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REVIEW

Interventional Radiology in Treating Acute Mesenteric Arterial Occlusion: A Narrative Review

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Abstract:
Acute mesenteric arterial occlusion, resulting from impaired blood flow in the superior mesenteric artery, is classified into embolism and thrombosis; both conditions lead to rapid intestinal ischemia, with a high mortality rate of >30% within 30 days. A multidisciplinary treatment approach, including prompt revascularization, necrotic intestinal tract resection, intensive postoperative care, and recurrence prevention, is crucial for managing acute mesenteric arterial occlusion. Recent meta-analyses have indicated that endovascular treatments result in lower bowel resection and mortality rates than open revascularization. As a minimally invasive treatment option, endovascular therapy can become prevalent in the aging population. Interventional radiologists who provide diagnostic imaging and endovascular procedures must understand the disease and play a central role in the treatment team.

Keywords:
acute mesenteric arterial occlusion, endovascular therapy, interventional radiology

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Introduction

Acute mesenteric ischemia (AMI) can be classified into three categories: acute mesenteric arterial occlusion (AMAO), nonocclusive mesenteric ischemia (NOMI), and mesenteric venous occlusion (MVO). AMAO is the most common cause of AMI, accounting for 60% of all cases, followed by NOMI at 30% and MVO comprising the remaining 10% [1]. AMAO is caused by a disturbance in blood flow in the SMA. The incidence rate was 8.6/100,000 person-years, increasing exponentially with age [2]. AMAO is categorized into two main subtypes based on the occlusion mechanism: SMA embolism—usually occurring due to the dislodgement of an intracardiac thrombus—and SMA thrombosis—often the result of plaque disruption or thrombus formation within pre-existing atherosclerotic stenosis. Both conditions lead to compromised blood flow, rapid onset of intestinal ischemia, and continue to exhibit a high mortality rate, with an early mortality rate of >30% within the first 30 days after the onset—even in recent years [3-5]. When early death is avoided, approximately 50% of patients are estimated to die within 5 years because of the complications associated with short bowel syndrome [6]. A multidisciplinary treatment approach, such as prompt revascularization, necrotic intestinal tract resection, intensive postoperative care, and prevention of recurrence, is crucial. Recent advancements in interventional radiology (IR) techniques and devices have improved outcomes in revascularization [7-9]. This article provides a recent update and an overview of IR for AMAO.

Diagnosis of Acute Mesenteric Arterial Occlusion

AMAO is typically suspected in the sudden onset of severe abdominal pain with poor abdominal physical findings in elderly patients with cardiac (atrial fibrillation, old myocardial infarction, and valvular diseases) or atherosclerotic disease [10]. D-dimer is widely recognized for its high sensitivity as a serum marker for diagnosing AMAO and is useful for excluding AMAO [11]. However, blood lactate levels are not reliable for diagnosis because they remain normal in approximately half of the patients in the early stages of the disease; additionally, blood lactate levels do not necessarily reflect the severity of intestinal ischemia because of liver

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metabolism [12, 13]. Intestinal fatty acid-binding protein (I-FABP), which originates from the intestinal tract, is reportedly a potential biomarker; however, it is only supported by a few case reports [14] and has not been recommended by the European Society for Vascular Surgery guidelines [11].

Several guidelines advocate immediate contrast-enhanced CT (CECT) imaging with three phases—arterial, portal, and equilibrium—using ≤1 mm slices when AMI is clinically suspected [11, 15, 16]. The diagnostic sensitivity and specificity of CECT for AMI were 94% and 95%, respectively, surpassing that of any serum marker and establishing it as the gold standard for AMI diagnosis [15]. For renal failures, CECT should not be delayed because it is critical to save lives [11]. SMA embolism often results in occlusion around the origin of the middle colic artery, whereas SMA thrombosis is occluded at a proximal site [17]. SMA thrombosis typically results in a more extensive ischemia and greater necrosis of the intestinal tract than SMA embolism. A Swedish autopsy study found that SMA embolism often occurs with multiple-site embolization [17]. Herein, 83 (68%) of 122 cases of SMA embolism presented with concurrent embolization affecting the brain, other abdominal organs, or lower extremity arteries. While diagnosing SMA embolism, evaluating the associated complications, such as cerebral infarction, myocardial infarction, embolism in other abdominal organs, and arterial emboli in the lower extremities, is essential. Routinely screening for arterial emboli in the lower extremities, which can be missed because of the overwhelming presence of severe abdominal symptoms, is particularly crucial (**Fig. 1**).

Treatment Strategies for Acute Mesenteric Arterial Occlusion

In AMAO treatment, the primary elements of the acute phase treatment strategy are revascularization and ischemic intestine assessments, which may include necrotic intestine resection. The intestine benefits from remarkable collateral circulation throughout its course and can tolerate 75% reduction in blood flow for up to 12 hours [18]. However, the time from diagnosis to treatment initiation should be as short as possible because the time between the onset of AMAO and treatment initiation is directly related to the patient's prognosis. Cases presenting with peritonitis or shock prioritize the resection of necrotic intestines as damage control surgery to prevent progression to multiorgan failure or sepsis caused by ischemia-reperfusion injury, followed by prompt revascularization [19]. On the contrary, several guidelines recommend prioritizing revascularization when CT imaging reveals minimal or no evidence of intestinal necrosis and peritonitis symptoms are absent [11, 19]. This should be followed by laparotomy to evaluate the ischemic intestines. Although each case must be considered individually, When intestinal necrosis is partial and potentially reversible areas are present, aggressive revascularization should be undertaken to avoid short bowel syndrome resulting from extensive intestinal resection. It is recommended for all cases that the initial treatment includes adequate hydration, oxygen administration, analgesics, antacids, broad-spectrum antibiotics, and simultaneous administration of heparin [11, 20]. **Fig. 2** shows the treatment strategy for AMAO.

