Art of Operative Technique

Minimally invasive staged segmental artery coil embolization (MIS^{2}ACE) for spinal cord protection

Josephina Haunschild[1], Tilo Köbel[2], Martin Misfeld[1,3,4,5,6,7], Christian D. Etz[1]

[1]Department of Cardiac Surgery, University Heart Center, Rostock University Medical Center, Rostock, Germany; [2]German Aortic Center, Department of Vascular Medicine, University Heart and Vascular Center, Hamburg, Germany; [3]Department of Cardiothoracic Surgery, Royal Prince Alfred Hospital, Sydney, NSW, Australia; [4]University Department for Cardiac Surgery, Leipzig Heart Center, Leipzig, Germany; [5]Sydney Medical School; University of Sydney; Sydney, NSW, Australia; [6]Institute of Academic Surgery, RPAH, Sydney, Australia; [7]The Baird Institute of Applied Heart and Lung Surgical Research, Sydney, Australia

Correspondence to: Christian D. Etz, MD, PhD. Department of Cardiac Surgery, University Heart Center, Rostock University Medical Center, Schillingallee 35, 18057 Rostock, Germany. Email: Christian.etz@med.uni-rostock.de.

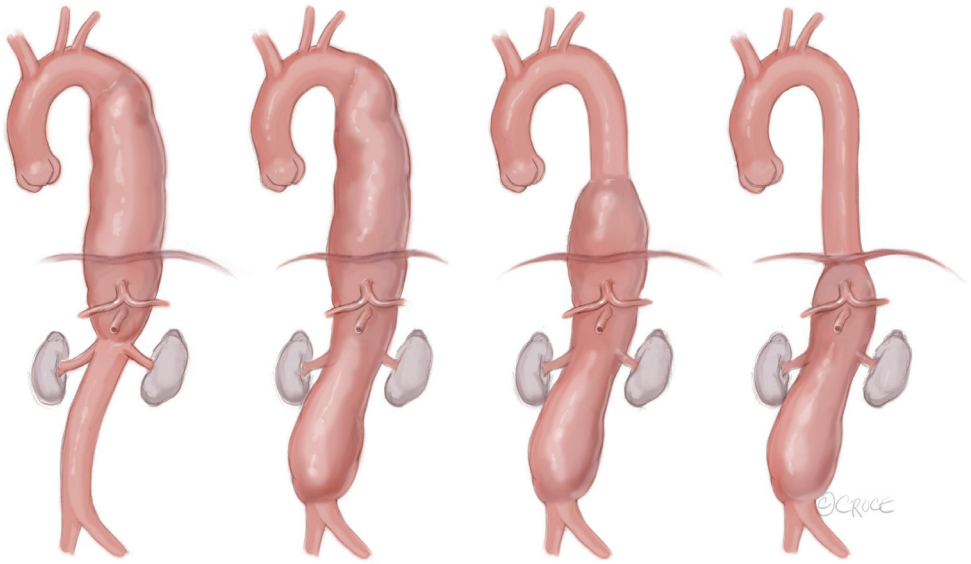
Minimally invasive staged segmental artery coil embolization (MIS^{2}ACE) is an emerging technology for priming of the paraspinous collateral network prior to open or endovascular thoracoabdominal aortic aneurysm (TAAA) repair. Its safety and efficacy have been previously proven in various experimental settings and confirmed in numerous multicentric pilot studies for open and endovascular repair. MIS^{2}ACE is safe and has the potential to decisively reduce the risk of postoperative paraplegia, the most devastating complication of open and endovascular TAAA repair, still affecting up to 20% of patients. Up to now, MIS^{2}ACE has been clinically implemented with excellent results, and is currently being investigated in the international, multicenter, randomized controlled trial PAPAartis, funded by the German Research foundation, and the European Union. MIS^{2}ACE can be performed under local anesthesia, enabling continuous monitoring of neurological function, and in case of clinical signs of imminent ischemia, preemptive interruption of the procedure. A thorough evaluation of preoperative computed tomography (CT) imaging for identification of open and accessible segmental arteries (SAs) is critical. Segmental artery occlusion can be achieved with either micro coils, or vascular plugs. A maximum number of seven SAs is currently recommended to be occluded in the same session, and a minimum interval of 5 days should be awaited between either two MIS^{2}ACE sessions or between MIS^{2}ACE and the final repair. Adjuvant side-effects of MIS^{2}ACE are the reduction in segmental back-bleeding during open repair leading to harmful steal phenomenon and the reduction of the incidence of type II endoleaks in endovascular repair. Current contraindications for MIS^{2}ACE are emergency cases, hostile anatomy, and a shaggy aorta. Other neuroprotective adjuncts such as cerebrospinal fluid (CSF) drainage, permissive hypertension, motor-evoked potentials (MEP)/somatosensory evoked potentials (SSEP) and monitoring of paraspinous muscle oxygenation by near-infrared spectroscopy should also be applied independent of prior MIS^{2}ACE procedure.

