Safety, Efficacy and Outcome of Rotational Thrombectomy assisted Endovascular Revascularisation of the Superior Mesenteric Artery in Acute Thromboembolic Mesenteric Ischaemia

Thrombembolischer Verschluss der A. mesenterica superior bei akuter Mesenterialischämie: Wirksamkeit und Sicherheit additiver Rotations-Thrombektomie bei der endovaskulären Revaskularisation

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ABSTRACT

Purpose To evaluate the efficacy and safety of percutaneous rotational thrombectomy-assisted endovascular revascularization of acute thromboembolic superior mesenteric artery occlusions in acute mesenteric ischemia.

Materials and Methods Fifteen cases of percutaneous rotational thrombectomy- assisted (Rotarex S, BD, USA) revascularization were retrospectively analyzed. The etiology was embolic in 40 % of cases and thrombotic in 60 %. A "Thrombectomy in Visceral Ischemia" (TIVI) 5-point score determined vessel patency at presentation, after percutaneous rotational thrombectomy, and after adjunctive technologies. TIVI 3 indicated nearly complete revascularization (minimal residual side branch thrombus). TIVI 4 indicated complete revascularization. Technical success was defined as successful device application and a final TIVI score of 3/4 after adjunctive technologies. Safety and outcome were also analyzed.

Results Device application via femoral access was feasible in 100 % of cases and improved flow in 86.7 % of cases (1 × TIVI 0→1, 11 × TIVI 0→2, 1 × TIVI 1→2). There was no change in 13.3 % of cases (2 × TIVI 2→2). Additional devices resulted in further flow improvement in 93.3 % of cases (8 × TIVI 3, 6 × TIVI 4). One recanalization failed (TIVI 2→2→2). After adjunctive technologies (10 × manual aspiration, 11 × angioplasty, 9 × stenting), the technical success rate was 93.3 %. The mean procedure time was 40.5(± 14) minutes for embolism and 72.1(± 20) minutes for thrombosis. There was one device-related major complication (catheter tip fracture) resulting in a device-related safety rate of 93.3 %. The overall major complication rate was 20 %. Surgical exploration (13 ×), bowel resection (9 ×) and Fogarty embolectomy/bypass (3 ×) were also performed. The 30-day mortality rate was 40 %.

Conclusion Percutaneous rotational thrombectomy is an effective adjunct for rapid endovascular recanalization of acute thromboembolic superior mesenteric artery occlusions with an acceptable rate of major procedural complications.

Key Points

- Percutaneous rotational thrombectomy-assisted superior mesenteric artery revascularization in acute occlusive mesenteric ischemia is feasible and effective.
- Percutaneous rotational thrombectomy facilitates rapid flow restoration in native and stented superior mesenteric artery segments.
- Brachial access should be considered in the case of steep take-off angles of the superior mesenteric artery.

ZUSAMMENFASSUNG

Ziel Evaluation von Wirksamkeit und Sicherheit additiver perkutaner Rotationsthrombektomie bei der endovaskulären Therapie akuter thrombembolischer Verschlüsse der Arteria mesenterica superior.

Material und Methoden Retrospektive Auswertung von 15 Fällen akut okklusiver Mesenterialischämie, bei denen eine perkutane Rotationsthrombektomie (Rotarex S, BD, USA) als additives endovaskuläres Verfahren eingesetzt wurde. Ursachen waren Emboli in 40 % und Thrombosen in 60 %. Ein „Thrombektomie In Viszeraler Ischämie" (TIVI)-5-Punkte-Score wurde als angiographischer Parameter zu Beginn der Intervention, nach perkutaner Rotationsthrombektomie und nach dem Einsatz additiver Verfahren erhoben. TIVI 3 stand für nahezu komplette Gefäßeröffnung mit winzigen Thrombusresten in Seitästen. TIVI 4 bedeutete vollständige Rekanalisation. Technischer Erfolg, definiert als erfolgreiche Rotarex-Applikation in Kombination mit einem TIVI-score 3/4 am Interventionsende, Sicherheit und Outcome wurden zusätzlich analysiert.