Recent meta-analyses have indicated that during AMAO revascularization, endovascular treatment tends to result in lower rates of intestinal resection and mortality compared with open surgical revascularization (**Fig. 3** and **4**) [8, 11]. A Swedish study, which reviewed data from 28 hospitals in 1999-2006, found that in 163 cases of AMAO treated with revascularization (42 endovascular and 121 open surgery cases), endovascular revascularization was associated with significantly reduced mortality rates at 30 days (28% vs. 42%, p = 0.03) and at 1 year (39% vs. 58%, p = 0.02) versus open surgical revascularization [6]. Furthermore, the 5-year survival rate was high in the endovascular treatment group (40% vs 30%, p = 0.02). Identified independent risk factors for decreased long-term survival included short bowel syndrome and advanced age. In addition, five nonrandomized comparative trials published in 2009-2014 indicated that endovascular revascularization results in a lower rate of intestinal resection (OR 0.37 [95% CI 0.23-0.59]) and a lower 30-day mortality rate (OR 0.37 [95% CI 0.30-0.83]) compared with open surgical revascularization [11]. The results from these nonrandomized comparative trials must be interpreted considering potential selection bias. However, endovascular treatment, which is less invasive and allows for quicker revascularization, is preferable especially in frail elderly patients or those with SMA thrombosis in the context of arteriosclerosis disease. This trend is similar to the recent expansion of indications for endovascular treatment for coronary and peripheral arterial disease.

Endovascular Treatment for Acute Mesenteric Arterial Occlusion

Percutaneous revascularization techniques include endovascular aspiration embolectomy, angioplasty, and intra-arterial thrombolytic therapy, often employed in combination based on the clinical situation. Treatment depends on various factors, such as the patient's clinical status, extent of occlusion, and presence of comorbidities. Generally, for large thrombi, thrombectomy—including aspiration embolectomy—is performed. Angioplasty is performed for residual atherosclerotic lesions after thrombectomy, and intra-arterial thrombolytic therapy is combined for distal microthrombi [21]. Most procedures can be performed via a transfemoral approach. However, in anatomically challenging cases—such as when the SMA has a steep branching angle or the occlusion is near the origin—a transbrachial or retrograde approach via the distal SMA may be necessary. This chapter overviews each endovascular treatment.

