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ORIGINAL RESEARCH

Midterm Outcome of Branch Vessel Stenting for Superior Mesenteric Artery Malperfusion Complicating with Acute Aortic Dissection

Kensuke Uotani[1], Masato Yamaguchi[2], Takuya Okada[2], Tomoyuki Gentsu[2], Noriaki Sakamoto[3], Ryota Kawasaki[4], Takanori Taniguchi[5], Hirotaka Tomimatsu[6], Koji Sugimoto[2] and Takamichi Murakami[2]

1) Department of Radiology, Hyogo Prefectural Awaji Medical Center, Japan
2) Department of Diagnostic and Interventional Radiology, Kobe University Graduate School of Medicine, Japan
3) Department of Radiology, Kakogawa Central City Hospital, Japan
4) Department of Radiology, Hyogo Prefectural Harima Himeji General Medical Center, Japan
5) Department of Radiology, Tenri Hospital, Japan
6) Department of Radiology, Nishi Kobe Medical Center, Japan

Abstract:
Purpose: To investigate the midterm stent patency and patient prognosis after stenting for superior mesenteric artery malperfusion complicating with acute aortic dissection.
Material and Methods: Thirteen patients who underwent branch vessel stenting for superior mesenteric artery malperfusion between 2011 and 2021 in six institutions were retrospectively reviewed. By comparing pre- and postoperative computed tomography scans in the same plane, the length of the stent implanted in the superior mesenteric artery and the stent-to-vessel diameter ratio were measured. The technical and clinical success of stenting, midterm patient prognosis, and stent patency were evaluated.
Results: Superior mesenteric artery stenting was technically successful in 12 patients (92.3%). The mean length of the stents implanted in the superior mesenteric artery was 61.3 ± 39.4 mm (range, 14-127 mm). The mean proximal and distal stent-to-vessel diameter ratios were 1.02 ± 0.16 and 1.30 ± 0.42, respectively. A weak correlation was found between the length of the stents implanted in the superior mesenteric artery and the distal stent-to-vessel diameter ratio (R^2 = 0.34). Two major complications occurred, one of which resulted in death within 30 days, and 12 (92.3%) were clinically successful. Of these 12 patients, no recurrent intestinal ischemia occurred during the follow-up duration (mean, 45.2 months). Partial occlusion of the stent distal edge without intestinal ischemia was observed in one patient (distal stent-to-vessel diameter ratio = 2.33) 42 months after stenting. The overall survival rate and primary stent patency rate were 84.6% and 91.7%, respectively.
Conclusions: Midterm stent patency and survival after superior mesenteric artery stenting for malperfusion were acceptable.

Keywords:
mesenteric ischemia, endovascular stenting, acute aortic dissection, superior mesenteric artery malperfusion

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Introduction

If untreated, acute mesenteric ischemia (AMI) is a life-threatening condition with a high mortality rate [1]. In patients with acute aortic dissection, AMI due to malperfusion of visceral branches occurs in 5.8% of patients with acute Stanford type A dissection [2] and 7.1% of type B [3], respectively. Invasive treatments for visceral branch malperfusion include open superior mesenteric artery (SMA) revascularization using the great saphenous vein, stenting of the SMA, entry closure by aortic stentgrafts, and intimal flap fenestration in the aorta. With the development of endovascular techniques, endovascular revascularization has become an accepted and widely used alternative to surgical repair for

Corresponding author: Kensuke Uotani, uota2k@gmail.com
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mesenteric arterial diseases [4]. Many reports suggested the feasibility of branch vessel stenting for malperfusion caused by acute aortic dissection [5-7]. Stenting for SMA dissection tends to require a longer stent length to cover the dissected SMA than stenting for chronic mesenteric ischemia, in which the lesion is often localized in the SMA orifice. To cover long lesions and follow the curve of the SMA, self-expanding stents are preferred for SMA dissection. The chronic outward force exerted by a self-expanding stent is an important factor to cause restenosis, and several investigations evaluated the effect of self-expanding stent oversizing on the risk of in-stent restenosis [8-11]. Implanted long self-expanding stents are commonly oversized in the SMA at the distal portion. To date, data on long-term stent patency and patient outcomes after stenting for SMA dissection are limited [4]. In addition, few papers analyzed the relation between stent length, diameter, and late stent occlusion. The purpose of this study was to investigate the mid-term stent patency and patient prognosis after stenting for SMA dissection.

