Endovascular occlusion of segmental arteries feeding the anterior spinal artery to stage endovascular thoracoabdominal aortic repair

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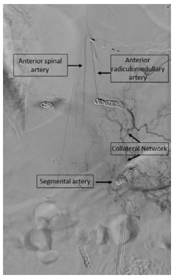
ABSTRACT

Objective: Minimally invasive segmental artery coil embolization was introduced to prevent spinal cord ischemia after endovascular repair of thoracoabdominal aortic aneurysms. There is no consensus on whether the endovascular occlusion of segmental arteries feeding directly the anterior radiculomedullary artery and anterior spinal artery can be safely performed without causing spinal cord ischemia. Our aim was to investigate the feasibility and clinical impact of endovascular occlusion of segmental arteries supplying the anterior spinal artery during minimally invasive segmental artery coil embolization in patients with thoracoabdominal aortic aneurysms.

Methods: Between January 2018 and July 2020, 54 patients (36 male; mean age, 71.1 ± 9.3 years) underwent direct embolization of segmental arteries feeding the anterior radiculomedullary artery before endovascular repair of thoracoabdominal aortic aneurysms. End points included technical success of minimally invasive segmental artery coil embolization of segmental arteries, anterior radiculomedullary artery, neurological complications, and in-hospital mortality after minimally invasive segmental artery coil embolization and endovascular repair of thoracoabdominal aortic aneurysms.

Results: The thoracoabdominal aortic aneurysm classification was type I (n = 8), type II (n = 24), type III (n = 11), and type IV (n = 11). During minimally invasive segmental artery coil embolization, 388 segmental arteries were occluded, each patient having 7.2 ± 3.1 coiled segmental arteries occluding 64.5% (25-100%) of open segmental arteries within the treated aortic segment. Altogether, 66 anterior radiculomedullary arteries were seen originating between Th8 and L3 levels from 85 (21.9%) segmental arteries. In 10 patients (18.5%), 2 large anterior radiculomedullary arteries were identified, and 1 patient (1.9%) showed 3 anterior radiculomedullary arteries on the spinal arteriography. No spinal cord ischemia or procedure-related complications occurred after minimally invasive segmental artery coil embolization. After 47.9 ± 39.4 days, all patients received endovascular repair of their thoracoabdominal aortic aneurysms. There was no in-hospital mortality. One male patient developed incomplete temporary spinal cord ischemia after endovascular repair.

Conclusions: Minimally invasive segmental artery coil embolization of segmental arteries feeding the anterior spinal artery in patients with thoracoabdominal aortic aneurysms to prevent spinal cord ischemia after endovascular repair is feasible and clinically safe. (JTCVS Open 2024;18:1-8)



SA feeding the ASA via the collateral network.

CENTRAL MESSAGE

Endovascular occlusion of SAs feeding the ARMA and the ASA to stage endovascular thoracoabdominal aortic repair is safe and effective.

PERSPECTIVE

Endovascular occlusion of SAs feeding the ARMA and the ASA as a staging procedure of ER of TAAAs can be safely performed and is associated with low rates of SCI after ER of extensive TAAAs, suggesting its potential beneficial effect.

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Abbreviations and Acronyms

ARMA	= anterior radiculomedullary artery
ASA	= anterior spinal artery
CN	= collateral network
CSF	= cerebrospinal fluid
CTA	= computed tomography angiography
ER	= endovascular repair
MISACE	= minimally invasive segmental artery coil embolization
PAU	= penetrating aortic ulcer
SA	= segmental artery
SCI	= spinal cord ischemia
TAAA	= thoracoabdominal aortic aneurysm

▶ Video clip is available online.