Endovascular Aspiration Embolectomy

Endovascular aspiration embolectomy has been reported

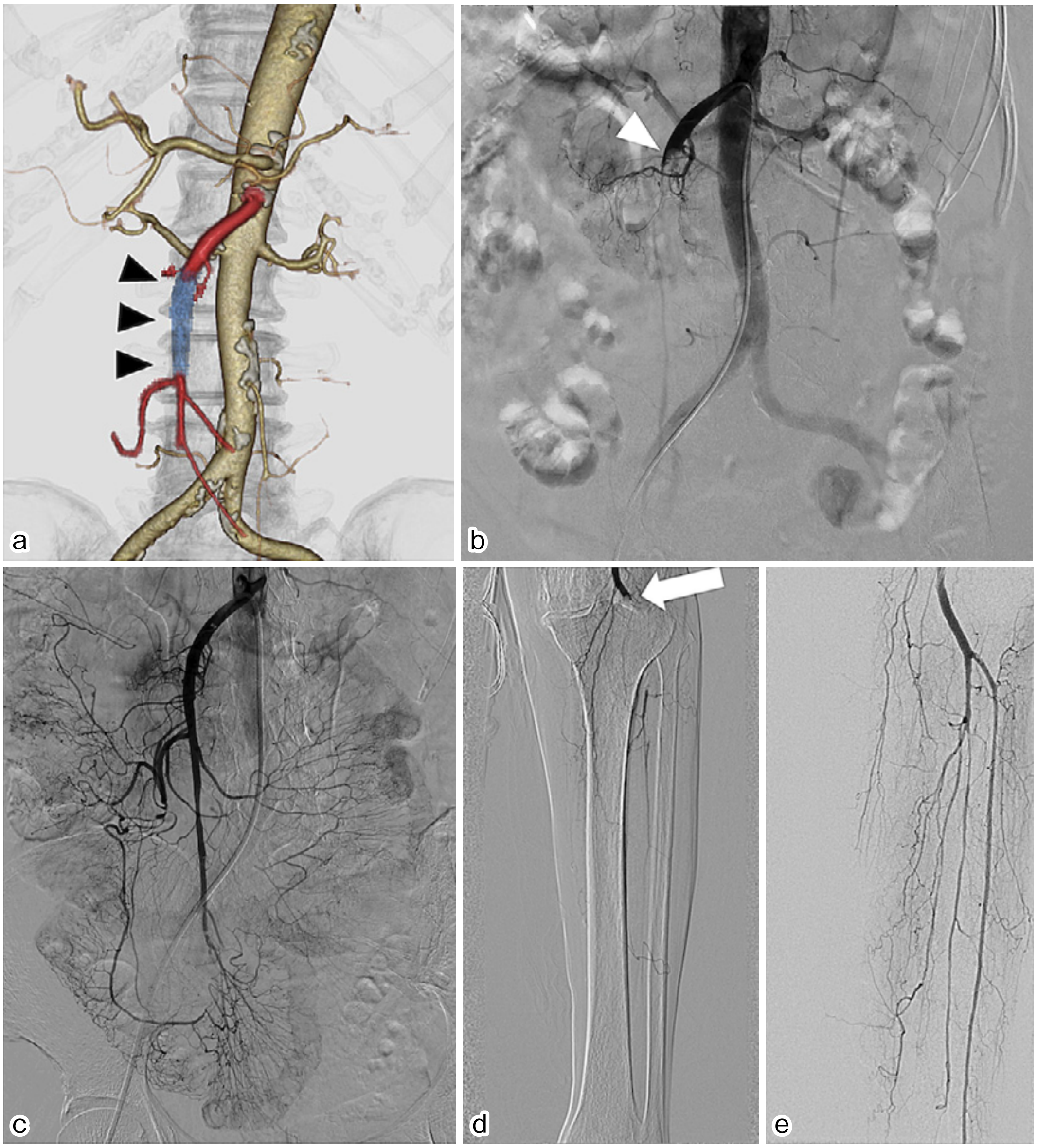

Figure 1. A man in his 80s with a history of atrial fibrillation presented at the hospital with sudden abdominal pain.
a: Contrast-enhanced computed tomography (CECT) revealed an occlusion of the main trunk of the SMA (indicated by black arrowheads). b: Selective angiography of the SMA demonstrated the occlusion similar to the preoperative CECT (indicated by white arrowhead). c: Postthrombus aspiration angiography confirmed the re-establishment of blood flow in the SMA. d: Selective angiography of the left lower extremity after thrombus aspiration of the SMA revealed occlusion of the popliteal artery (indicated by white arrow). e: A Fogarty thrombectomy was performed simultaneously just before bowel surgery to confirm patency of the popliteal artery.

in multiple studies and allows simple and rapid restoration of blood flow [11]. **Table 1** shows the main outcomes of endovascular aspiration embolectomy. Several reports have demonstrated the effectiveness of this technique, particularly when using large bore guiding catheters [22, 23, 26]. Thrombus aspiration using large bore guiding catheters to proximally bite off the thrombus can remove the thrombus with minimal risk of distal embolization (**Fig. 5**) [23]. Reportedly, vacuum-assisted thrombectomy (VAT) uses the Indigo™ System (Penumbra, Alameda, Calif.; **Fig. 6**), which was released by Penumbra Inc., approved by the FDA in 2012, and obtained the CE mark in 2014 as an embolism removal system for peripheral arteries and venous systems. VAT can remove thrombus with stronger suction force than manual suction, and the catheters are designed flexible, with few complications and less dissection of blood vessels. The largest VAT study on AMAO was a multicenter study primarily conducted in Europe and reported in 2021 [27]. This study is a retrospective review of data from a multinational registry, including consecutive patients with acute thrombosis or thromboemboli of the SMA who underwent VAT at 11 international study centers. The study enrolled 98 patients (54% female; mean age, 73 years) undergoing VAT for AMAO from 11 centers. The technical success rate was

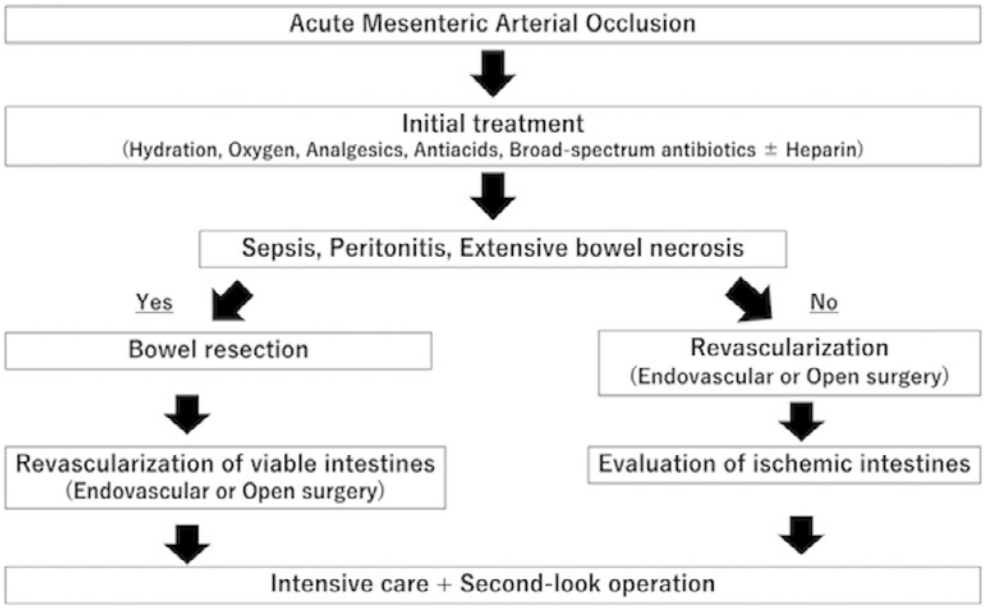

Figure 2. Treatment strategies for acute mesenteric arterial occlusion.