Material and Methods

The medical records of six institutions from January 2011 to November 2021 were retrospectively reviewed, and 13 patients with AMI who underwent stenting for SMA malperfusion complicating with acute aortic dissection were identified. The patients comprised nine men and four women with a mean age of 60.7 ± 12.8 years (range, 40-82 years). Six patients presented with Stanford type A aortic dissection and seven patients presented with type B. All patients with type A dissection underwent ascending aortic replacement or total arch replacement with or without a frozen elephant trunk before stenting. In two patients with type B dissection, thoracic endovascular aortic repair (TEVAR) was followed by SMA stenting. Five patients with type B dissection were treated with SMA stenting and conservative therapy. All patients presented with acute onset of abdominal pain, and contrast-enhanced computed tomography (CECT) demonstrated static obstruction of the SMA with narrowing of the true lumen and decreased intestinal enhancement. SMA stenting was performed on the same day or the day after the onset of SMA malperfusion.

This study was approved by the institutional review boards of all participating institutions. The requirement for informed consent was waived because of the retrospective nature of the study; an opt-out method was alternatively employed.

Procedures

A mesenteric angiogram was obtained via femoral access using a 4 F diagnostic catheter with a 4.5 F or 6 F guiding sheath. After administration of a heparin bolus, a micro guidewire was advanced to the distal SMA beyond the stenotic lesion. After advancing a stent delivery catheter over a stiff guidewire, to cover the dissected SMA, a stent was deployed to the stenotic true lumen. An additional stent was placed for long lesions that could not be covered by a single stent or for lesions with different diameters in the proximal and distal regions. Oral antiplatelet agents were administered after stent placement, including oral clopidogrel at 75 mg/day and/or aspirin at 100 mg/day. The patency of the stents and perfusion of the SMA were confirmed by mesenteric angiography.

Technical success was defined as stent patency and good distal SMA run-off on final angiography. Next, clinical success was defined as cases in which enteral nutrition became possible after stenting, with or without open laparotomy. Major complications were defined as those that resulted in a prolonged hospital stay for therapy, an unplanned increase in the level of care, permanent adverse sequelae, or death. Minor complications were defined as those that resulted in no sequelae or required nominal therapy.

Clinical follow-up

After discharge, outpatient clinic visits were continued to survey the recurrence of intestinal ischemia. To investigate the recurrence of intestinal ischemia and stent patency, routine blood biochemical tests and CT scans were performed on demand.

Analysis

The length of the stents implanted in the SMA was calculated on sagittal CT images obtained after stenting. If the stent protruded toward the aorta, the distance from the origin of the SMA to the distal end of the stent was measured. The stent-to-vessel (S/V) diameter ratio was determined by calculating the stent diameter (nominal diameter) and the vessel diameter (measured on CECT before stenting, comparing with postoperative CT in the same plane) at the proximal and the distal ends of the stents. The vessel diameter of the dissected area was measured as the maximum diameter of the artery including the false lumen. The number of side branches covered by the stents, occlusion of side branches, patency of the stents, and recurrence of intestinal ischemia (decrease of intestinal enhancement with or without stenosis of the SMA) were assessed on follow-up CT images. Continuous data are shown as mean ± standard deviation. Statical analyses were performed using Statmate 4 (ATOMS, Tokyo, Japan).

Results

All patients' baseline clinical manifestations and results of stenting are summarized in **Table 1**. Details of the implanted stents and follow-up outcomes are summarized in **Table 2**.

Technical success of stent placement

Technical success of SMA stenting was achieved in 12 of 13 patients (92.3%). In one patient (case 10), arteriography after stenting showed that the stent was patent, but the distal artery was slow-flow (**Fig. 1A-D**), and the patient was considered unsuccessful. Next, CECT eight days after stenting

Table 1. Patient Demographics and Outcomes of Stent Implantation.

