterior occlusion location*	100/100 (100.0%)	102/102 (100.0%)
ICA/carotid T	21/100 (21.0%)	21/102 (20.6%)
MCA	74/100 (74.0%)	76/102 (74.5%)
M1	71/100 (71.0%)	73/102 (71.6%)
M2	3/100 (3.0%)	3/102 (2.9%)
ACA	1/100 (1.0%)	1/102 (1.0%)
Other	3/100 (3.0%)	3/102 (2.9%)
Cannot determine	2/100 (2.0%)	2/102 (2.0%)

*Assessments made by the independent imaging core lab.
ACA, anterior cerebral artery; ASPECTS, Alberta Stroke Program Early CT Score; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CAS, carotid artery stenting; CEA, carotid artery endarterectomy; COPD, chronic obstructive pulmonary disease; DVT, deep vein thrombosis; ICA, internal carotid artery; IV-tPA, intravenous tissue plasminogen activator; MCA, middle cerebral artery; mITT, modified intent-to-treat; mRS, modified Rankin scale; NIHSS, National Institutes of Health Stroke Scale; TIA, transient ischemic attack.

Hospitalization analysis

Hospitalization analysis for the index procedure and unscheduled rehospitalizations for the mITT analysis set are summarized in online supplemental table 2. Median (IQR) total LOS was 8.0 (4.0–13.0) days and median LOS in the ICU was 3.0 (2.0–5.0) days. Patients with a total index LOS ≤2 days were likely transferred to another hospital. A total of 34.7% (33/95) patients were discharged home with self-care, 33.7% (32/95) discharged to other hospitals, and 24.2% (23/95) discharged to a rehabilitation center. A total of 12.6% (12/95) patients had at least one rehospitalization with a total of 14 rehospitalizations. Median LOS for rehospitalizations was 9.0 (8.0–20.0) days.

Efficacy and safety outcomes

Efficacy and safety outcomes are summarized in table 3. In the mITT analysis set, successful end-of-procedure mTICI ≥2b revascularization was achieved in 98.0% (97/99) of patients, with 87.9% (87/99) achieving successful procedural revascularization with no change in frontline therapy or use of thrombolytics during the procedure. A total of 86.9% (86/99) patients had complete procedural revascularization (final mTICI ≥2c), 53.5% (53/99) reached mTICI ≥2c following the first pass with EMBOVAC, and 72.7% (72/99) reached mTICI ≥2b following the first pass with EMBOVAC. Mean time to recanalization was 27.8±20.6 min and the 90-day mRS ≤2 rate was 56.6% (56/99). In the safety analysis set, the rate of device-related SAEs within 90 days was 1.0% (one patient with cerebral artery occlusion) and there were no instances of 24-hour sICH. Mean NIHSS at baseline was 14.8±6.4 and at 24 hours post-procedure was 8.0±6.4, with a mean change of −6.9±6.4. All-cause 90-day mortality was 12.9%.

Subgroup analysis

Online supplemental table 3 summarizes successful revascularization analyzed by subgroups, including patients aged ≤65 or >65 years, vascular location, ASPECTS (0–5, 6–7, and 8–10), baseline NIHSS <8 or >8, EMBOVAC used in combination with or without CEREBASE, and the aspiration device position <5 mm or >5 mm from the clot interface in the first pass. Outcomes were similar between each subgroup. In one subject, poor-quality images were not assessed by the core lab.

Systems approach

Online supplemental table 4 summarizes the safety and effectiveness endpoints in a subgroup of patients where EMBOVAC was used in combination with either CEREBASE (n=14) or other devices (n=51). The rate of successful revascularization (final mTICI ≥2b) when EMBOVAC was used in combination with CEREBASE (ie, no stent retriever used) in any pass was 100.0% (14/14) and with a non-CEREBASE long sheath was 98.0% (49/50). First pass mTICI ≥2c with no change in frontline therapy or use of thrombolytics during the procedure with CEREBASE was 85.7% (12/14) and with non-CEREBASE was 70.0% (35/50). Mean time to recanalization was 17.4 min with CEREBASE and 24.2 min with non-CEREBASE. The 90-day mRS ≤2 with CEREBASE was 78.6% (11/14) and with non-CEREBASE was 54.9% (28/51). The 90-day all-cause mortality was 0% with CEREBASE and 17.9% with non-CEREBASE.