Endovascular repair (ER) of thoracoabdominal aortic aneurysms (TAAAs) has been highly successful over the past decade, leading to favorable perioperative outcomes.[1] However, ischemic spinal cord injury (SCI) remains a devastating complication after ER with rates ranging from 4% to 31% negatively affecting postoperative survival.[2-4] ER of TAAA significantly compromises spinal cord blood supply through extensive, sudden, and simultaneous occlusion of multiple segmental arteries (SAs), but results in a lower rate of SCI compared with open repair of TAAAs, supporting the concept of collateral network (CN) of spinal cord perfusion.[2,5] Although preservation of SA by reimplantation is recommended in open TAAA repair to reduce SCI,[6] reattachment of SA during ER is technically challenging and has shown limited clinical benefits.[7] Therefore, techniques to prevent SCI have focused mostly on indirectly improving spinal cord perfusion by increasing mean arterial blood pressure, cerebrospinal fluid (CSF) drainage, preserving subclavian and hypogastric arteries, and staging SA sacrifice.[6] Partial stenting of the thoracic aorta,[8] transient perfusion of the aneurysm sac through a branch intentionally left open,[9] and minimally invasive segmental artery coil embolization (MISACE)[10] were used to stage aortic repair. MISACE followed by endovascular aneurysm exclusion has been shown to reduce paraparesis and paraplegia after ER of extensive TAAA.[10] The concept of MISACE is based on the theory of CN of blood supply to the spinal cord, according to which any SA can supply blood to the spinal cord and can develop into collateral circulation to the anterior spinal artery (ASA).[6] Thus, MISACE occludes only the main trunk of the SA, allowing regeneration and new development of arterial collaterals to the spinal cord fed by alternative sources of inflow such as the subclavian and hypogastric arteries.[10] Therefore, the assumption that maintaining direct blood supply to the ASA from the aorta via SA and the great anterior radiculomedullary artery (ARMA) is an important factor in reducing the risk of SCI has been questioned. Therefore, the direct coverage of the SA origin during aortic ER and MISACE has been advocated.[11] There is no consensus on whether SAs feeding the great ARMA and thus ASA can be safely occluded without causing SCI. Furthermore, the effects of direct occlusion of SA feeding the ARMA and ASA have not been studied in detail. Because the angiographic detection of SA supplying the ASA via the ARMA is technically feasible,[12] we aimed to investigate the feasibility and the clinical impact of MISACE of SA supplying the ASA in patients with TAAA to prevent SCI after endovascular treatment.

MATERIALS AND METHODS

Study Design and Patient Selection

In this retrospective single-center study, we evaluated early outcomes of preemptive selective percutaneous occlusion of the ostium of SA feeding the ASA in patients with TAAA to prevent SCI between January 2018 and July 2020. Patients with atherosclerotic and postdissection TAAA greater than 60 mm and rapid aneurysm enlargement (>10 mm/year) and with penetrating aortic ulcers (PAUs) anatomically suitable for ER were included in the study. Preemptive embolization of SAs was not performed especially in patients with symptomatic and ruptured aortic aneurysms. The inclusion and exclusion criteria for the study are detailed in Table 1. Overall, 148 patients underwent ER of their TAAA during the study period. Because of the inclusion in another clinical trial, 12 patients were excluded from the present analysis. Of the remaining 136 patients, 104 underwent MISACE before ER to prevent SCI as part of our clinical routine, and we identified 54 patients (51.9%) with preemptive embolization of SA supplying the ASA. Because of the acute presentation, 32 patients were excluded from MISACE before ER and 50 patients had no ARMA-ASA on the spinal angiogram (Figure 1). In the group with no ARMA-ASA, the incidence of SCI after ER was 0%. Aneurysms were classified according to the Crawford classification of the extent of endovascular aortic repair.[13] The study was performed in accordance with the principles of the Helsinki Declaration. The Institutional Review Board approved the analysis of the retrospective data set (AZ 319-15/Amendment May 4, 2016). Because of the retrospective nature of the study, informed consent of the patients was not required because the study analyzed anonymous clinical data of the patients.

Spinal Arteriography and Minimally Invasive Segmental Artery Coil Embolization Technique

On the basis of 1-mm sliced computed tomography angiography (CTA), patent SAs were identified at the extent of the planned aortic repair, including the proximal and distal aortic neck, to be occluded with MISACE. The patent SAs were counted twice in every patient by 2 different investigators (D.B. and A.G.). Patency of SAs was defined as evidence of perfusion of the vessel from the aortic lumen. The technique of catheterization and opacification of spinal cord vasculature, and the MISACE technique have been described in detail.[10,12] Briefly, the procedure was performed in local anesthesia without CSF drainage and under continuous monitoring of the neurologic function 48 to 72 hours after the procedure. The antihypertensive drugs were temporarily paused before the procedure to allow permissive hypertension. MISACE consisted of selective catheterization by the femoral route followed by the manual injection of contrast material for the imaging of thoracic and lumbar SAs until the arteries that supplied the ASA were identified (Video 1). The goal was the delineation of the aortic

TABLE 1. Selection of patients for staged endovascular repair of thoracoabdominal aortic aneurysm with minimally invasive segmental artery coil embolization

Inclusion criteria	Exclusion criteria
• TAAA, Crawford types I, II, or III	• Symptomatic and ruptured TAAA
• TAAA, Crawford types IV when after the endovascular repair the aortic segment covered by the stent graft will reach the sixth rib	• Preoperative neurological deficits or spinal cord dysfunction
	• Urgent treatment due to a planned operation of a malignancy
	• High risk for SA embolism such as shaggy aorta
	• Patients with no SAs and with very small SAs (<2 mm) on the CTA at the aortic segment to be covered by the stent graft
	• Patients with chronic renal insufficiency (GFR <30 mL/min/1.73 m^2)