Ergebnisse Von femoral gelang der Einsatz von Rotarex zu 100 % und konnte den Fluss in 86,7 % der Fälle verbessern (1 × TIVI 0→1, 11 × TIVI 0→2 und 1 × TIVI 1→2). Bei 13,3 % gab es keine Verbesserung (2 × TIVI 2→2). Nach additiven Verfahren weitere Flussverbesserung in 93,3 % (8 × TIVI 3, 6 × TIVI 4). Eine Rekanalisation war frustran (TIVI 2→2→2). Die technische Erfolgsrate nach additiven Verfahren (10x manuelle Aspiration, 11 × Angioplastie, 9 × Stenting) war 93,3 %. Die mittlere Interventionsdauer betrug 40,5(± 14) min bei akuter Embolie und 72,1(± 20) min bei akuter Thrombose. Wegen einer schweren Komplikation (Katheterspitzenbruch) lag die gerätebezogene Sicherheitsrate bei 93,3 %. Die Gesamtrate an Major-Komplikationen betrug 20 %. Es erfolgten zudem 13 chirurgische Explorationen, 9 Darmresektionen und 3 chirurgische Revaskularisationen. Die 30-Tage-Mortalitätsrate war 40 %.

Schlussfolgerung: Perkutane Rotationsthrombektomie unterstützt eine schnelle, effektive endovaskuläre Revaskularisation bei akut okklusiver Mesenterialischämie mit einer akzeptablen Rate an prozedurbedingten Major-Komplikationen.

Kernaussagen

- Ergänzende perkutane Rotationsthrombektomie bei der Rekanalisation akuter Verschlüsse der Arteria mesenterica superior ist praktikabel und wirksam.
- Die perkutane Rotationsthrombektomie unterstützt eine schnelle Revaskularisation von nativen und gestenteten Abschnitten der Arteria mesenterica superior.
- Bei steilen Abgangswinkeln der Arteria mesenterica superior ist ein brachialer Zugang ratsam.

Zitierweise

- Thurner A, Peter D, Dalla Torre G et al. Safety, Efficacy and Outcome of Rotational Thrombectomy assisted Endovascular Revascularisation of the Superior Mesenteric Artery in Acute Thromboembolic Mesenteric Ischaemia. Fortschr Röntgenstr 2024; DOI 10.1055/a-2234-0333

Introduction

Current guidelines recommend endovascular techniques as the first-line treatment for patients with acute embolic or thrombotic occlusion of the superior mesenteric artery (SMA) when immediate surgical intervention is not required and specific expertise is available [1]. In addition, the proportion of thrombotic AMIs (TAMIs) has increased significantly in recent years, while cases of embolic AMIs (EAMIs) are less common [2].

Mechanical thrombectomy devices are available for use in peripheral arteries to rapidly remove atherosclerotic plaque and acute and/or subacute thrombus. They may therefore facilitate endovascular visceral revascularization procedures in occlusive AMI by allowing rapid thrombus removal and additional atherectomy. However, data on their use in visceral arteries are scarce [3–7].

The aim of this clinical investigation was to evaluate the safety, efficacy, and outcome of using a dedicated percutaneous rotational thrombectomy (PRT) device in combination with adjunctive technologies in patients with occlusive AMI.

Materials and Methods

A retrospective review of all patients who underwent endovascular revascularization of a thromboembolic SMA occlusion at our tertiary care center between May 2011 and January 2022 was performed. 15 patients (6 men, 9 women; mean age 65.7 ± 9 years) who underwent endovascular recanalization of the SMA using the Rotarex PRT device (BD, Franklin Lakes, NJ, USA) were identified.

Data on patient demographics, medical history, clinical symptoms, laboratory values, imaging results, and the post-procedure follow-up including surgical treatment, morbidity, and mortality were collected from the patients' electronic medical records and the Picture Archiving Communication System.

Patients gave written informed consent before the procedure. The study was conducted in accordance with the Declaration of Helsinki and its later amendments. The requirement for patient consent for inclusion in this retrospective evaluation was waived by the local ethics committee.

Clinical presentation and imaging findings

All patients presented with acute abdominal pain. Of these, 66.7 % had mild to moderate peritonism. Sepsis was noted in three patients. One of these patients had infective prosthetic mitral valve endocarditis with septic embolism. A second septic patient developed acute-on-chronic TAMI with shock following high-energy polytrauma. The third patient, newly diagnosed with aggressive T-cell lymphoma, developed shock following severe paraneoplastic multiple system thromboembolism.

Of the five patients with malignant disease, a further three had a newly diagnosed or progressive disease concurrent with the diag-

nosis of AMI (i. e., pancreatic cancer (n = 2) and lung cancer (n = 1)). Patient characteristics are shown in ▶ **Table 1**.