DISCUSSION

PERFECT is the first clinical study of EMBOVAC characterizing the performance of EMBOVAC using ADAPT for AIS patients in a real-world, post-market clinical setting. EMBOVAC demonstrated high rates of successful mTICI ≥2b revascularization, few device passes, good clinical outcomes, and low complication rates, demonstrating the safety and effectiveness of EMBOVAC. Our systems approach analysis also demonstrated good angiographic and safety outcomes when EMBOVAC was used together with CEREBASE, supporting the use of these devices together.

Efficacy outcomes

PERFECT demonstrated high rates of final successful mTICI ≥2b revascularization with EMBOVAC used as a first-line contact aspiration approach, similar to studies with comparable patient populations. Three RCTs (ASTER,[3] Penumbra Separator 3D,[1] and COMPASS[5]) compared endovascular approaches of aspiration versus stent retriever thrombectomy. In ASTER, the rate of core lab-adjudicated successful end-of-procedure revascularization (mTICI ≥2b) after first-line contact aspiration was 85.4%.[3] In Penumbra Separator 3D, mTICI ≥2b was achieved in 75.8% of patients per core lab.[1] In COMPASS, TICI ≥2b at final assessment was achieved in 92% of patients who received aspiration first pass thrombectomy.[5] Several meta-analyses have assessed successful revascularization rates with direct aspiration, including one specifically evaluating the efficacy of the SOFIA catheter, which reported mTICI ≥2b rates from 88.65–89%.[8–10] Additionally, EMBOVAC had comparable rates of first pass mTICI ≥2b and mTICI ≥2c compared with a meta-analysis of nine studies using the SOFIA catheter for direct aspiration (first pass effect (FPE) 23.6%, modified FPE 36.1%),[8] a meta-analysis by Arturo Larco *et al*[11] of 13 studies assessing per-pass recanalization (FPE 32%, modified FPE 40%), COMPASS (modified FPE 57%),[5] and a study by Baek *et al*[12] assessing per-pass recanalization rates (modified FPE 45.3%). It is worth noting that, in PERFECT, 16% (16/100) of patients in the mITT and 16.7% (17/102) of patients in the safety analysis sets were treated without a microcatheter during the procedure, creating less than optimal support configuration, although good outcomes were still achieved with EMBOVAC.

Frontline therapy

Compared with applicable literature, successful revascularization rates without changing frontline therapy or using thrombolytics during the procedure in PERFECT are similar to the relevant RCTs, ranging from 63–83%.[1 3 5] In ASTER, successful