Age	60.7 ± 12.8
Gender	
Male	9 (69.2)
Female	4 (30.8)
Stanford type	
Type A	6 (46.2)
Type B	7 (53.8)
Past medical history	
Hypertension	11 (84.6)
Diabetes	2 (15.3)
Renal dysfunction (eGFR <50)	2 (15.3)
Coronary arterial disease	3 (23.1)
Cerebral vessel disease	2 (15.3)
History of smoking	
Never smoker	5 (38.4)
Current smoker	4 (30.8)
Former smoker	4 (30.8)
Technical success	12 (92.3)
Clinical success	12 (92.3)
Type of stents	
Self-expanding	10 (76.9)
Balloon-expandable	3 (23.1)
Length of the stents implanted in the SMA	61.3 ± 39.4 mm
Number of stents used	
1 stent	11 (84.6)
2 stents	2 (15.3)
Major complication	2 (15.3)
Stent-induced new entry	1 (7.8)
Renal artery injury	1 (7.8)
Minor complication	1 (7.8)
Puncture site pseudoaneurysm	1 (7.8)
Open laparotomy	6 (46.2)
With enterectomy	3 (23.1)
Without enterectomy	3 (23.1)

eGFR: estimated glomerular filtration rate, SMA: superior mesenteric artery

Continuous data are shown as mean ± standard deviation, and categorical data are shown as number (% of each group).

showed that the stent and the distal artery were patent without stenosis (**Fig. 1E, F**). Therefore, vasospasm in the distal SMA was supposed to be the cause of slow-flow. The dissected SMA was fully covered in 11 patients and partially covered in two patients. Then, the two patients (cases 4 and 5) had SMA dissection distal to the ileocolic artery; however, severe true lumen stenosis was observed only in the ostium of the SMA, and the flow of the distal SMA was well maintained after stenting for the SMA ostium. The bare metal stents used for the SMA were Express LD (Boston Scientific, Marlborough, MA, US) or SMART CONTROL (Cordis, Bridgewater, NJ, US) or Zilver 518 (Cook Medical, Bloomington, IN, US). Next, to achieve precise positioning of the stent, balloon-expandable stents were used for three patients with short-segment dissections (21 mm or less) that were localized in the proximal portion of the SMA, and self-expanding stents were used for ten patients. Two stents were used for two patients to treat long lesions and to address the diameter difference between the proximal and distal SMA. The other 11 patients were treated with a single stent. The mean length of the stents implanted in the SMA was 61.3 ± 39.4 mm (range, 14-127 mm). The mean stent diameter was 8.1 ± 1.2 mm (range, 6-10 mm). The mean S/V ratio at the proximal and distal edge of the stents was 1.02 ± 0.16 (range, 0.84-1.38) and 1.30 ± 0.42 (range, 0.89-2.33), respectively. No correlation was found between the length of the stents implanted in the SMA and proximal S/V ratio (R^2 = 0.04), and a weak correlation was found between the length of the stents implanted in the SMA and distal S/V ratio (R^2 = 0.34) (**Fig. 2**).

Complications

Major complications were observed in two patients (15.3%). One patient (case 4) developed stent-induced new entry (SINE) in the distal edge of the stent with recurrent intestinal ischemia. The patient developed severe abdominal pain on the day after stenting. Next, CECT showed that the stent was patent, but SINE with true lumen severe stenosis distal to the stent and decreased intestinal enhancement were observed. Further, emergent open laparotomy revealed extensive intestinal necrosis, and resection from the ileum to the rectum was performed. Finally, the patient developed recurrent intestinal ischemia postoperatively and died 29 days after stenting. The other patient (case 6) presented with a renal artery perforation due to guidewire injury. A 0.035-inch guidewire was accidentally inserted into the right renal artery, resulting in peripheral renal artery perforation with subcapsular hematoma, which was successfully treated by coil embolization. As a minor complication, puncture site pseudoaneurysm was observed in one patient, which could be managed with manual compression.