Contrast-enhanced CT scans were available in fourteen cases. All patients had vessel-filling defects in the SMA. The median occlusion length was 39.3 mm (range: 10–98). The probable etiology of AMI was embolism in 40 % of cases and arterial thrombosis in 60 % of cases. In the nine patients with TAMI, CTA showed two cases of single visceral artery disease, one case of double, and six cases of triple. 60 % of the target vessels were non-calcified or mildly calcified.

Thrombotic material was lodged in proximal side branches of the SMA in 73.3 % of cases. In-stent occlusion occurred in five patients. The indications for previously implanted bare metal or covered stents were chronic mesenteric ischemia (n = 4) and post-pancreatectomy hemorrhage (n = 1).

Bowel dilatation and hazy mesentery were present in > 70 % of the cases. However, limited pneumatosis intestinalis was recorded in only two cases. Imaging findings are included in ▶ **Table 1**.

Treatment decision

If clinical and/or imaging findings were highly suggestive of occlusive AMI, all patients received therapeutic anticoagulation (bolus of 5000 IU unfractionated heparin followed by continuous infusion of 10 000 IU/24h; target activated partial thromboplastin time 60 s). A multidisciplinary on-call team consisting of visceral surgeons, vascular surgeons, and interventional radiologists immediately determined the further treatment strategy.

Patients with evidence of advanced ischemia, defined as severe peritonitis, metabolic acidosis, extensive pneumatosis/portal gas or free intra-abdominal gas on imaging, or hemodynamic instability underwent immediate surgery, if comorbidities and clinical status allowed for the option of curative treatment. The endovascular approach was the first-line treatment for patients without indications for immediate surgery.

In cases where small thromboemboli were found distally in the SMA, standard manual aspiration thrombectomy was performed (e. g., small emboli at the level where the right colic artery originates before the ilieocolic artery as the terminal branch of the SMA).

The rationale for using PRT as an adjunct to standard endovascular revascularization was to restore flow to the main stem of the SMA as quickly as possible. In cases of high thrombus burden in the main stem of the SMA or acute-on-chronic SMA occlusions, manual aspiration thrombectomy alone can be time-consuming or ineffective, further delaying rapid and effective revascularization. In order to consider adjunctive PRT, the following inclusion/exclusion criteria had to be met:

- No need for immediate surgical intervention
- Availability of specific personal expertise and technical skills
- Adequate target vessel diameter according to the 6F Rotarex device instructions for use (> 3 mm)
- Absence of massive target vessel calcification
- Complex SMA lesions, such as high thrombus burden within the main stem of the SMA, long segment occlusions, in-stent occlusions, acute-on-chronic occlusions, or emboli associated with malignancy, vasculitis, or Covid-19 disease
- Delayed diagnosis (optional)

▶ **Table 1** Patient characteristics and imaging findings (CT/angiography).

Patient characteristics	
▪ Age, y	65.7 (± 9)
▪ Female gender	9 (60)
▪ Body mass index, kg/m²	25.1 (± 7)
Cardiovascular risk factors	
▪ Tobacco use (> 20 pack years)	4 (26.7)
▪ Arterial hypertension	11 (73.3)
▪ Dyslipidemia	8 (53.3)
▪ Diabetes mellitus	3 (20)
▪ Anemia (hemoglobin < 13.5 g/dl; hematocrit < 40 %)	6 (40)
Cardiovascular history	
▪ Coronary bypass surgery/valve repair/prosthetic valve endocarditis	5 (33.3)
▪ Stroke/peripheral artery disease	6 (40)
▪ Atrial fibrillation/cardiac thrombi/left ventricular aneurysm	5 (33.3)
Other relevant comorbidities	
▪ Malignancy	5 (33.3)
▪ Vasculitis (polyarteritis nodosa with visceral aneurysms)	1 (6.7)
▪ Severe COVID-19 disease	1 (6.7)
Clinical and imaging findings at presentation	
Acute abdominal pain	15 (100)
Diarrhea/hematochezia	9 (60)
Peritonism	10 (66.7)
Sepsis	3 (20)
Probable etiology of AMI	
▪ *Embolic*	6 (40)
▪ *Thrombotic*	9 (60)
In-stent occlusion	5 (33.3)
Underlying visceral artery disease in thrombotic AMI	
▪ *Single*	2 (13.3)
▪ *Double*	1 (6.7)
▪ *Triple*	6 (40)
Calcium load SMA	
▪ *None to mild (< 25 % circumference)*	9 (60)
▪ *Moderate (25–50 %)*	3 (20)
▪ *Severe (> 50 % or circumferential)*	3 (20)
Take-off angle aorta-SMA, degree	47.1 (± 18)
Bowel/peritoneum on computed tomography	
▪ *Diminished or absent enhancement of bowel wall*	9 (64.3)
▪ *Bowel dilatation*	11 (78.6)
▪ *Hazy mesentery*	10 (71.4)
▪ *Limited pneumatosis intestinalis*	2 (14.3)
▪ *Pneumoperitoneum*	0 (0)