Keywords: Minimally invasive staged segmental artery coil embolization (MIS^{2}ACE); aortic aneurysm; paraplegia

Submitted May 08, 2023. Accepted for publication Sep 05, 2023. Published online Sep 19, 2023.
doi: 10.21037/acs-2023-scp-21
View this article at: https://dx.doi.org/10.21037/acs-2023-scp-21

Introduction

Minimally invasive staged segmental artery coil embolization (MIS^{2}ACE) is an emerging technique currently being investigated in the international, randomized controlled multicenter trial PAPAartis (1), for priming of the paraspinous collateral network in preparation of open or endovascular aortic aneurysm repair (2). The risk of paraplegia in the context of thoracoabdominal aortic aneurysm (TAAA) repair is still high and can be estimated by the extent of the aortic aneurysm according



	Extent I	Extent II	Extent III	Extent IV
Open	9%	17%	16%	8%
Endovascular	16%	17%	13%	2%

Figure 1 Paraplegia rates in open and endovascular aortic repair depending on Crawford extent of repair (2,3).

to the Crawford classification (displayed in *Figure 1*) and the degree of planned repair and is especially relevant for endovascular repair (landing zones!) (2,3).

Several neuroprotective adjuncts have been established in the clinical setting aiming for a reduction in spinal cord ischemia (SCI). Previous experimental and clinical evidence has generated very promising evidence that staging of TAAA repair either by MIS^{2}ACE or by using multiple stent-grafts can significantly reduce the rate of paraplegia (4-6). The pathophysiological background is the presence of a strong paraspinal collateral network and its capacity to remodel by arteriogenesis (7,8). MIS^{2}ACE in the context of TAAA repair has been first described in 2014 (9). One year later the first-in-man cases were performed (10), followed by some larger series (4,11). Since then, MIS^{2}ACE has been thoroughly investigated focusing on technique of coil embolization and choice of occlusion method (12).

Operative techniques

Preoperative planning

Preoperative assessment of the patient includes a contrast-enhanced, thin-layer, computed tomography (CT) of the entire aorta to assess the extent of aortic pathology and to evaluate patency, origin, and diameter of accessible segmental arteries (SA) as well as access options (e.g., femoral). Target SAs for coil deployment are identified considering the extent of planned repair and individual SA anatomy. In case of contraindications to contrast-enhanced CT, magnetic resonance imaging may be used as alternative imaging modality despite less spatial resolution.

In patients with chronic type B aortic dissection, as displayed in *Figure 2*, SAs may be already occluded or difficult to access; occasionally entries in the dissection membrane may be considered for access to false-lumen originating SAs. Detailed 3D-reconstruction of the aorta can help plan the procedure and final repair. Especially in endovascular aortic repair, preoperative imaging is essential for stent-graft design and positioning. With regard to aneurysm repair, general assessment of cardiovascular health of the patient is recommended: electrocardiogram (ECG), pulmonary function tests, echocardiogram, and coronary angiogram should all be considered.

Monitoring

During and after the procedure the patient's arterial blood pressure is monitored closely (and preferably invasively) for 48 hours. For monitoring of paraspinous muscle oxygenation, near-infrared spectroscopy can be applied

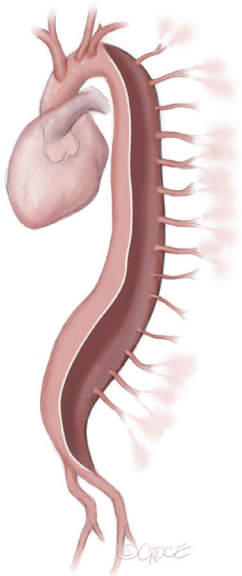


Figure 2 Schematic drawing of a type B aortic dissection. Assessment of open or chronically occluded segmental arteries and femoral access sites should take place. Analysis of possible landing zones for final endovascular aortic repair should be considered.

as shown in *Figure 3* (13). As the patient is awake during the MIS²ACE procedure, neurological assessment can be performed after each SA coil embolization. Caution is advised in case of back pain as sign of ischemia and should mandate interruption of the procedure. The procedure may be performed with or without spinal fluid drainage.

Exposition

SA embolization usually is conducted through a transfemoral access in local anesthesia. The biggest advantage of local instead of general anesthesia is the possibility of immediate feedback by the awake patient with regard to potential neurological symptoms. After access to the common femoral artery, a 6 F angled sheath and a sidewinder-type 5 F catheter is typically used to engage the SA ostium. Then a microcatheter of choice and a hydrophilic guidewire are used to gain a stable access to the main stem of the SA (see *Figure 4*).