Clinical success and midterm follow-up results of stent placement

Six patients required open laparotomy for investigation of intestinal ischemia immediately or the day after stenting. Of these, three patients presented with intestinal necrosis on surgical findings and underwent intestinal resection. The mean follow-up duration was 45.2 ± 30.3 months. Clinical success was achieved in 12 of 13 patients (92.3%). Of the 12 patients, one died of renal failure 46 months after stenting, which was not related to aortic dissection or SMA stenting. Next, none of the clinically successful patients developed recurrent intestinal ischemia or delayed complications associated with SMA stenting. The side branch vessels of the SMA were covered with stents in 22 branches of six patients, and all these branches were patent during follow-up. Late stent occlusion at the distal edge was observed in one patient (case 10) with the largest distal S/V ratio (2.33) 42 months later, despite continued antiplatelet therapy. CECT showed occlusion in the distal part of the stent (**Fig. 1f**); however, the proximal to the middle part of the stent was patent, and all side branches of the SMA covered by the stent remained patent. The distal small intestine was per-

Table 2. Results of Stenting and Midterm Follow-up Outcome.

Case	Age/Gender	Stanford type	Preceded treatment	Stents used	Length of the stents implanted in the SMA (mm)	Number of stents used	Nominal stent diameter (mm)	S/V ratio proximal	S/V ratio distal	Days from stenting to most recent CECT	Stent patency	Follow-up duration (days)	Result
1	54/M	B	None	Express LD	14	1	7	0.85	0.93	1200	Patent	2752	Alive
2	70/M	B	None	Express LD	17	1	8	1.1	1.14	2157	Patent	2634	Alive
3	82/M	B	None	Express LD	21	1	8	1.21	1.21	15	Patent	1383	Dead (renal failure)
4	69/F	A	TAR+FET	SMART CONTROL	30	1	8	0.94	1.00	1	Patent (SINE)	29	Dead (intestinal ischemia)
5	46/M	B	None	SMART CONTROL	40	1	8	0.89	0.89	480	Patent	2629	Alive
6	67/F	B	TEVAR	SMART CONTROL	41	1	8	1.38	1.19	1039	Patent	1732	Alive
7	40/M	B	TEVAR	SMART CONTROL	58	1	8	1.14	1.33	N/A	N/A	863	Alive
8	48/M	A	AAR	Zilver 518	60	1	10	0.91	1	N/A	N/A	472	Alive
9	47/M	A	TAR+FET	SMART CONTROL	77	1	10	1.04	1.22	1377	Patent	1377	Alive
10	68/F	A	AAR	SMART CONTROL	80	1	7	0.88	2.33	1244	Partial occlusion	1287	Alive
11	51/M	A	TAR+FET	SMART CONTROL	110	2	8 and 10	1.06	1.20	236	Patent	430	Alive
12	74/M	B	None	SMART CONTROL	122	2	6 and 8	0.84	1.43	116	Patent	1622	Alive
13	64/F	A	TAR+FET	SMART CONTROL	127	1	7	1.04	2	1	Patent	433	Alive

SMA: superior mesenteric artery, S/V ratio: stent-to-vessel diameter ratio, CECT: contrast-enhanced computed tomography, M: male, F: female, TAR: total arch replacement, FET: frozen elephant trunk, SINE: stent-induced new entry, TEVAR: thoracic endovascular aneurysm repair, N/A: not applicable, AAR: ascending aortic replacement

fused by collaterals from the side branches, and no intestinal ischemia was observed. The patient remained asymptomatic and required no further treatment. Two patients were followed up with noncontrast CT and did not undergo CECT after stenting (cases 7, 8).

Discussion

This study revealed that the midterm patency rate after stenting for SMA dissection was 91.7%, and overall survival rate was 84.6%. Next, late stent occlusion was observed in one patient; however, the occlusion was localized to the distal edge of the stent, and the intestine was well perfused by patent side branches of the SMA. The stent occlusion progressed slowly due to intimal hyperplasia, and the patient exhibited no relapse of symptoms, probably because sufficient time was allowed to develop collateral flow through the mesenteric side branches.