Data are presented as n (%) or mean ± standard deviation.

Consequently, fifteen patients were eligible for PRT-assisted revascularization between 2011 and 2022 based on the above inclusion/exclusion criteria.

Endovascular procedure

The time from symptom onset to treatment (time to revascularization, TTR) was > 24 hours in 73.3 % of cases. Approximate time intervals between symptom onset, CT, and endovascular treatment are included in **Table S1**. The main reasons for delay were misinterpretation of non-specific clinical symptoms by the attending physician or surgeon in the emergency department (n = 4), missed SMA thrombus by the radiologist (n = 2), and late presentation by the patients themselves (e. g. due to gradual worsening of non-specific symptoms in cases of acute-on-chronic mesenteric ischemia; n = 4). 60 % of patients were admitted to our tertiary care center from other hospitals for further management of clinically suspected AMI, causing further delay due to the time required for patient transport. 60 % of the endovascular interventions were performed out of hours.

The procedures were performed by a board-certified interventionist with 26 years of experience via a femoral access in an angiography suite under local anesthesia (n = 12) or general anesthesia (n = 3). Selective digital subtraction angiography (DSA) of the mesenteric arteries was performed to visualize the extent of the thromboembolic SMA occlusion and to assess the collateral flow via the mesenteric arcades. The initial sheath was then exchanged for a 6F or 7F guiding sheath.

The primary revascularization technique was PRT using the 6F Rotarex system guided by a 0.018'' wire. In brief, this rotational thrombectomy system combines aspiration, fragmentation, and evacuation of acute to chronic, not severely calcified occlusions in native vessels and in vessels fitted with stents and stent grafts [8]. Upfront PTA was performed in seven proximal SMA lesions to allow positioning of the rotational thrombectomy device at the intended starting point. In the majority of cases, two to three rotational thrombectomy device passages ("to and fro") were performed in the main stem of the occluded SMA.

Adjunctive manual aspiration thrombectomy within the side branches, percutaneous transluminal angioplasty (PTA), and/or mesenteric stenting were performed at the discretion of the operator to optimize treatment results. Catheter-directed thrombolysis and embolic filters were not used.

The puncture site was closed in eleven cases with clip-based vascular closure devices (10 × 6F StarClose, Abbot, Plymouth, MN, USA; 1 × 6F Celt, Vasorum Ltd., Dublin, Ireland). In three cases, the sheath was left in place for further medical treatment. In one case, manual compression and pressure dressing were required to achieve hemostasis due to failure of the closure device.

Early periprocedural period and outcome

Depending on the patient's condition, supportive care with continuous anticoagulation and close monitoring in the intensive care unit or exploratory laparoscopy/laparotomy to assess bowel viability was performed.

▶ **Table 2** Thrombectomy-In-Visceral-Ischemia (TIVI) scoring system.

TIVI score	Superior mesenteric artery revascularization result description
0	No recanalization of the thrombotic occlusion
1	Incomplete or partial recanalization of the thrombotic occlusion without distal flow
2	Incomplete or partial recanalization of the thrombotic occlusion with minor, insufficient distal flow
3	Complete recanalization of the thrombotic occlusion with normal distal flow and only minimal residual thrombus in up to 1–2 side branches
4	Complete recanalization of the thrombotic occlusion with normal distal flow and no visually discernable residual thrombus in the side branches

Endpoint definition

The primary endpoint was technical success. Technical success was defined as the ability to apply PRT to the occluded vessel segment concurrent with vessel patency on the final angiogram after the use of PRT and any adjunctive technology.

Vessel patency was assessed using a five-point "Thrombectomy-In-Visceral-Ischemia" (TIVI) score, adopted and modified from a scoring system for acute lower limb ischemia [9]. ▶ **Table 2** details the TIVI scoring system. TIVI 3 and 4 indicated vessel patency. The TIVI score was assessed by angiography on the initial angiogram, immediately after PRT, and during the final control after the use of any adjunctive technology.