TAAA, Thoracoabdominal aortic aneurysm; *SA,* segmental artery; *CTA,* computed tomography angiography; *GFR,* glomerular filtration rate.

branches to the ASA at the level of the aorta to be covered by the stent graft and to find which one, if any, contained a branch typical of the great ARMA (Figure 2). The criteria for the visualization of the great ARMA artery were the presence of a branching artery with an oblique course along the anterior surface of the spinal cord with a hairpin-shaped connection to the ASA (Figure 3, *A*).[12] The number of ARMA feeding arteries to the thoracolumbar ASA was assessed. The branching level of the ARMA was determined on the basis of the anatomic level of the SA that was seen supplying the ARMA. After angiography, using coils or microvascular plugs, the ostial segment of the SA was occluded closest to its aortic origin to theoretically allow any collateralization to maintain flow into the ARMA.[10] A maximum of 6 SAs were planned to be occluded per session to avoid iatrogenic SCI (Figure 2).[14] Because the procedure's goal was to occlude all patent SAs at the aortic level to be covered by the stent graft, multiple MISACE sessions were scheduled in some patients with a clinical assessment of spinal cord viability between stages to prevent a critical acute reduction in spinal cord perfusion. The time interval between staging sessions was determined on the basis of the patients' anatomy, including the aneurysm size, the number of patent SAs at the aortic segment to be covered by the stent graft, the kidney function, and the recovery time. Drawing from insights gained in experimental studies, we opted for a minimum interval of at least 1 week between 2 MISACE sessions[15] to allow sufficient time for arterial priming of the CN to occur. Standardized postinterventional management, including neurological examination, was performed as previously published.[10]

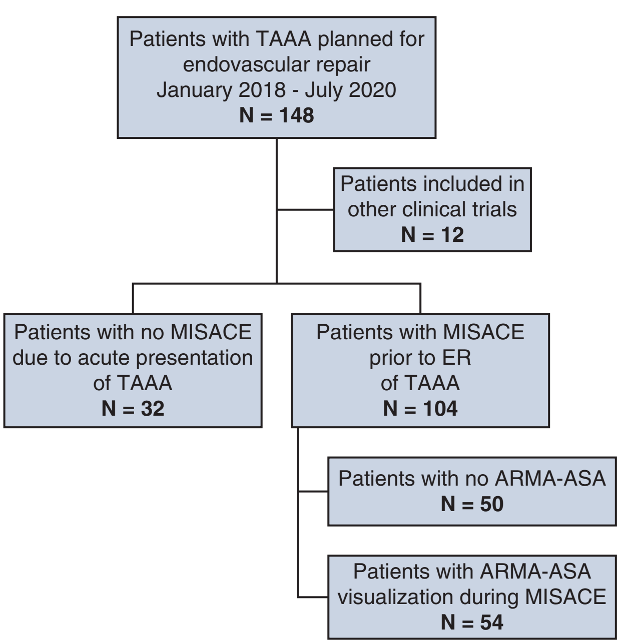
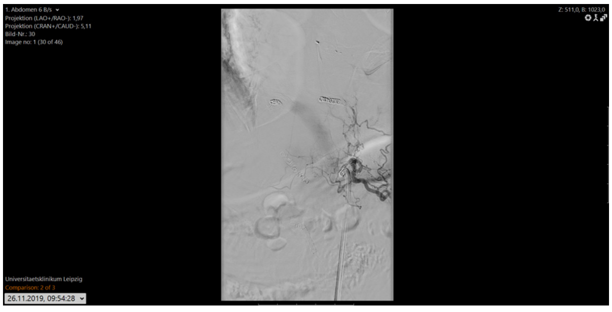


FIGURE 1. Patient flow diagram. Patients presented with TAAA and treated with ER between January 2018 and July 2020 are shown. *TAAA*, Thoracoabdominal aortic aneurysm; *MISACE,* minimally invasive segmental artery coil embolization; *ER,* endovascular repair; *ARMA,* anterior radiculomedullary artery; *ASA,* anterior spinal artery.

Endovascular Repair of the Aneurysm

Endovascular aneurysm repair after MISACE has been described.[10] The complete exclusion of the aneurysm was performed no sooner than 7 days after the MISACE to allow the preconditioning of the CN.[15] Briefly, implantation of standard and custom-made stent grafts was performed no sooner than 5 days after MISACE to permit the priming of the spinal



VIDEO 1. In this digital subtraction angiography, which was performed in an anteroposterior projection in the thoracoabdominal region, the opacification of the large ARMA (typical hairpin shape) and the anterior vertebral artery can be seen after injection of contrast medium via an angiography catheter placed in the ostium of the left SA at the level of the vertebral body Th12. The SA at the level of Th12 feeds the ARMA via the rich CN of the spinal cord that developed after endovascular occlusion of the SAs at the level of Th 12 on both sides, Th 12 left side, and Th 10 right side. Video available at: https://www.jtcvs.org/article/S2666-2736(24)00051-2/fulltext.