In patients with complicated type B aortic dissection, TEVAR has become the first-line therapeutic option. Among such patients, those presenting with visceral malperfusion require concomitant visceral branch stenting to manage end-organ ischemia [12]. In previous studies, patients who presented with type B aortic dissection complicating visceral malperfusion and were treated by TEVAR with branch vessel stenting showed long-term survival similar to that of patients with uncomplicated type B aortic dissection [5, 7]. Additionally, a recent study demonstrated that patients with complicated type B aortic dissection who needed branch vessel stenting for end-organ malperfusion showed 30-day mortality, in-hospital reintervention rate, and long-term survival similar to those of patients without branch vessel stenting [13]. No significant difference was found in patient outcomes as the complexity of additional procedures increased, which added evidence that branch interventions should be performed when necessary.

The long-term outcome of stent placement for SMA dissection has not yet been defined. Several studies of isolated SMA dissection showed good stent patency without stent occlusion at 1 to 2 years of follow-up [14-19]. Kim et al. [18] reported that stent obstruction was observed in 1 of 10 patients 99 months after stenting for isolated SMA dissection. In that case, similar to ours, blood flow through the distal part of the ileocolic artery was maintained via a collateral route from the ileal artery. Hang et al. [19] analyzed the risk factors for distal edge stenosis after stent placement for isolated SMA dissection. Distal edge stenosis was observed in 20 of 45 patients (44.4%), and the distal edge stenosis tended to occur more commonly with greater oversizing of the stent and a steeper angle between the distal