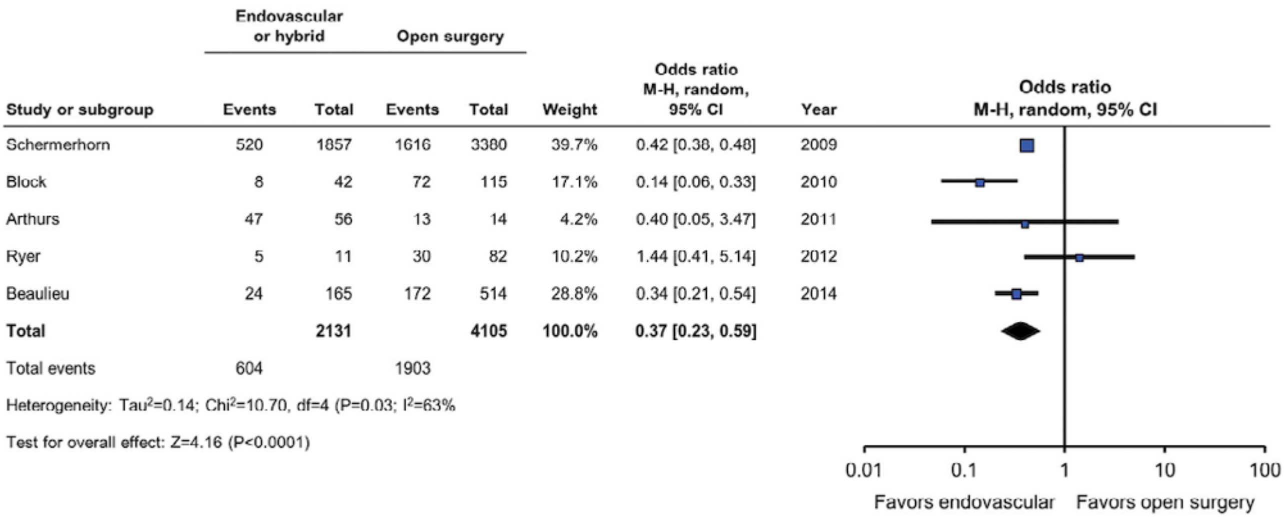

Figure 3. Meta-analysis of bowel resection rates after open and endovascular therapy of acute mesenteric ischemia (This figure will be republished with the authorization from the original publisher. Reference #11).

100% with no periprocedural mortality, 24-hour mortality rate was 0%, 4/98 cases (2.2%) required bowel resection in the late phase, 30-day mortality rate was low at 2/98 cases (2%), and no procedure-related adverse events were present. The overestimated clinical outcome should be interpreted with caution because the mean lesion length was short at 20 mm (18-22mm), 35 patients (36%) with partial occlusions were included, and the procedure was performed in patients with relatively mild disease. However, the high technical success rate and safety of VAT in neurovascular and lower limbs have been confirmed in earlier studies [30, 31], and if more cases are accumulated in AMAO, VAT might become a powerful therapeutic tool to advance endovascular therapy to first-line therapy in AMAO.

Angioplasty

Angioplasty involves balloon dilation of the occluded lesion, followed by the placement of a bare metal stent (BMS) or SG. Although good outcomes have been reported for angioplasty, concerns remain regarding distal embolization and dissection during lesion dilation, similar to arteriosclerotic lesions in the lower limbs [32, 33]. Regarding distal embolization, debris was visible to the naked eye in 43 of 65 cases (66%) in angioplasty studies for SMA stenosis or occlusion that used a peripheral protection device [34]; this report indicates that despite using peripheral protection devices, four cases (6%) of distal embolization required additional thrombectomy, concluding that sufficient vigilance for distal embolization, especially with acute lesions, is required. For treating residual stenosis in SMA thrombosis, BMS or SG placement is recommended rather than angioplasty with bal-