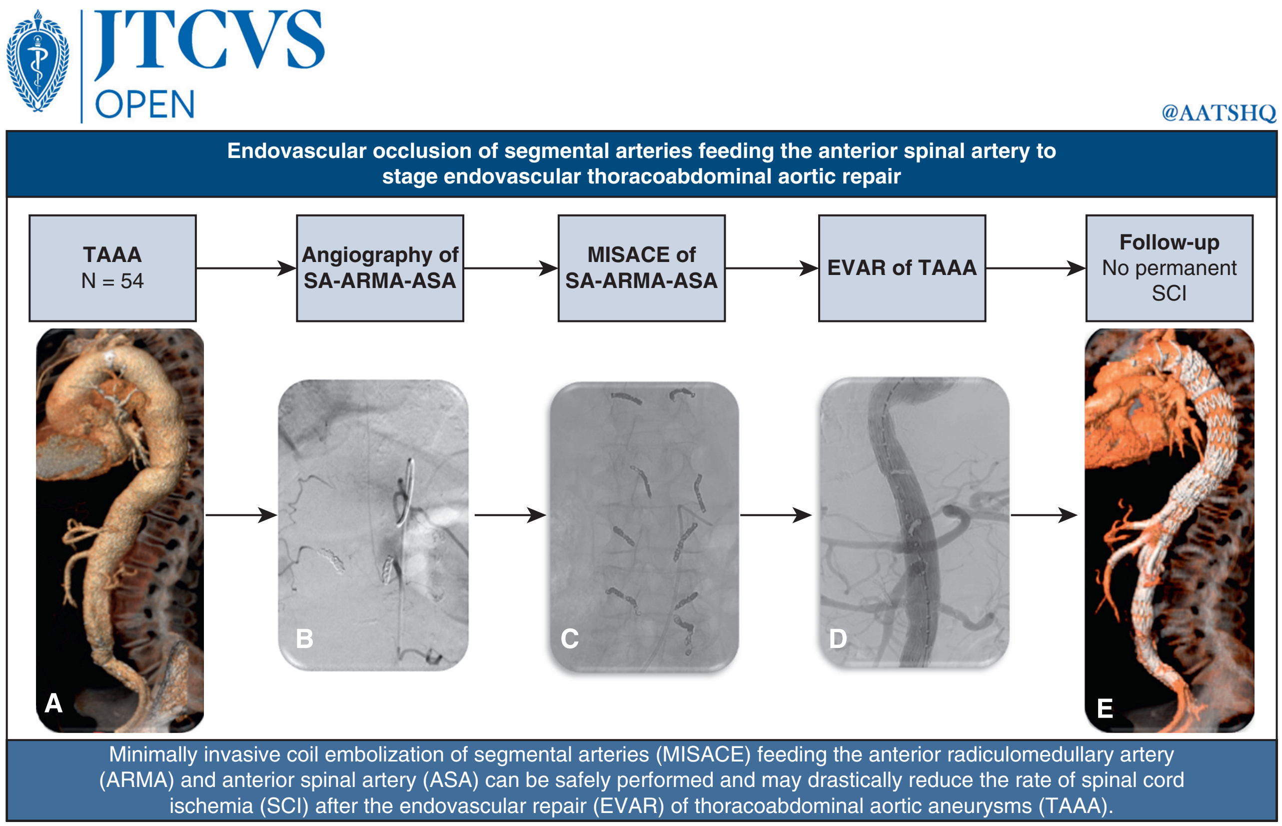


FIGURE 2. Staged ER of TAAA with endovascular occlusion of SAs feeding the ASA. A, Lateral view of the 3-dimensional reconstruction of a TAAA. B, Selective transfemoral catheterization and opacification of the SAs originating in the thoracoabdominal area and suppling the ASA via the branch typical of the great anterior radiculomedullary artery. C, Occlusive coils in the origin of SAs originating from the thoracoabdominal aorta after minimally invasive SA coil embolization. D, Completion angiography after ER of a TAAA. E, Lateral view of the 3-dimensional reconstruction of a TAAA after ER.

cord CN (Figure 2). The endovascular procedures of the aneurysm exclusion were performed in general anesthesia, and classic perioperative neuroprotective strategies were used as per institutional protocol.[10]

Perioperative Management and Postoperative Evaluation

All patients underwent standardized postoperative management with at least 24-hour monitoring in the intensive care unit. No prophylactic CSF drainage was used. The mean arterial blood pressure was kept at greater than 80 mm Hg, and the administration of any antihypertensive drugs was temporarily paused. Transfusion of blood products was indicated in the first 48 hours after the procedure to keep a target hemoglobin 10 g/dL or more. The neurological examination was performed before intervention, every 6 hours during the intensive care unit stay, and daily on the normal ward. New neurological changes that might indicate a new neurological event triggered acquisition of brain and spinal cord imaging. Postoperative magnetic resonance imaging was performed when not contraindicated. In case of SCI after ER of TAAA, therapeutic CSF drainage was recommended. Contrast-enhanced ultrasound and CTA were performed routinely before discharge.