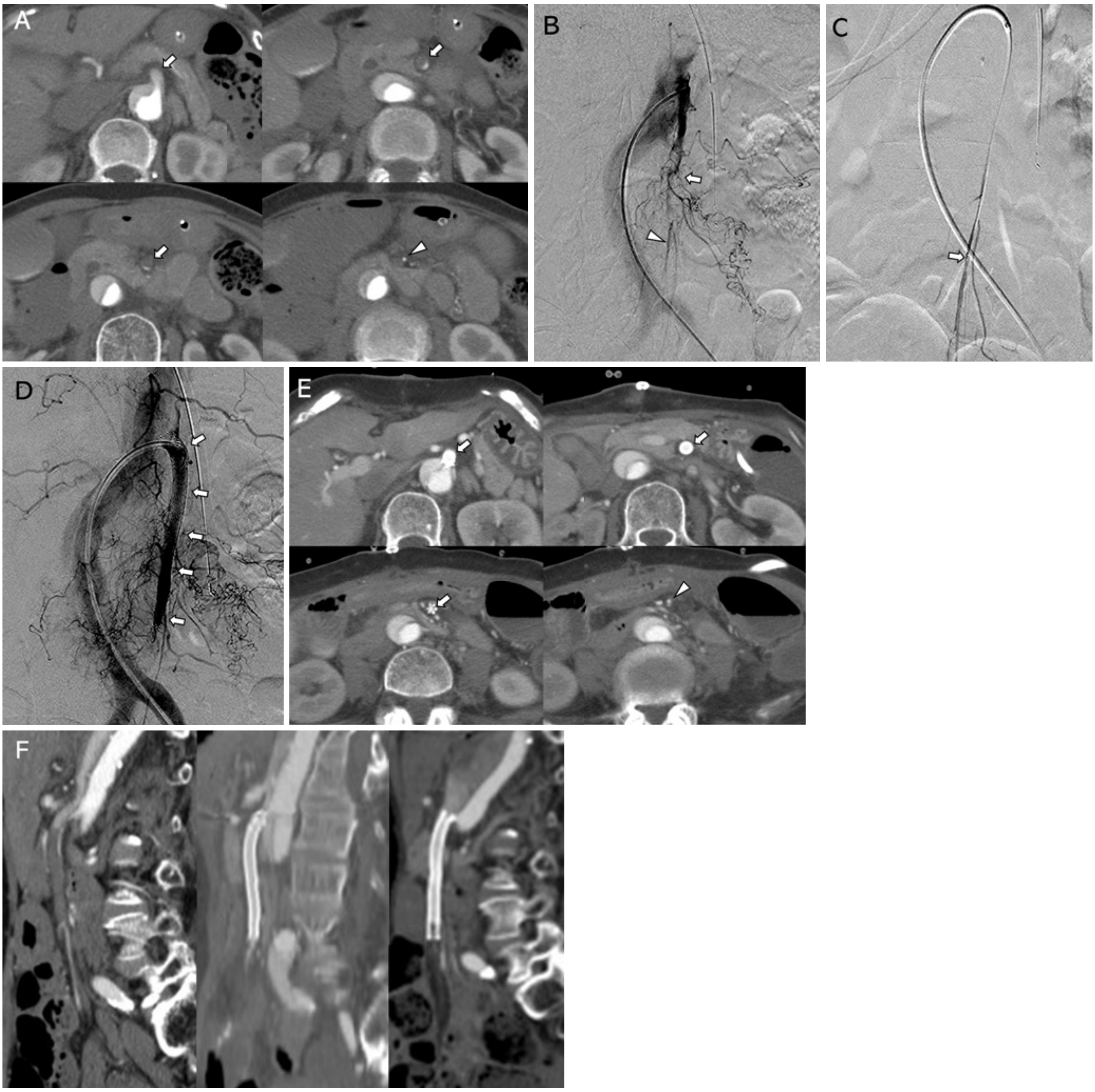

Figure 1. Images of a woman with Stanford type A aortic dissection complicating superior mesenteric artery (SMA) malperfusion (case 10). (A) Contrast-enhanced computed tomography (CECT) after ascending aortic replacement shows obstruction of the true lumen of the SMA by the thrombosed false lumen (arrow). The diameter of the SMA distal to the dissection (arrowhead) was 3.0 mm. (B) True lumen angiography of the SMA demonstrated obstruction of the SMA (arrow). The SMA distal to the ileocolic artery (arrowhead) was perfused by collaterals. (C) A 6 F guiding sheath (Ansel Guiding Sheath, Cook Medical, Bloomington, IN, US) was placed in the SMA orifice, and a 1.8 F microcatheter (Carnelian PIXIE, Tokai Medical Products, Aichi, Japan) was advanced distally to the dissected SMA through the true lumen. Next, angiography demonstrated the tip of the microcatheter (arrow) was in the true lumen of the SMA beyond the dissected lesion. (D) After exchanging a guidewire for a hard guidewire (Amplatz Super Stiff Guidewire, Boston Scientific, Marlborough, MA, US), a 7 mm diameter self-expanding stent (SMART Control, Cordis, Bridgewater, NJ, US) was placed in the SMA. Angiography after stent (arrow) placement showed improved flow of the side branches of the SMA; however, the SMA at the distal portion of the stent was poorly contrasted, and the in-stent flow was slow. Resection of the distal ileum and right hemicolon was performed immediately after stenting. (E) CECT 8 days after stenting showed that the stent (arrow) and SMA distal to the stent (arrowhead) were patent. (F) CECT curved planar reconstruction images before (left), 8 days (center), and 3 years (right) after stenting. CECT 3 years later shows that the proximal end of the stent is located in the false lumen of the aorta due to an intimal frap tear within the aorta by the proximal edge of the stent. The distal edge of the stent was occluded at 3 years; however, the patient remained asymptomatic, and CECT showed no intestinal ischemia.