Table 2 Procedural characteristics

Category	mITT analysis set n=100	Safety analysis set n=102
Type of sedation used, n/N (%)		
General anesthesia	59/100 (59.0%)	59/102 (57.8%)
Local anesthesia	7/100 (7.0%)	7/102 (6.9%)
Conscious sedation	34/100 (34.0%)	36/102 (35.3%)
Femoral arterial puncture, n/N (%)	100/100 (100.0%)	102/102 (100.0%)
Time to arterial puncture since stroke onset, n	94	96
Median (IQR) (minutes)	268.5 (183.0–389.0)	268.5 (183.5–388.0)
Mean±SD (minutes)	377.1±357.7	374.0±354.6
Time to first aspiration attempt since stroke onset, n	94	94
Median (IQR) (minutes)	281.0 (199.0–400.0)	281.0 (199.0–400.0)
Mean±SD (minutes)	396.1±357.0	396.1±357.0
Time to first aspiration attempt since stroke onset by subgroup, n/N (%)		
≤8 hours	74/94 (78.7%)	74/94 (78.7%)
>8 hours	20/94 (21.3%)	20/94 (21.3%)
Type of post-thrombectomy intervention if used, n/N (%)	6/100 (6.0%)	6/102 (5.9%)
Proximal lesion stenting	1/6 (16.7%)	1/6 (16.7%)
Target lesion stenting	5/6 (83.3%)	5/6 (83.3%)
Target lesion angioplasty	5/6 (83.3%)	5/6 (83.3%)
Use of stent retrievers, n/N (%)		
At least once	35/100 (35.0%)	35/102 (34.3%)
First use of stent retriever within first 3 procedural passes for vessels >2.0 mm	6/100 (6.0%)	6/102 (5.9%)
First use of stent retriever within first 3 procedural passes for vessels <2.0 mm	14/100 (14.0%)	14/102 (13.7%)
First use of stent retriever after 3 passes	15/100 (15.0%)	15/102 (14.7%)
None	65/100 (65.0%)	67/102 (65.7%)
Use of BGC, n/N (%)	5/100 (5.0%)	5/102 (4.9%)
Use of microcatheter, n/N (%)	84/100 (84.0%)	85/102 (83.3%)
Total number of EMBOVAC passes, n/N (%)		
Zero passes	0/100 (0.0%)	2/102 (2.0%)
One pass	59/100 (59.0%)	59/102 (57.8%)
Two passes	15/100 (15.0%)	15/102 (14.7%)
Three passes	11/100 (11.0%)	11/102 (10.8%)
Four passes	4/100 (4.0%)	4/102 (3.9%)
Five passes	9/100 (9.0%)	9/102 (8.8%)
Six passes	1/100 (1.0%)	1/102 (1.0%)
Eleven passes	1/100 (1.0%)	1/102 (1.0%)
Total number of EMBOVAC passes, mean±SD	2.0±1.6	2.0±1.6
Total number of non-EMBOVAC passes, mean±SD	0.4±1.1	0.5±1.2
Total number of passes (all devices), mean±SD	2.4±2.2	2.4±2.2
Rescue therapy during the first three passes of EMBOVAC	10/100 (10.0%)	11/102 (10.8%)
Any change in frontline device therapy to remove the target occlusion in a vessel of at least 2.0 mm in size	7/10 (70.0%)	7/11 (63.6%)
Pass 1	1/7 (14.3%)	1/7 (14.3%)
Pass 2	3/7 (42.9%)	3/7 (42.9%)
Pass 3	4/7 (57.1%)	4/7 (57.1%)
Use of intracranial lesion stenting during procedure	5/10 (50.0%)	5/11 (45.5%)
Use of intra-arterial thrombolytic agent during the procedure	0/10 (0.0%)	0/11 (0.0%)

BGC, balloon guide catheter; mITT, modified intent-to-treat.

revascularization after first-line contact aspiration alone yielded an mTICI ≥2b rate of 63.0%.[3] In Penumbra Separator 3D, mTICI ≥2b was achieved in 69.8% of patients who received aspiration alone.[1] In COMPASS, rates of TICI 2b with the primary modality of aspiration first pass thrombectomy were 83%.[5]

Safety outcomes

The good functional outcome rate was higher in PERFECT compared with other studies. In the meta-analysis by Gory *et al*, the 90-day mRS ≤2 rate was 52.0%,[10] and the meta-analysis by Phan *et al*[13] reported 52.3%. The SOFIA meta-analysis reported a 90-day mRS ≤2 rate of 40.3%.[8] The ASTER trial

Table 3 Efficacy and safety outcomes using EMBOVAC

Endpoint	Number of subjects n/N (%)	95% exact binomial CI
Successful revascularization (final mTICI ≥2b)*	97/99 (98.0%)	(92.9% to 99.8%)
Successful revascularization (final mTICI ≥2b) with no change in frontline therapy or use of thrombolytics during the procedure*	87/99 (87.9%)	(79.8% to 93.6%)
Complete revascularization (final mTICI ≥2c)*	86/99 (86.9%)	(78.6% to 92.8%)
First pass effect (mTICI ≥2c)*	53/99 (53.5%)	(43.2% to 63.6%)
Modified first pass effect (mTICI ≥2b)*	72/99 (72.7%)	(62.9% to 81.2%)
Time to recanalization, n	71	
Mean±SD, minutes	27.8±20.6	
Median (IQR), minutes	22.0 (15.0–34.0)	
mRS ≤2 at 90 days (independently assessed)	56/99 (56.6%)	(46.2% to 66.5%)
sICH at 24 hours post-procedure per CEC	0/101 (0.0%)	(0.0% to 3.6%)
24-hour post-procedure NIHSS total score, n	101	
Mean±SD	8.0±6.4	
Median (IQR)	6.0 (3.0–12.0)	
Change from baseline NIHSS total score, n	101	
Mean±SD	−6.9±6.4	
Median (IQR)	−7.0 (−11.0 to −3.0)	