End Points

We analyzed the safety and technical feasibility of MISACE of SAs directly feeding the ASA. Study end points were in-hospital rate of SCI and all-cause mortality both after MISACE and after ER of TAA and TAAA.

Data Collection and Statistical Analysis

Demographics, medical history, and procedure-related data were extracted for analysis from our electronic database. Complications were defined using the Society for Vascular Surgery's reporting standards for endovascular aortic aneurysm repair.[13] Preoperative and postoperative imaging studies were analyzed with multiplanar reconstruction on a workstation (3mensio Medical Imaging). Data were analyzed using SPSS version 20.0 (IBM). Categorical variables are presented as number (percentages), and continuous variables are presented as mean ± SD or median (range).

RESULTS

Patient Demographics

We identified 54 consecutive eligible patients (36 male; mean age, 71.1 ± 9.3 years) treated with MISACE of SAs directly supplying the ASA to prevent SCI after ER of TAAA. Patients' demographics and indications for treatment are summarized in Table 2. An average of 11.9 ± 4.2 SAs (median, 12; range, 3-22) were found patent on CTA and were to be covered by the stent graft at the end of the ER of TAAA.

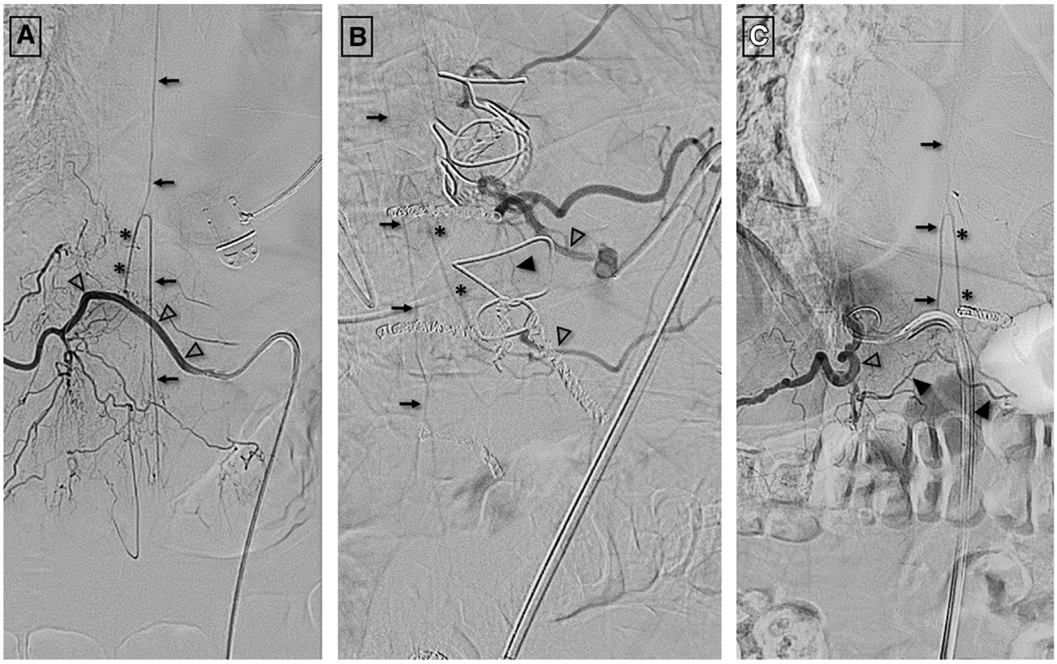


FIGURE 3. Arteriogram showing visualization of the great ARMA and ASA (A) directly through the SA, (B) indirectly through the adjacent SA, and (C) indirectly through the contralateral SA. The *arrow* shows the ASA, the *asterisk* shows the ARMA, the *transparent arrowhead* shows the SA, and the *black arrowhead* shows the anastomotic circulation.