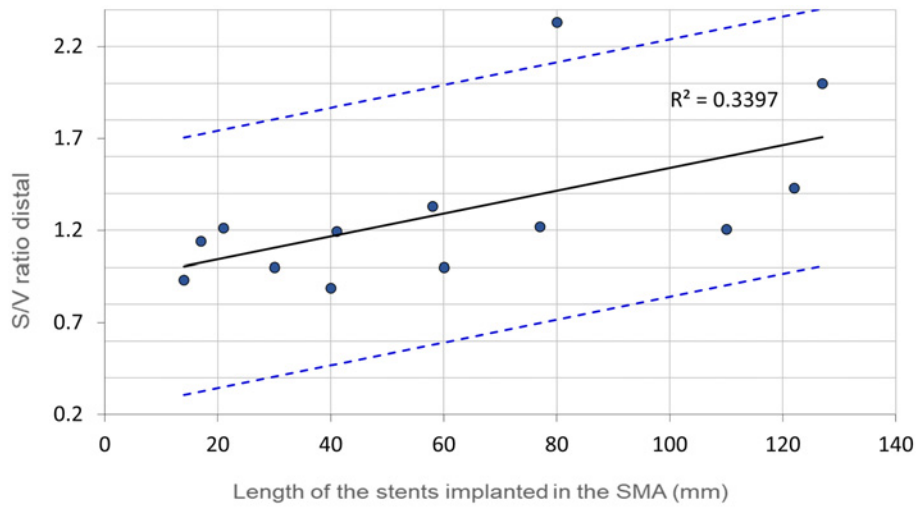

Figure 2. Correlation between the length of the stents implanted in the SMA and stent-to-vessel diameter ratio (S/V) at stent distal edge. The dotted lines indicate 95% confidence interval.

stent edge and the distal main trunk of the SMA. Also, no incidence of stent occlusion was observed. The minimum diameter of peripheral self-expanding stents commercially available in our country is much larger than that of the SMA distal to the ileocolic artery, making oversizing inevitable when treating a distal SMA lesion with self-expanding stents. To avoid stent oversizing at the distal edge, the use of stents with a tapering configuration that is designed for carotid artery stenting is more suitable for placement in the mesenteric artery.

Balloon-expandable stents are preferred for treating calcified lesions such as chronic mesenteric ischemia because they demonstrate enhanced radial strength and can be more precisely placed [20]. Unfavorable artery angulation or risk of arterial dissection at the distal end of the balloon-expandable stent is treated by extension with a self-expanding stent into the mid-SMA [4]. In cases of SMA dissection, self-expanding stents are preferred because they often extend beyond the flexure of the SMA and tend to increase the treatment length to cover dissected vessels. However, whether stents should be placed to cover the entire length of the true luminal stenosis or only at the entrance to the dissection remains unclear. In the present study, the stents were placed to cover the entire length of the stenotic true lumen for immediate relief of mesenteric ischemia in 11 of 13 patients. In the remaining two patients, stenting was required in the SMA ostium, and the SMA flow was well maintained even though the distal portion of the dissection without flow restriction remained untreated. However, one of the two patients developed SINE at the distal end of the stent (case 4), which resulted in recurrent intestinal ischemia. In conclusion, determining the appropriate extent of stent placement from the present study remains difficult.

Limitations

This study exhibits several limitations. First, this study was a multicenter retrospective design with a small number of patients, making it difficult to standardize stenting techniques such as the selection of stent type, stent diameter, and extent of the stenting zone. Second, follow-up data are limited because of the lack of consensus on optimal follow-up intervals or modalities after SMA stenting. In this study, CECT was performed on demand when clinically indicated, and long-term follow-up by imaging modalities was lacking in some cases. Third, in patients with SMA malperfusion, the assumption exists that the vessel diameter of the distal SMA is smaller than normal due to reduced perfusion and vasospasm, but measuring the true vessel diameter is difficult.

In conclusion, the midterm stent patency and survival rates after SMA stenting for SMA dissection were acceptable.

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Author Contribution: Conception and design of the study: Kensuke Uotani, Masato Yamaguchi
Acquisition of data: Kensuke Uotani, Masato Yamaguchi, Takuya Okada, Tomoyuki Gentsu, Noriaki Sakamoto, Ryota Kawasaki, Takanori Taniguchi, Hirotaka Tomimatsu
Analysis and/or interpretation of data: Kensuke Uotani
Drafting the manuscript: Kensuke Uotani
Revising the manuscript critically for important intellectual content: Masato Yamaguchi, Takuya Okada, Koji Sugimoto, Takamichi Murakami
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