Our secondary endpoint was procedural safety. Procedural safety was defined as the absence of major complications according to the Society of Interventional Radiology [10]. Details of clinical presentation, imaging results, endovascular procedure, surgical therapy, occurrence of short bowel syndrome, and mortality were also analyzed.

Statistical analysis

Statistical analysis was performed using GraphPad Prism (version 9.1.2 (226), GraphPad Software Inc., San Diego, CA, USA). The Friedman test was used to evaluate the changes in TIVI scores at the three treatment time points, i. e., initial angiogram, after rotational thrombectomy, and final angiogram after any adjunctive technology. A p-value of less than 0.05 was considered significant.

Results

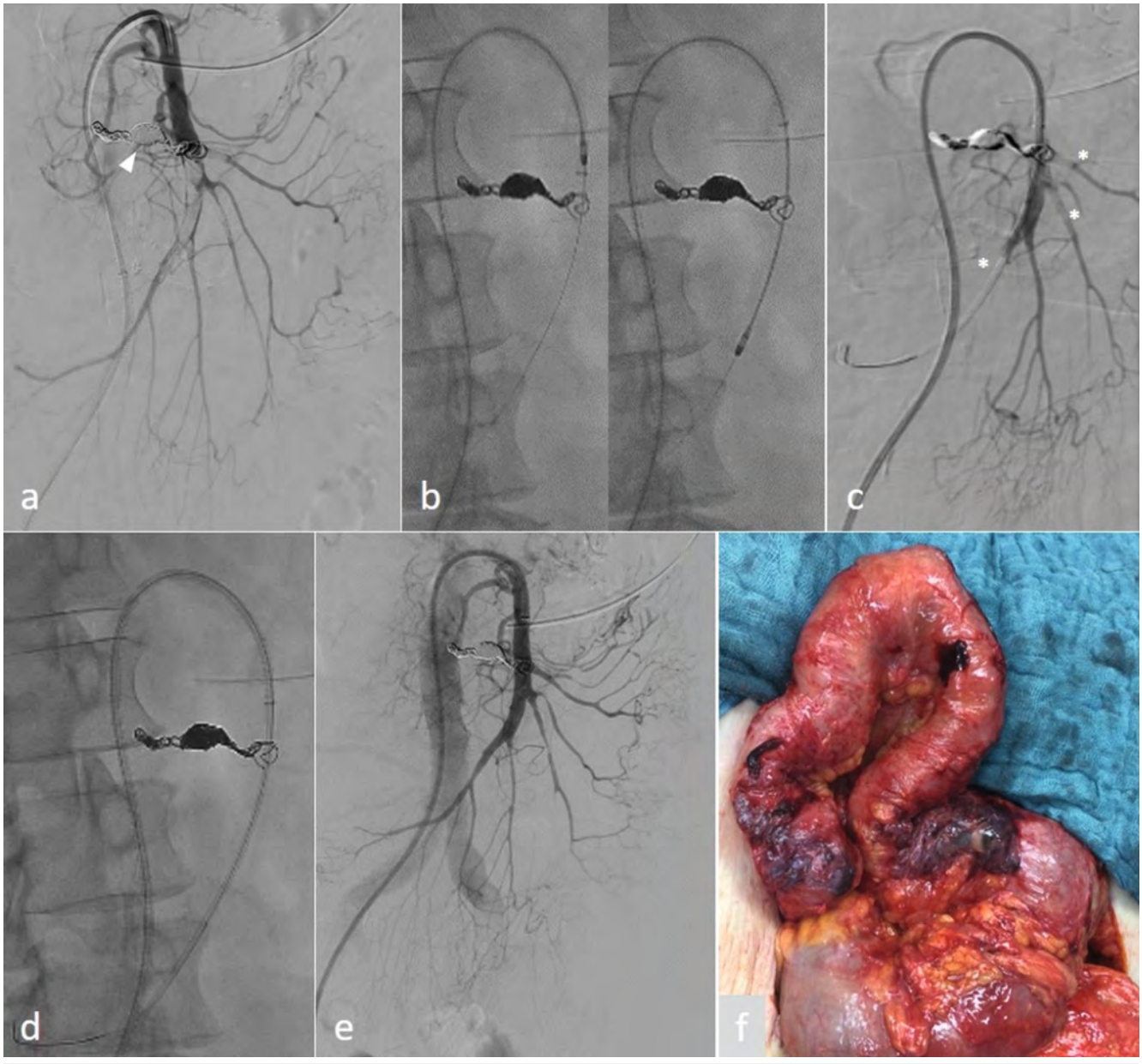
Technical success

Technical success, defined as successful application of the rotational thrombectomy device to the target lesion combined with vessel patency (TIVI 3/4) at the end of the procedure after PRT and any adjunctive technology, was achieved in 93.3 % of cases.