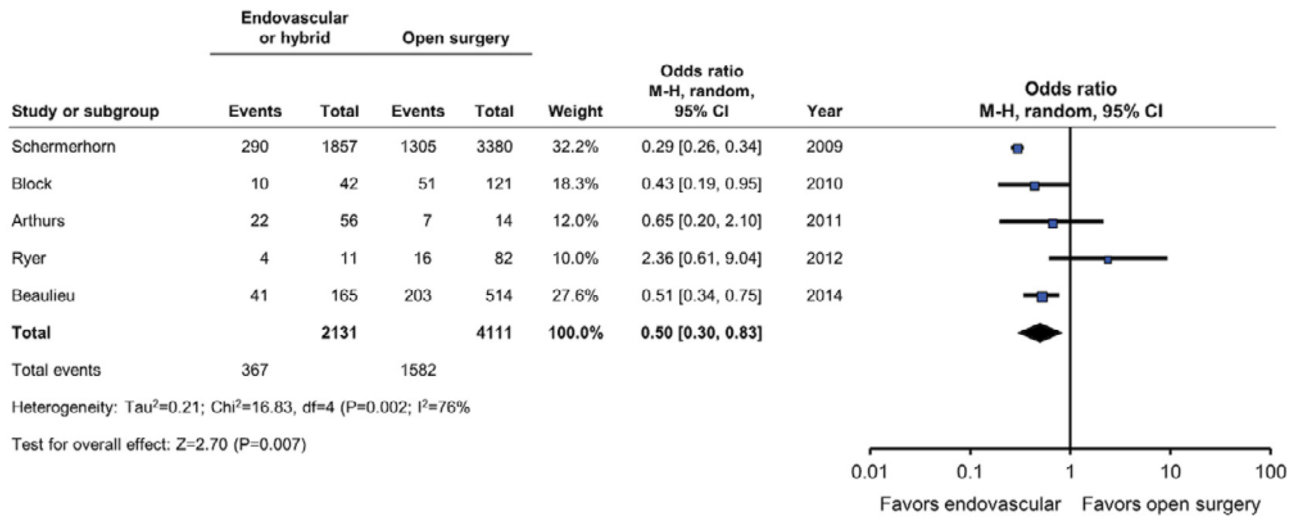

Figure 4. Meta-analysis of 30-day mortality rates after open and endovascular therapy of acute mesenteric ischemia (This figure will be republished with the authorization from the original publisher. Reference #11).

Table 1. Outcomes of Endovascular Aspiration Embolectomy.

Author	Year	Technique	Patients	Mean age (years)	Success rate (%)	Bowel resection rate (%)	30-day mortality (%)	Adjunctive therapy (n)
Acosta S.[21]	2009	C-Asp	10	78.9	77.8	10	10	TL (2), embolectomy (1)
Heiss P.[22]	2010	C-Asp	15	76.2	73.3	20	33.3	TL (9)
Jia Z.[7]	2014	C-Asp	21	70.5	100	23.8	9.5	TL (14), PTA + stent (1)
Kawasaki R.[23]	2014	C-Asp	7	67	85.7	85.7	14.3	TL (2)
Kärkkäinen JM[24]	2015	C-Asp	18	79	94	28	39	TL (4), PTA + stent (3)
Raupach J.[25]	2003–2014	C-Asp	37	75.5	91.9	40.5	27	TL (2), PTA + stent (2), embolectomy (1)
Kyu Sung Choi[26]	2015	C-Asp	9	67	100	11.1	11.1	TL (3)
Bella H.[27]	2021	VAT	98	73	100	4.1	2.0	PTA + stent (5)
Kawano M.[28]	2021	VAT	4	79	100	20	0	None
Allison K Mak.[29]	2022	VAT	5	62.2	100	40	60	Stent (4)

Abbreviations: C-Asp, aspiration thrombectomy by using large bore catheter; VAT, vacuum-assisted thrombectomy; TL, thrombolytic therapy; PTA, percutaneous transluminal angioplasty

loon dilation alone [11]. Balloon-expandable stents are preferred for hard lesions at the SMA origin due to calcification. For lesions involving bent lesions, or in cases with dissection at the distal end of a stent, the addition of a self-expanding stent should be preferred [11]. In addition, when the lesion is extensive, BMS must be selected because it minimizes the risk of disrupting blood flow in the lateral branches. Meanwhile, for short-segment lesions, SGs reportedly provide superior patency and a lower rate of reintervention [35]. This report primarily analyzed 225 cases with SMA lesions averaging >20 mm in length, retrospectively comparing groups that received BMS (164 cases) with those that received SG (61 cases). At the 3-year postoperative follow-up, the primary patency rates were 52% ± 5% and 92% ± 6% in the BMS and SG groups, respectively, which is substantially higher in the SG group. These results suggest that SGs are less influenced by neointimal hyperplasia and have a lower rate of restenosis; this is because another study (COBEST study) demonstrated the long-term patency benefits of SG over BMS for occlusive lesions of the iliac arteries [36]. A recent multicenter prospective randomized trial (CoBaGI study) conducted in the Netherlands compared SG (Advanta V12, Getinge) and BMS (Palmaz Blue, Cordis) treatments in patients with chronic mesenteric ischemia because of stenosis at the SMA origin [37, 38]. In total, 94 patients were allocated 1:1 to the stent and stent-graft groups, with the primary outcome set to the primary patency at 2 years. The primary patency of covered stents (42 [81%] of 52 stents) was superior to that of BMSs (26 [49%] of 53; odds ratio [OR] 4.4 [95% CI 1.8-10.5]; $p < 0.0001$). Only for lesions at the SMA origin limited in length (<25 mm), there is potential for the SG superiority being supported by strong evidence, similar to iliac artery lesions.