Anatomy of Segmental Arteries Feeding the Anterior Spinal Artery and Minimally Invasive Segmental Artery Coil Embolization

A total of 388 SAs were occluded by MISACE with each patient having a mean of 7.2 ± 3.1 coiled SAs (median, 7; range, 2-16), occluding 64.5% (range, 25%-100%) of direct open segmental arterial inflow to the spinal cord within the treated aortic segment. The great ARMA was found in 85 (21.9%) of 388 coiled SAs. The origin of ARMA was located between Th8 and L3 levels. ARMA arose on the left side in 64 (75.3%) of the vessels (Figure 4). Visualization of ARMA was direct through the injected SA in 64 (75.3%) vessels (Figure 3, *A*) and indirect via anastomotic circulation in 21 (24.7%) vessels. Anastomoses were longitudinal with an immediately adjacent SA in 14 (16.5%) vessels (Figure 3, *B*) and transverse with a contralateral SA in 7 (8.2%) vessels (Figure 3, *C*). In 32 (59.2%) cases, ARMA was visualized from only 1 SA, in 14 (25.9%) cases the same ARMA was visualized after arteriography of 2 different SAs, in 7 (12.9%) cases after arteriography of 3 SAs, and in 1 (1.9%) case after arteriography of 4 SAs. Altogether, we identified 66 great ARMAs. In 10 patients (18.5%), 2 large ARMAs were identified before MISACE, and 1 patient (1.9%) showed 3 ARMAs on the spinal arteriography. Five (45.4%) of the 11 patients with more than 2 ARMAs had TAAA Crawford type II. In 43 patients (79.6%), the great ARMA was the only artery that supplied the ASA at the aortic level to be stented. During the first MISACE session, 42 (49.4%) of the 85 SAs feeding the ARMA were coiled. During the second MISACE session, 26 (30.6%) SAs were coiled. During the third MISACE session, 14 (16.5%) SAs were coiled. During the fourth MISACE session, 3 (3.5%) SAs were coiled. Altogether, 136 sessions of MISACE were performed: Eight patients received 1 session, 20 patients received 2 sessions, 19 patients received 3 sessions, 4 patients received 4 sessions, and 3 patients received 5 sessions of coil embolization. The MISACE sessions lasted a mean of 58.7 ± 31.1 minutes, using 28.6 ± 24.2 mL of iodine contrast media and mean dose area product of 122.2 ± 77.6 Gy cm^2.

Neurological Complications and Interval Management After Minimally Invasive Segmental Artery Coil Embolization

No major procedure-related complications occurred during and after MISACE, especially no neurological deficit such as SCI and stroke. No alteration of the renal function after MISACE was recorded. In 2 patients, 2 SAs planned to be coiled were left open because of the unstable position of the catheters caused by extreme aortic kinking and large aneurysm diameter. After 20 (14.7%) MISACE sessions, patients reported back pain most likely indicating skeletal muscle ischemia, which was treated with nonsteroidal anti-inflammatory drugs. The hospital stay associated with MISACE averaged 4.8 ± 3.1 days.

TABLE 2. Demographics, clinical, and anatomic characteristics of 54 patients with thoracoabdominal aortic aneurysms

Variable	N	%
Total	54	
Male	36	66.7
Age (y)	71.1 ± 9.3	
Hypertension	50	92.6
Diabetes mellitus	14	25.9
Coronary heart disease	22	40.7
Smoker	23	42.6
COPD	9	16.7
Peripheral arterial disease	8	14.8
Hyperlipidemia	52	96.3
Renal insufficiency (GFR < 60 mL/min/1.73 m^2)	10	18.5
Body mass index (kg/m^2)	27.7 ± 5	
ASA classification		
ASA III	40	74.1
ASA IV	14	25.9
Aortic diameter (mm)	61.6 ± 10.4	
Thoracoabdominal aortic aneurysms		
Type I	8	14.8
Type II	24	44.4
Type III	11	20.4
Type IV	11	20.4
Pathology		
Aneurysm	47	87.0
PAU	7	13.0
Etiology		
Degenerative	41	75.9
Postdissection	13	24.1
Previous aortic procedure		
Ascending aortic repair	6	11.1
Elephant trunk procedure	1	1.9
Frozen elephant trunk procedure	3	5.6
TEVAR	3	5.6
EVAR	6	11.1
Time from aortic procedure (y)	4.4 ± 5.1	

Continuous data are presented as mean ± SD; categorical data are given as counts (percentage). *COPD,* Chronic obstructive pulmonary disease; *GFR,* glomerular filtration rate; *ASA,* American Society of Anesthesiologists; *PAU,* penetrating aortic ulcer; *TEVAR,* thoracic endovascular aortic repair.