Initial DSA showed complete SMA occlusion (TIVI 0) in twelve cases and a minimally preserved flow within the occluded segment without adequate distal flow (TIVI 1/2) in three cases.

After PRT, the flow improved in 86.7 % of cases, as evidenced by an increase in the TIVI score. Twelve total occlusions showed flow improvement with partial recanalization of the occluded segment but insufficient distal flow (TIVI 0→1/2). In one case, there was a flow improvement from TIVI 1→2. In two cases, no significant change in the flow pattern was observed after rotational thrombectomy (TIVI 2→2).

After adjunctive devices, further flow improvement was achieved in 93.3 %. There were six complete recanalizations (TIVI 4) (▶ **Fig. 1**) and in eight patients, complete recanalization was gained with normal distal flow and only minimal non-flow-limiting residual thrombus in the side branches (TIVI 3). This was achieved in 66.7 % of cases by adjunctive manual aspiration thrombectomy within the side branches. In addition, adjunctive PTA was performed in eleven



▶ **Fig. 1** 54-year-old woman with EAMI after anticoagulation interruption for renal biopsy. DSA of the SMA with embolic occlusion involving jejunal and ileocolic arteries. History of coil embolization of ruptured visceral aneurysms associated with polyarteritis nodosa (arrowhead) (**a**). PRT via guiding sheath (**b**). Angiogram after PRT: the main thrombus load in the SMA trunk is removed. Small residual thromboemboli in side branches (asterisks) (**c**). Additional manual aspiration thrombectomy in side branches (**d**). Final angiogram confirming complete recanalization of the embolic occlusion with normal distal flow and no visually discernible residual thrombus in side branches (TIVI 4) (**e**). Intraoperative image: a planned second-look procedure within 48 h revealed a bifocal transmural ischemia near to an ileo-transversostomy. There had been no signs of transmural bowel ischemia during the initial laparotomy immediately after the endovascular procedure (**f**).

patients and mesenteric stenting was performed in nine patients (i. e., bare metal stent alone (n = 2), covered stent alone (n = 5), and both, bare + covered (n = 2)). Adjuvant PTA and/or stenting was required due to the underlying chronic lesion (n = 2), residual thrombus (n = 7), or both (n = 6). Recanalization failure occurred in one patient with TAMI and insufficient distal flow at the end of the procedure (TIVI 2→2→2).

Therefore, vessel patency, defined as a final TIVI score of 3/4, was achieved in fourteen patients. The Friedman test comparing the differences between the overall medians of the TIVI scores at the three treatment time points (i. e., at the time of the initial angiogram, after PRT, and after the use of any adjunctive technology) showed statistical significance after each procedure step ($p < 0.05$).

Procedural safety

The device-related procedural safety rate was 93.3 % and the overall major procedural complication rate was 20 %. The three major complications were a catheter tip fracture, a mesenteric hematoma found during exploratory laparotomy immediately after the endovascular procedure, and an ischemia-reperfusion injury with systemic inflammatory response. The catheter tip fracture occurred in a patient with acute-on-chronic occlusion of a covered stent. The detached tip migrated peripherally into a jejunal artery and was successfully removed with a snare loop catheter. There were no vessel perforations or dissections associated with the use of the PRT device.

Minor complications included one post-PTA dissection, two peripheral thrombus migrations, and three vasospasms. The vasospasms were alleviated by intra-arterial administration of prostaglandin E1 (i. e., 4 µg bolus and, in two patients, continued via infusion pump at 60–80 µg/24 h). There were also three minor access site hematomas, which did not require intervention.

Early periprocedural period and outcome

Transmural ischemia was excluded by exploratory surgery after successful endovascular revascularization in two patients with TAMI (TTR: 6 h and > 24 h) who recovered completely without bowel resection. Five patients with TTR > 24 h required bowel resection even after successful endovascular thrombectomy.