				Event (failure) probability		
	Number of subjects with events	Number of subjects censored	Number of subjects at risk	Point estimate	Standard error	95% CI
90-day device-related SAEs per CEC†	1	33	71	1.0%	0.0099	(0.1% to 6.8%)
90-day all-cause mortality†	13	21	71	12.9%	0.0335	(7.7% to 21.2%)

*Assessments made by the independent imaging core lab.
†Safety analysis set.
CEC, clinical events committee; mITT, modified intent-to-treat; mRS, modified Rankin Scale; mTICI, modified Thrombolysis In Cerebral Infarction; NIHSS, National Institutes of Health Stroke Scale; SAE, serious adverse event; sICH, symptomatic intracerebral hemorrhage.

reported a 45.3% rate of 90-day mRS ≤2 for first-line contact aspiration,[3] Penumbra Separator 3D reported 45.8% for patients treated with aspiration alone,[1] and COMPASS reported 52% for aspiration first pass thrombectomy.[5] These trials also had blinded mRS assessment. The 90-day all-cause mortality rate in PERFECT is comparable to or better than other published rates, including Gory *et al* (15.0%),[10] Phan *et al* (12.5% for patients receiving ADAPT),[13] ASTER (19.3% in patients with first-line contact aspiration),[3] Penumbra Separator 3D (26.0% in patients receiving aspiration alone),[1] COMPASS (22% in patients with aspiration first-pass thrombectomy),[5] and the SOFIA meta-analysis (21.8%).[8] There were no cases of sICH in PERFECT per independent clinical events committee adjudication of all ICH identified by the independent core imaging laboratory and a low procedural complication risk, supporting a good safety profile for EMBOVAC.

Limitations

PERFECT was a single-arm study with no direct comparison to other devices. Independent imaging core laboratory and clinical outcome assessors were not blinded to device use because all patients used EMBOVAC. The independent imaging core laboratory was designed to mitigate potential site bias with an independent and standardized image assessment. The 90-day mRS assessors were required to be independent and not involved in previous assessments, treatments, or data entry for subjects. All safety endpoints were adjudicated by an independent clinical events committee, providing an impartial and standardized review of these events. PERFECT took place during the COVID-19 pandemic, which may have had an impact on the consistency of follow-up times and health of the patients, who are considered high risk for contracting COVID-19. The inclusion/exclusion criteria and the allowance of patient consent post-procedure introduces potential selection bias. Additionally, the small sample size limited subgroup and correlation analysis, restricting conclusions and generalizability.

Conclusion

The PERFECT study demonstrates that in the endovascular treatment of AIS using a direct aspiration technique, EMBOVAC achieves successful reperfusion with clinical outcomes comparable to those reported in the literature. The PERFECT study demonstrates that EMBOVAC is safe and efficacious in a real-world setting in patients with AIS secondary to large vessel occlusion.

Author affiliations
[1]Neuroradiology, Ospedale Niguarda Ca' Granda, Milano, Italy
[2]University Hospital, Christian-Albrechts – University Kiel, Kiel, Germany
[3]Interventional and Diagnostic Neuroradiology, Bordeaux University Hospital, Bordeaux, France
[4]Department of Diagnostic and Interventional Neuroradiology, CHRU Nancy, Nancy, Lorraine, France
[5]Neuroradiology, Städtisches Klinikum Solingen, Department of Diagnostic and Interventional Neuroradiology, Solingen, Germany
[6]Witten/Herdecke University, Department of Health, School of Medicine, Witten, Germany
[7]Neuroradiology, Asklepios Clinic Altona, Hamburg, Germany
[8]Radiological Sciences, Catholic University of Sacred Heart, "A. Gemelli" Hospital, Rome, Italy
[9]Diagnostic and Therapeutic Neuroradiology, Hôpital Purpan, Toulouse, France
[10]Department of Radiology and Neuroradiology, Klinikum Vest GmbH, Recklinghausen, Nordrhein-Westfalen, Germany