Recently, when penetrating occlusive lesions in an antegrade approach is challenging, the effectiveness of retrograde open mesenteric stenting (ROMS)—a vascular reconstructive procedure performed using a retrograde approach from the exposed ileocolic artery or the distal end of the

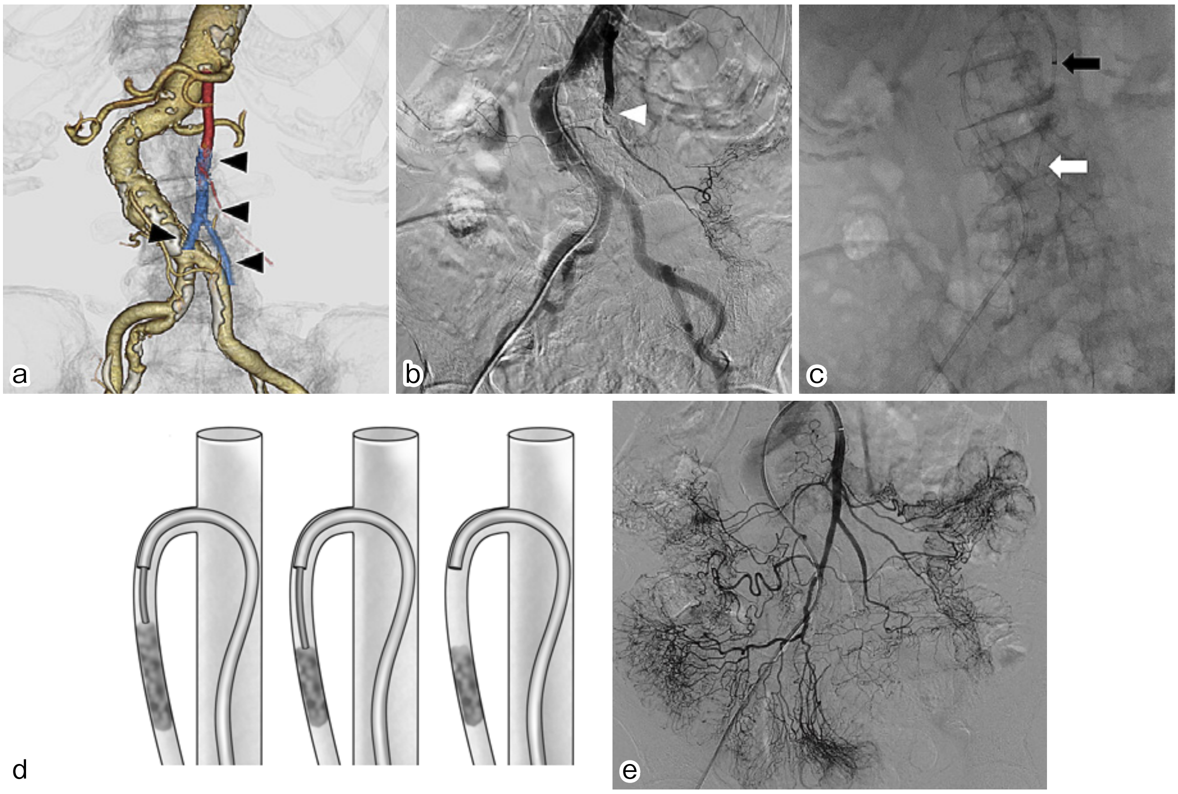

Figure 5. A woman in her 90s with a history of atrial fibrillation presented at the hospital with sudden abdominal pain. a: Contrast-enhanced computed tomography (CECT) revealed occlusion of the main trunk of the SMA (indicated by black arrowheads). b: Selective angiography of the SMA demonstrated the findings similar to those observed in the preoperative CECT (indicated by white arrowhead). c: Image captured during thrombus aspiration of the SMA shows the tips of the 6Fr guiding catheter (Mach-1™, Boston Scientific, Natick, Massachusetts, USA, indicated by the white arrow) and sheath (Flexor Ansel™ Guiding Sheath, Cook Medical, Bloomington, IN, USA, indicated by the black arrow). d: Aspirating the thrombus using large bore guiding catheters to bite off the thrombus from proximally can aspirate the thrombus with minimal complications of distal embolization. e: Angiography after thrombus aspiration confirmed the re-establishment of blood flow in the SMA.

Figure 6. Indigo™ System (This image was provided by Asahi Intecc and has been reproduced with permission from the copyright holder).

SMA in the operating room—has been reported [39-41]. One advantage of this method is that surgically exposing SMA allows the prevention of distal embolism. In addition, it simplifies the approach to the occlusive site, even when cannulation is challenging because of lesions at the origin (**Fig. 7**). In facilities equipped to perform hybrid surgery, considering ROMS as a treatment option is important. As a technical tip for ROMS, approaching from a mesenteric