Endovascular Repair of Thoracoabdominal Aneurysm and Thoracoabdominal Aortic Aneurysm

After a mean period of 47.9 ± 39.4 days after MISACE, the ER of the aortic aneurysm was performed. All patients were treated in general anesthesia using percutaneous femoral access. A total of 38 custom-made fenestrated and branched stent grafts and 16 commercially available aortic stent grafts were implanted. A total of 150 visceral arteries were incorporated in stent grafts with technical success of visceral artery stenting of 99.3% (149/150) because the celiac trunk was not connected to the stent graft in 1 case. The subclavian artery was patent in all cases, and 1 of the hypogastric arteries was occluded in 11 patients (20.4%). The total endovascular operating time was 121.2 ± 83.3 minutes, and radiation time was 38.7 ± 23.8 minutes with a radiation dose of 255.5 ± 174.5 Gy cm^2. The length of the aortic coverage was a mean 243.7 ± 63.3 minutes.

In-Hospital Neurological Outcomes After Endovascular Repair of Thoracoabdominal Aortic Aneurysm

No in-hospital mortality after ER of TAAA occurred. One patient (1.8%) with a postdissection type II TAAA developed incomplete transient SCI. This 61-year-old male patient, having 21 open SAs in the aortic area to be stented and great ARMA coming from Th10 on the right side, received MISACE of 7 SAs during 3 sessions. Five days after MISACE, ER of TAAA was performed in 1 session covering 355 mm of the aorta. One day after the procedure, he developed paraparesis and impairment of bladder control. After refusing therapeutic CSF drainage, the patient underwent intensive conservative treatment exclusively. He was discharged on postoperative day 16, with minimal walking impairment and with complete restoration of the bladder function. At 1-year follow-up, the patient demonstrated full recovery of lower-limb motor function and restored bladder control. Ischemic stroke was recorded in 1 patient (1.8%) most likely due to his shaggy aorta. In-hospital stay after ER of TAAA averaged 9.8 ± 6.5 days.

DISCUSSION

SCI caused by extensive coverage of SAs after ER of TAAA remains the most feared complication with an incidence of up to 20% of patients with type II TAAA.[2] Treatment focus has centered on strategies to prevent SCI such as permissive hypertension, CSF drainage, and staging the aortic procedures.[6] In a recent monocentric retrospective study, MISACE, without knowledge of location of great ARMA, to precondition the paraspinous CN as a staging procedure for ER of TAAA, has been shown to be clinically feasible and to reduce paraparesis and paraplegia after total ER of TAAA.[10] Nevertheless, there is still paucity of consensus on whether SAs feeding directly the ARMA can be safely occluded in patients with TAAA without causing SCI, because data are scarce and come mostly from neuroradiological studies. Salame and colleagues[16] reported 3 patients with embolization of 3 pairs of SA to treat vertebral tumors, occluding inclusively the great ARMA, without causing postoperative neurological deterioration.

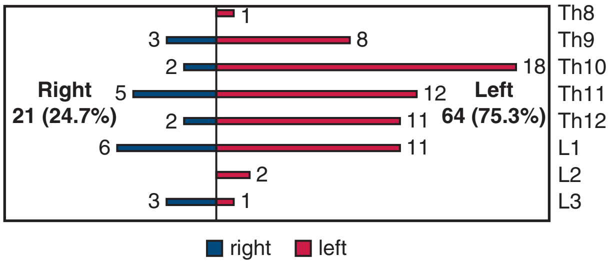


FIGURE 4. The origin of the great anterior radiculomedullary artery from the SA. Diagram showing the origin of ARMA between Th8 and L3 levels. ARMA arose on the left side in 75.3% of the vessels.