[11]Department of Medicine, Surgery and Neurosciences, Diagnostic Imaging Unit, University of Siena, Siena, Siena, Italy
[12]Klinikum Vest Knappschaftskrankenhaus Recklinghausen, Department of Radiology and Neuroradiology, Recklinghausen, Germany
[13]Department of Advanced Biomedical Sciences, Ospedale Niguarda Ca Granda, Milano, Lombardia, Italy
[14]University Medical Center Hamburg-Eppendorf, Hamburg, Germany
[15]Eppdata GmbH, Hamburg, Germany
[16]Physiology, CURAM, University of Galway, Galway, Ireland
[17]Imaging Department, Imperial College Healthcare NHS Trust, London, UK

Acknowledgements First, the authors would like to acknowledge Superior Medical Experts for editorial assistance. The authors would also like to acknowledge the contribution of the independent Clinical Events Committee members Chairperson Dr Heinrich Mattle (Department of Neurology, University of Bern), Dr Gerhard Schroth (Department of Interventional Neuroradiology, University of Bern), and Dr Mohamed Aggour (Department of Interventional Neuroradiology, The Royal London Hospital) for their assistance with study endpoints adjudication.

Contributors MP, OJ: concept and design, data acquisition, critical revision of the manuscript for important intellectual content. GM, BG, HN, BE, AP, CC, CL, MZ, AS, AM: data acquisition, critical revision of the manuscript for important intellectual content. JF, KD: data acquisition, analysis, and interpretation, critical revision of the manuscript for important intellectual content. KL: guarantor, concept and design, data acquisition, analysis, and interpretation, manuscript drafting, critical revision of the manuscript for important intellectual content, supervision.

Funding The PERFECT study is sponsored by Cerenovus, Johnson & Johnson. Grant number: N/A.

Competing interests OJ: personal fees: Fa. Arcandis/Germany. GM: payment/honoraria for lectures, presentations, Speakers Bureaus, manuscript writing, educational events: Medtronic, Microvention; consulting fees: Stryker Neurovascular, Microvention Europe, Balt SAS, Sim and Size; paid lectures: Medtronic 675, Cerenovus, Bracco, Phenox. BG: consulting fees: Surge2surgery. HN: payment/honoraria for lectures, presentations, educational events: Acandis, Cerenovus, Phenox, Rapid medical. CC: payment/honoraria for lectures, presentations, Speakers bureaus, manuscript writing, educational events: Medtronic, Microvention, MIVI, Stryker. CL: proctoring/consultant services: Phenox; consultant services: Penumbra; travel and meeting expenses: Acandis, Penumbra; payment of honoraria for lectures and support for attending meetings: Phenox, Penumbra, Acandis. AS: employed by/holds shares: GSK. JF: research support: German Ministry of Science and Education, German Ministry of Economy and Innovation, German Research Foundation, European Union, Hamburgische Investitions-/ Förderbank, Medtronic, Microvention, Philips, Stryker; consultancy appointments: Acandis, Bayer, Boehringer Ingelheim, Cerenovus, Medtronic, Microvention, Penumbra, Phenox, Roche, Route92, Stryker, Tonbridge, TG Medical; stock holdings: Tegus Medical, Vastrax, Eppdata. KD: academic grants: Science Foundation Ireland. MP, BE, AP, MZ, AM, KL: nothing to disclose.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by 1) CPP Nord-Ouest I (2021-A00659-32), 2) Ethik-Kommission der Ärztekammer Hamburg (2020-10052-BO-bet), 3) Ethik-Kommission der Christian-Albrechts-Universitat zu Kiel (D 516/20), 4) Ethik-Kommission der Medizinischen Fakultät der Ruhr-Universität Bochum (2020-724-b-S), 5) Ethik-Kommission der Ärztekammer Nordrhein (2021382), 6) Comitato Etico Univ. Cattolica del Sacro Cuore Policlinico Universitario Agostino Gemelli (3371), 7) Comitato Etico Milano Area 3 (343-18052022), 8) Comitato Etico Regione Toscana - Area Vasta Sud-Est (C.E.A.V.S.E.) (19941), 9) NRES Committee London - South East (20/LO/1111). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