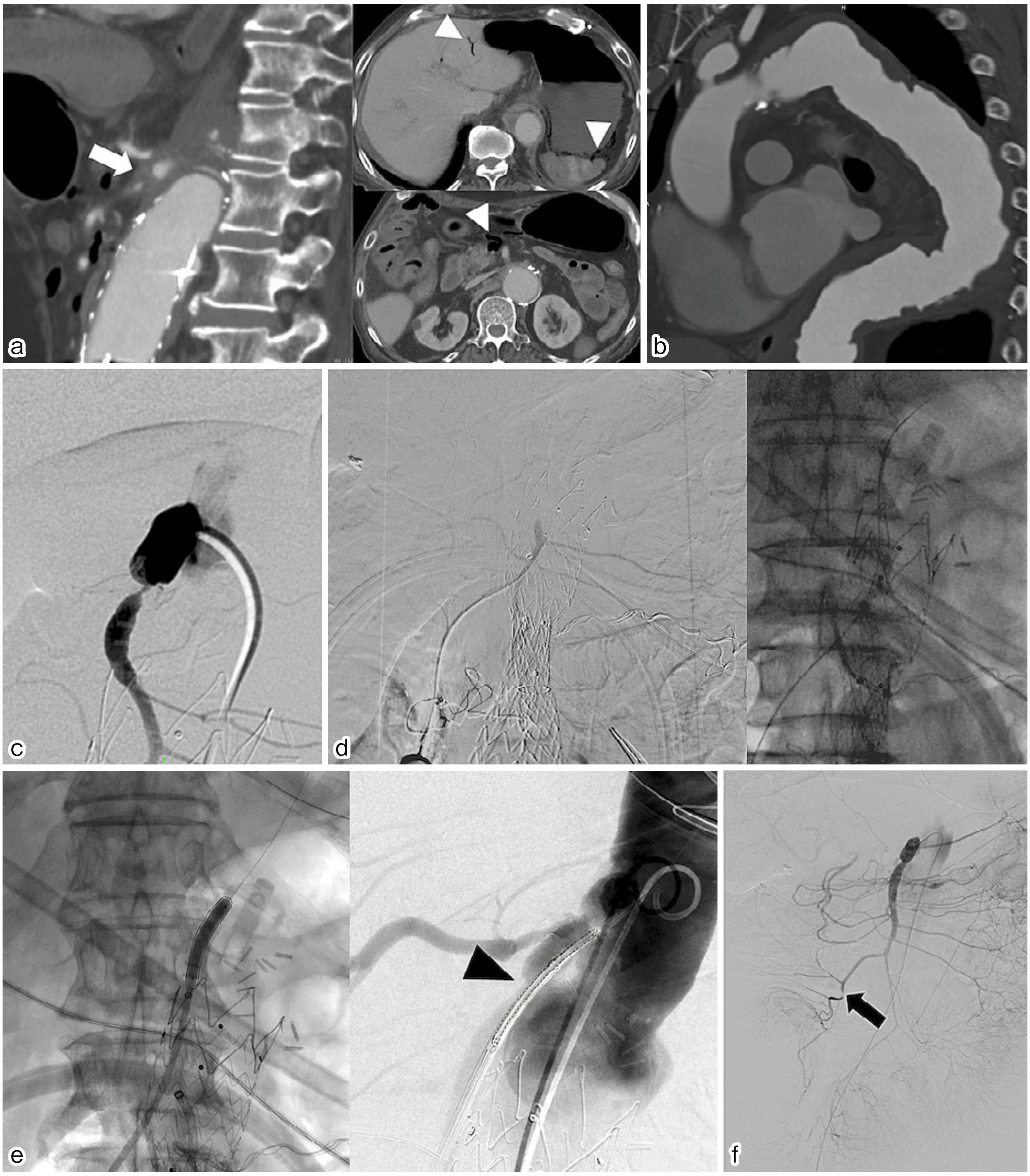

Figure 7. A man in his 70s, who underwent thoracoabdominal aortic aneurysm replacement surgery, presented at the hospital with the chief complaint of sudden abdominal pain; a: SMA was suspected to be occluded at the graft anastomosis site (indicated by the white arrow), and air was observed in the superior mesenteric, gastro-omental, and intrahepatic portal veins (indicated by the white arrowheads). b: An approach from the upper arm was challenging because the thoracic aorta was "shaggy." c: Angiography from the femoral artery showed the SMA severe stenosis, which was near the SMA origin and did not provide sufficient back-up force for penetration, making antegrade penetration challenging. d: Given that the procedure was originally initiated in the hybrid operating room for bowel assessment, the surgically exposed ileal artery was punctured retrogradely with a 22G needle (Surflo^{TM}, Terumo, Tokyo, Japan) through a small incision, and a mini access kit (Merit MAK^{TM}, Merit Medical, South Jordan, Utah, USA) was inserted. After confirming insertion into the SMA, the sheath was replaced with a 6Fr guiding sheath (Destination^{TM}, TERUMO, Tokyo, Japan). Retrograde entry of the occluded lesion was easily achieved using a 4Fr support catheter (CXI^{TM}, Cook Medical, Bloomington, IN, USA). e: Thrombus aspiration was not performed as the occlusion was a very short section confined to the anastomosis site. The occluded lesion (indicated by black arrow head) was predilated with a 4 × 40 mm^2 balloon catheter (Sterling^{TM}, Boston Scientific, Natick, Massachusetts, USA; indicated by solid line), and a 10 × 40 mm^2 stent (SMART^{TM}, Cordis Corporation, Miami, FL, USA; indicated by dotted line) was implanted. f: SMA angiography revealed good dilation of the occluded lesion and clear visualization of the intestines. Despite a contrast defect at the puncture site (indicated by black arrow), the periphery of the puncture site was preserved by blood flow from the marginal artery.

branch on the central side rather than a marginal artery saves time for exposing the vessel and maintaining intestinal blood flow, even if the puncture site is occluded.