Until now, SA reimplantation during open TAAA repair remains the most widespread strategy to avoid postoperative SCI.[6] Various factors contribute to SCI, such as extensive coverage of aorta in ER, and, in open repair, prolonged aortic crossclamp time and fluctuations in body temperature, often resulting in permanent paraplegia. The CN concept proposes a strategy to alleviate acute perfusion loss through staged occlusion of SAs with MISACE. This approach allows for regeneration and the de novo generation of arterial collaterals supported by alternative inflow sources, such as subclavian and hypogastric arteries in patients with TAAA, regardless of the type of planned repair. We currently lack clinical experience with MISACE in patients with known or suspected connective tissue disease. We demonstrated in the present study the feasibility and safety of MISACE of SA directly supplying the ARMA and ASA in patients with TAAA to prevent SCI after ER. In this cohort of 54 patients, 66 ARMAs were identified originating from 85 (21.9%) SAs of 388 SAs coiled in the aortic area to be stented. The rate of ARMA-ASA identification on the spinal arteriography was lower than data published by Kieffer and colleagues.[12] When we could not locate a major radicular contribution to ASA originating from the aneurysm, we assumed that collateral vessels had developed from other vascular territories, reflecting the natural process of preconditioning of the CN in patients with aneurysm-related occluded SAs.[6] Most origins of ARMAs (75.3%) were situated on the left side between Th8 and L3, similar to previously published data.[12] Furthermore, 20.4% of our patients had more than 2 ARMAs feeding the ASA in the aortic area to be stented during spinal cord angiography, and 45.4% of these patients had a type II TAAA. Interestingly, in 40.8% of cases the same ARMA was visualized after dye injection in more than 1 SA with a maximum of 4 SAs feeding the same ARMA. This implies that the development of atherosclerosis or mural thrombus especially in patients with TAAA may occlude some originally important SAs, leaving the spinal cord dependent on diverse collateral arteries. This also underlines the fact that spinal cord supply is unlikely to depend on a single SA, and the occlusion of the SA may not be the only causative factor of SCI. Nevertheless, the detection of great ARMA can be difficult because of various levels of its origin, its small size, and the amount of time needed to obtain the angiogram.[17] Fukui and colleagues[11] demonstrated that collateral arteries connect to ARMA after stent graft occlusion of the SA feeding the ARMA in patients with TAAA. Three patterns of collateral circulation have been described, the most important being the intersegmental type.[11] In 24.7% of our cases, ARMA was visualized via longitudinal and transversal intersegmental anastomotic circulation. The importance of these contributions to the spinal cord circulation superimposed on a background of anatomic diversity creates difficulties in the management of patients with extensive aneurysmal disease. However, the message from our clinical experience is that the arterial supply to the spinal cord is adaptable. Thus, after the MISACE of all detected SAs feeding the ARMA, we encountered no SCI in our cohort. Furthermore, no major procedure-related complications were recorded in the present study, underlying the safety profile of this new minimally invasive staging method for ER of TAAA. Nonetheless, there are distinctions in the approach to patients with atherosclerotic disease and PAUs when compared with those with postdissection aneurysms. In cases of atherosclerotic disease and PAUs, there typically exists an intraluminal thrombotic component covering the origin of some SAs. This process acts as an ischemic preconditioning of the CN. Despite the potentially lower number of SAs to be occluded, the presence of a large intraluminal thrombus raises the risk of catheter manipulation leading to embolization of material into the SAs, causing iatrogenic SCI. Therefore, MISACE is not recommended in case of "shaggy aorta." Conversely, the risk of peripheral thrombotic embolization is lower in aortic dissection, but the number of SAs to be embolized is higher because of the smaller amount of thrombus. Furthermore, because of the double aortic lumen after dissection, SAs originating from both aortic lumens should be embolized to achieve the desired effect of MISACE. Consequently, the number of MISACE sessions is higher in patients presenting with postdissection aortic aneurysms. The only SCI encountered after ER of aortic aneurysms was partial and transient, most likely due to the extensive coverage of the aorta after occluding only 30% of the patents SAs in the aortic area to be covered by the stent graft. This low rate of SCI overlaps with the previously published effect of MISACE on the rate of neurological complications after ER of TAAA,[10] highlighting the potential role of this staging method.

MISACE may have a dramatic impact on patients' quality of life by saving them from a wheelchair after developing SCI and an impact on financial systems through savings in 3 important aspects: lower care costs, lower payouts in disability insurance, and loss of output in economic systems because of resulting unemployment.[18] Furthermore, MISACE may reduce the risk of complications after aneurysm repair and in particular avoid type II endoleaks, and thus reduce the need for reinterventions.[19]

Embolization of SAs is a routine procedure for interventional radiologists.[16] Although this technique has become part of the repertoire of vascular surgeons with the introduction of embolization of aneurysmal sac branches before ER to prevent type II endoleaks,[19] we advocate collaboration with interventional radiologists in situations of uncertainty.

Study Limitations

This study is too small for multivariate analysis. Furthermore, the spinal cord angiography was performed only for the aortic area planned to be covered by the stent graft. Thus, ARMAs situated outside of this area were not described. As is generally known with retrospective and uncontrolled studies, they tend to overestimate effect sizes.[13]

CONCLUSIONS

MISACE of SA feeding directly the great ARMA and ASA in patients with TAA and TAAA to prevent SCI after ER is technically feasible and encouraging in terms of safety. MISACE of SA-ARMA followed by endovascular aneurysm exclusion may substantially reduce postoperative ischemic spinal cord injury.

Conflict of Interest Statement

D.B.: grants: Artivion, Bentley Innomed, COOK Medical, Endologix, Getinge, Medtronic. S.S.: speakers' honorarium: Bayer Medical, research funding: C.R. Bard. D.S.: consultant or advisory board member for Abbott, Biotronik, Boston Scientific, Cook Medical, Cordis, BD, Gardia Medical, Medtronic, TriReme Medical, and Upstream Peripheral Technologies. A.S.: Consulting/speakers honorarium: Abbott Vascular, BD, Boston Scientific, Cook, Cardinal Health/Cordis, Phillips, and Upstream Peripheral. All other authors reported no conflicts of interest.

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