ORCID iDs
Gaultier Marnat http://orcid.org/0000-0002-7611-7753
Hannes Nordmeyer http://orcid.org/0000-0002-8049-1203
Christophe Cognard http://orcid.org/0000-0003-4287-2627
Matteo Zanoni http://orcid.org/0000-0002-5847-3316
Kyriakos Lobotesis http://orcid.org/0000-0001-5093-9751

REFERENCES

1 Nogueira RG, Frei D, Kirmani JF, *et al*. Safety and efficacy of a 3-dimensional stent retriever with aspiration-based thrombectomy vs aspiration-based thrombectomy alone in acute ischemic stroke intervention: a randomized clinical trial. *JAMA Neurol* 2018;75:304–11.
2 Maus V, Behme D, Kabbasch C, *et al*. Maximizing first-pass complete reperfusion with SAVE. *Clin Neuroradiol* 2018;28:327–38.
3 Lapergue B, Blanc R, Gory B, *et al*. Effect of endovascular contact aspiration vs stent retriever on revascularization in patients with acute ischemic stroke and large vessel occlusion: the ASTER randomized clinical trial. *JAMA* 2017;318:443–52.
4 Turk AS, Spiotta A, Frei D, *et al*. Initial clinical experience with the ADAPT technique: a direct aspiration first pass technique for stroke thrombectomy. *J Neurointerv Surg* 2014;6:231–7.
5 Turk AS, Siddiqui A, Fifi JT, *et al*. Aspiration thrombectomy versus stent retriever thrombectomy as first-line approach for large vessel occlusion (COMPASS): a multicentre, randomised, open label, blinded outcome, non-inferiority trial. *Lancet* 2019;393:998–1008.
6 Mokin M, Ansari SA, McTaggart RA, *et al*. Indications for thrombectomy in acute ischemic stroke from emergent large vessel occlusion (ELVO): report of the SNIS standards and guidelines committee. *J Neurointerv Surg* 2019;11:215–20.
7 von Kummer R, Broderick JP, Campbell BCV, *et al*. The Heidelberg bleeding classification: classification of bleeding events after ischemic stroke and reperfusion therapy. *Stroke* 2015;46:2981–6.
8 Bolognini F, Lebedinsky PA, Musacchio M, *et al*. SOFIA catheter for direct aspiration of large vessel occlusion stroke: a single-center cohort and meta-analysis. *Interv Neuroradiol* 2021;27:850–7.
9 Primiani CT, Vicente AC, Brannick MT, *et al*. Direct aspiration versus stent retriever thrombectomy for acute stroke: a systematic review and meta-analysis in 9127 patients. *J Stroke Cerebrovasc Dis* 2019;28:1329–37.
10 Gory B, Armoiry X, Sivan-Hoffmann R, *et al*. A direct aspiration first pass technique for acute stroke therapy: a systematic review and meta-analysis. *Eur J Neurol* 2018;25:284–92.
11 Arturo Larco J, Abbasi M, Liu Y, *et al*. Per-pass analysis of recanalization and good neurological outcome in thrombectomy for stroke: systematic review and meta-analysis. *Interv Neuroradiol* 2022;28:358–63.
12 Baek J-H, Kim BM, Heo JH, *et al*. Number of stent retriever passes associated with futile recanalization in acute stroke. *Stroke* 2018;49:2088–95.
13 Phan K, Dmytriw AA, Teng I, *et al*. A direct aspiration first pass technique vs standard endovascular therapy for acute stroke: a systematic review and meta-analysis. *Neurosurgery* 2018;83:19–28.