One patient with an uneventful early post-procedural course underwent a complex surgical procedure 28 hours after successful revascularization for symptom recurrence related to acute in-stent thrombosis.

Despite successful endovascular revascularization, best supportive care (BSC) had to be initiated in four patients: Two patients with EAMI (TTR of > 24 h) in whom exploratory laparotomy revealed a surgically unsalvageable extent of the necrotic bowel, and two other patients who deteriorated rapidly after the procedure due to their progressive malignant disease with recurrent incurable gastrointestinal bleeding (n = 1) and multiple organ failure (n = 1).

One patient with a TTR of > 24 h, who developed TAMI in the setting of severe COVID-19 disease, underwent immediate damage control surgery (DCS) and Fogarty embolectomy after endovascular therapy failed. Despite further surgical intervention, the patient died of multiple organ failure five days after the initial procedure.

Two patients underwent exploratory laparotomy prior to the PRT-assisted procedure: One patient with TAMI underwent DCS and Fogarty embolectomy. However, an endovascular procedure was required to further improve the mesenteric flow (i. e., to further treat the residual thrombus and the underlying SMA stenosis). These measures did not prevent the patient's clinical deterioration, and after a second-look laparotomy revealed unsalvageable bowel necrosis, BSC was performed. The second patient suffering from mitral valve prosthesis endocarditis with large vegetations and septic embolism associated with severe aortic insufficiency underwent an endovascular manual SMA thrombus aspiration attempt and subsequent cardiac surgery for embolic source control. However, the patient's abdominal condition worsened the following day, and a new CT scan was suspicious for recurrent/progressive embolism to the SMA. After exclusion of transmural necrosis by laparotomy, a second endovascular SMA revascularization procedure with PRT was successfully performed. **Table S1** provides an overview of the multidisciplinary treatment and outcome.

According to the pathology reports, the median length of colon resection was 16.9 cm (range: 4–24 cm) and the median length of small bowel resection was 80.5 cm (range: 19–247 cm). The median length of hospital stay was 17.4 ± 13 days. The median follow-up time of patients after discharge was 95.2 days. Six patients died in hospital or within 30 days, resulting in a 30-day mortality rate of 40 %. Three months after discharge, one patient died of aspiration and cardiac arrest. Of the nine patients in follow-up after discharge, three (33.3 %) required treatment for small bowel syndrome.

Discussion

With a technical success rate of 93.3 %, our study confirms that PRT is a technically feasible and effective adjunct to endovascular revascularization in patients with acute thromboembolic AMI. PRT alone significantly improved the flow in 86.7 % of the cases. The device was particularly useful when a total occlusion was caused by thrombosis of an underlying chronic SMA stenosis or in-stent-stenosis. Mechanical thrombectomy devices, which allow rapid restoration of blood flow by combining aspiration and debulking of complex arterial lesions, promise to be more effective than manual aspiration and time-consuming pharmacological thrombolysis. However, it should be noted that the investigated device is not designed for atherectomy of heavy calcifications. In addition, the complexity of the arterial lesions and the anatomy of the SMA with its extensive branching pattern required additional measures in each case to achieve normal distal flow.

The rationale for using PRT in EAMI was to restore the flow in the main stem of the SMA as quickly as possible. Indeed, compared to the mean procedure time of 84 ± 41 minutes reported by Kärkkäinen et al. [11], the mean total procedure time of 59.5 ± 24 minutes in our patient cohort was significantly shorter. Kärkkäinen treated embolic and thrombotic SMA occlusions with manual aspiration and, if necessary, additional PTA, stenting, or thrombolysis [11]. As expected, this time-saving effect was even more evident when

the etiology of thromboembolic SMA occlusions was further subdivided: The mean procedure time was 40.5 ± 14 minutes for EAMI cases and 72.1 ± 20 minutes for TAMI cases.

The overall major procedural complication rate of 20 % seems acceptable and comparable to previously published data [11–13]. Regarding the mechanisms of the three major procedural complications reported (i. e., catheter tip fracture, mesenteric hematoma detected during exploratory laparotomy immediately after the endovascular procedure, and ischemia-reperfusion injury with systemic inflammatory response), one of the three was not due to the endovascular revascularization technique itself, but to the reperfusion of the ischemically injured bowel. As a result, the procedure-related/technical major complication rate was 13 %. This is comparable, for example, to Kärkkäinen et al, who reported a procedural/technical complication rate of 10 % after conventional endovascular revascularization [11]. When systemic complications such as cardiopulmonary, cerebrovascular, or renal failure are included, other studies have reported peri- and early post-procedural complication rates of 42–44 % after conventional endovascular revascularization [11, 13].