Thrombolytic Therapy

Thrombolytic therapy plays a complementary role in residual thrombosis after endovascular aspiration embolectomy and angioplasty [42]. The main study for evaluating thrombolytic therapy was conducted in Sweden; it registered 34 patients with acute SMA occlusion from 12 hospitals. Herein, alteplase was administered for acute SMA occlusion, resulting in technical recanalization in 30 cases (88%). The median alteplase dose was 20 mg (IQR, 11.6-34.0 mg), and the median infusion rate was 0.7 mg/h (IQR, 0.5-1.0 mg/h). However, hemorrhagic complications were observed in six cases (17%), and the in-hospital mortality rate was relatively high, with nine cases (26%) [43]. Although good outcomes have been reported with thrombolytic therapy alone, there is a risk of bleeding, making the determination of appropriate indications difficult [44]. Because it affects open abdominal surgery, sufficient consultation with the surgical team is necessary during thrombolytic therapy.

There are no clear guidelines for blood revascularization endpoints; however, the ileocecal region typically plays an important role in enteral nutrition. Considerably, enteral nutrition is possible if 50 cm of the small intestine remains when the ileocecal part is preserved, and 100 cm of the small intestine remains when the ileocecal part is not preserved [11]. The objective of revascularization is to reconstruct blood flow such that the branches of the ileocolic artery are delineated; however, the ultimate objective is to visualize the marginal artery of the intestine. In other words, for small thrombi that only extend to the branches within the mesentery, if blood flow is sustained in the peripheral marginal arteries, further pursuit is unnecessary and one should promptly transition to an open evaluation of the intestinal tract.

Management and Follow-up After Revascularization for Acute Mesenteric Arterial Occlusion

For evaluating the intestines after revascularization, if the findings do not indicate intestinal necrosis before revascularization, and unless revascularization is performed, open surgery, which assesses the entire intestine, is recommended rather than laparoscopy [11]. The effectiveness of fluorescence imaging, with the fluorescent dye indocyanine green (ICG) as an auxiliary method for evaluating intestinal blood flow, has been reported. Karampinis et al. concluded that using ICG fluorescence imaging in combination with ischemic intestine evaluation can provide additional information regarding blood flow in 18 of 52 patients (35%) with AMI, leading to extended survival in 6 patients (11%) [45]. Additionally, recent literature reviews have suggested that adding objective intestinal blood flow information from ICG fluorescence imaging to the surgeon's visual inspection can accurately identify ischemic intestines [46]. Further, navigation surgery using ICG will potentially become widespread in the future.

Effective management after revascularization and surgical removal of necrotic bowel tissue depends on two critical factors: meticulous infection control and vigilant recurrence prevention. In cases involving necrotic intestinal tissue, compromised barrier function resulting from mucosal damage may facilitate bacterial translocation, allowing gut bacteria to migrate to extraintestinal sites, thereby precipitating sepsis [47]. The prophylactic administration of broad-spectrum antibiotics is recommended for patients requiring intestinal resection [11]. Furthermore, the intestinal viability assessment should not be based solely on initial postrevascularization evaluations. Reportedly, a second-look operation, typically conducted 24-8 hours after the initial surgery, is imperative because it reveals the need for further resection in approximately 30% of cases [48]. Considerably, repeated assessment of intestinal viability is recommended when feasible [11]. For preventing recurrence, anticoagulant or antiplatelet medication is recommended depending on the cause. In addition, for cases in which atherosclerotic disease contributes, it is recommended to evaluate the risks to the brain and cardiovascular system, offer smoking cessation guidance, and prescribe statins [11]. Anticoagulants are critical for treating SMA embolism. Recently, there has been a considerable shift toward the use of direct oral anticoagulants (DOACs), which target and selectively inhibit specific clotting factors such as thrombin and factor Xa. Studies have demonstrated that DOACs are as effective as warfarin for preventing the recurrence of embolic events and offer the additional advantage of a lower risk of intracranial hemorrhage [49]. The European Society of Cardiology guidelines recommend DOACs as the preferred anticoagulant for nonvalvular atrial fibrillation [50]. Although definitive evidence regarding antiplatelet therapy for SMA thrombosis is lacking, the current guidelines recommend the administration of dual antiplatelet therapy for at least 1 month postsurgery, followed by a lifetime of single antiplatelet therapy [50]. Follow-up care after SMA thrombosis treatment is critical, with mandatory imaging evaluations for restenosis. Intimal hyperplasia often develops at the stent site 3-15 months after the procedure. Monitoring stent patency through CECT scans at 1-, 3-, 6-, and 12-month postprocedure, or at least semiannually, and then annually thereafter, is recommended. According to previous studies, 50% of patients who experienced acute occlusion after SMA stent placement have died [51]. Recurrence of AMAO can be life-threatening. It is imperative for interventional radiologists to emphasize the importance of follow-up outpatient care and provide comprehensive education to patients before discharge, which should further improve adherence to prescribed treatments, such as anticoagulants and antiplatelet medications.

Summary

This study provides an overview and recent updates on IR for AMAO. Given the rising demand for minimally invasive treatments with a growing elderly population, IR is set to become a remarkable treatment option for AMAO. Introducing new devices has enabled secure and reliable revascularization, and as more cases are documented, IR can be expected to evolve into a reliable treatment method. Interventional radiologists handling patient care from diagnostic imaging to performing endovascular procedures must understand AMAO comprehensively.

Conflict of Interest: None

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