Regarding catheter tip fracture, it should be emphasized that tip and shaft fracture of the Rotarex device occurs in cases where there is a sharp angulation of the tip and the sheath during use, as this creates friction on the device. This can occur during SMA revascularization from a femoral approach. In fact, in this particular case, the angle between the SMA and the aorta was 30°. Therefore, to avoid this complication in the presence of a steep take-off angle, a brachial approach is recommended, as preferred by Freitas et al. [3].

In our study, the 30-day mortality rate was 40 %, which is consistent with the study by Freitas et al. [3]. However, other studies reported significantly lower mortality rates [7, 14]. For example, the 30-day mortality rate reported by Jia et al. was 9.5 % [14]. This may be due to the significantly shorter TTR in these studies. The time from symptom onset to treatment was on average 18 hours shorter than in our patient population [14]. Delay in treatment is known to be one of the main factors responsible for high mortality rates of up to 70 % [1, 15]. Mortality is known to double for every 6 hours of delay in treatment [1]. As a result of delayed treatment, technical success in restoring SMA flow does not necessarily prevent the development of irreversible bowel ischemia due to a no-reflow phenomenon caused by obstruction of small intramural vessels [16]. The risk of a no-reflow phenomenon is particularly relevant in cases of complete occlusion of the SMA trunk and advanced atherosclerotic visceral artery disease when collateral flow capacity is significantly reduced. Unfortunately, early diagnosis and treatment are still often hampered by non-specific symptoms, lack of reliable laboratory tests, and incorrect or incomplete/misleading CT reports, as confirmed by our study.

As a result, our study population consisted mainly of patients with intermediate stages of AMI, as several factors were present that have been associated with increased morbidity and mortality in other studies [16–18]. For example, we found severe comorbidities (e. g., malignancy and underlying atherosclerotic multiple visceral artery disease), delayed diagnosis and treatment, or clinical and imaging evidence of prolonged ischemia (e. g., peritonism, lactate, CRP and leukocyte elevation, abnormal bowel wall enhancement, hazy mesentery, and pneumatosis).

Therefore, the outcome of our complex study population is considered promising. However, it could be argued that the intervention in patients with signs of prolonged ischemia with pneumatosis intestinalis and/or portal gas on CT is not beneficial, since in our patient cohort all such patients died within 30 days of technically successful revascularization.

The main limitation of the present study was its retrospective design, which did not allow for direct comparison with other revascularization devices or techniques. The sample size was small with a high degree of heterogeneity, and it was biased by the selection of patients eligible for use of the studied device. In addition, the use of adjunctive devices significantly improved the technical success, so the overall value of PRT itself could not be clearly attributed. In addition, longer follow-up is needed to gain a more complete understanding of the observed results.

The authors state that the use of the investigated PRT device in visceral arteries is an off-label use. In terms of visceral revascularization, most commonly used devices are not specifically approved for use in visceral arteries. Therefore, the benefits of off-label use of PRT to assist in rapid restoration of SMA flow can be considered a predominant benefit given its high safety rate.

Conclusion

Beyond the beneficial use of the PRT device to assist in rapid and efficient restoration of SMA flow, the overall outcome remains highly dependent on timely diagnosis and a structured multidisciplinary treatment approach.

In selected patients with complex thromboembolic SMA occlusions in whom surgical revascularization of the SMA is considered difficult or associated with significant morbidity, endovascular-assisted treatment may be a valuable option not only in the early stages of AMI, but also in AMI patients with evidence of prolonged ischemia without pneumatosis intestinalis/portal gas, or bowel perforation. In these cases, rapid and less invasive endovascular restoration of SMA blood flow may reduce the need for bypass surgery, and revascularization prior to surgical exploration may help to preserve at-risk bowel in the border zones between non-salvageable necrotic and clearly viable bowel segments.

Clinical relevance

- PRT-assisted SMA revascularization for acute occlusive mesenteric ischemia is feasible and effective with an acceptable rate of major procedural complications.
- PRT facilitates rapid restoration of flow in embolic and thrombotic occlusions of the native SMA and within previously implanted stents.
- A brachial approach is recommended for steep SMA take-off angles.

Conflict of Interest

The authors declare that they have no conflict of interest.

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