SA occlusion

MIS²ACE is usually performed using a fixed imaging system with large flat panel detector in either a hybrid operating room or an angiography suite, overview displayed in *Figure 5*.

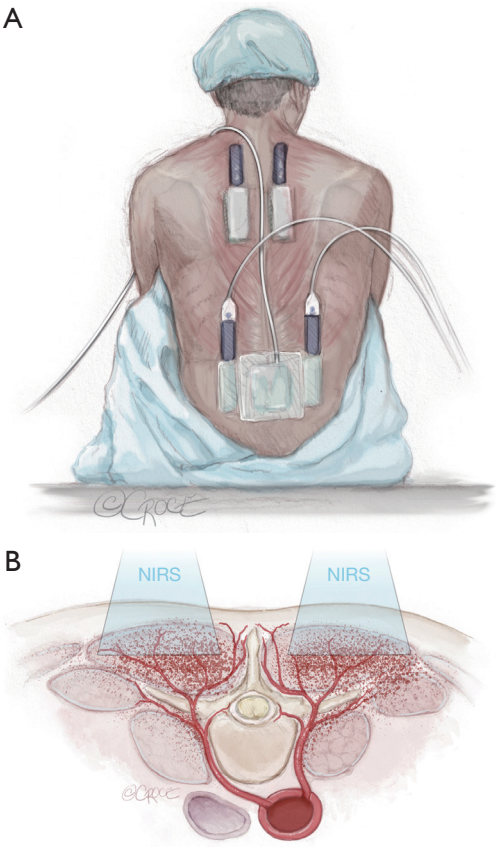


Figure 3 Positioning of the optodes on the paraspinous muscles for cnNIRS during and after the MIS²ACE procedure. (A) Backview of a patient; (B) cross-sectional view through the paraspinous muscles. NIRS, near-infrared spectroscopy; cnNIRS, collateral network near-infrared spectroscopy; MIS²ACE, minimally invasive staged segmental artery coil embolization.

Digital subtraction angiography (DSA) in multiple projections is used to identify SAs. Image-fusion techniques to create an overlay with anatomic information from preoperative CTAs serving as anatomic reference prior to SA catheterization can be very helpful and can reduce radiation and procedure time. SA embolization can be performed using pushable or detachable coils, as well as vascular plugs, as seen in *Figure 6*.

The use of particles and liquid embolic agents is strongly discouraged, due to the risk of peripheral embolization to the anterior spinal artery. Embolization is aimed to be performed in the proximal SA main stem to ensure that the collateral network itself is not affected. According to the protocol of the ongoing PAPAartis trial, a maximum of seven SAs should be occluded in one MIS²ACE session

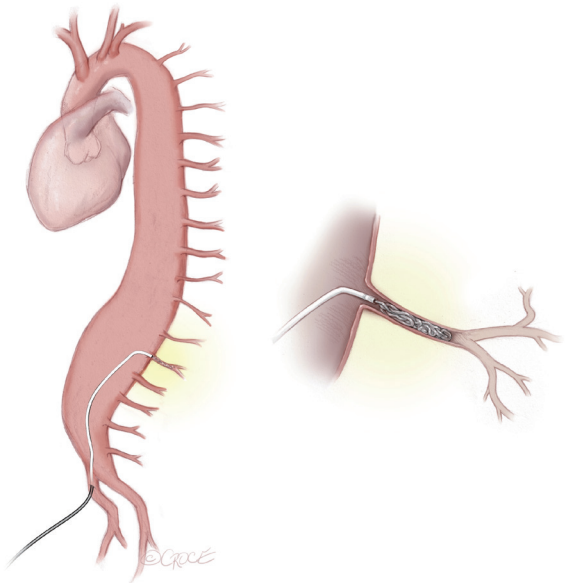


Figure 4 Thoracoabdominal aorta with sheath and microcatheter in one of the preoperatively identified segmental artery, accessed from the femoral artery.

and a time interval of minimum 21 days between MIS^{2}ACE sessions is recommended, however, a safety minimum of 5 days is possible (1).

Post-MIS^{2}ACE monitoring

It is essential to carefully control the individual patient's systolic blood pressure during and after the procedure (14). Invasive monitoring of blood pressure is advantageous, and hypotensive periods should be meticulously avoided for a sufficient mean arterial pressure (MAP) and for optimal stimulation of the paraspinous collateral network. Interruption/reduction of oral anti-hypertensive medication and use of intravenous vasopressors is preferable to volume therapy, which increases central venous pressure and thereby cerebrospinal fluid (CSF) pressure, leading to a reduction in spinal cord perfusion (15). Ideally the patient should stay in the intermediate care unit (IMCU) for at least 48 hours. Neurological function should be regularly examined by applying the modified Tarlov scale (16).

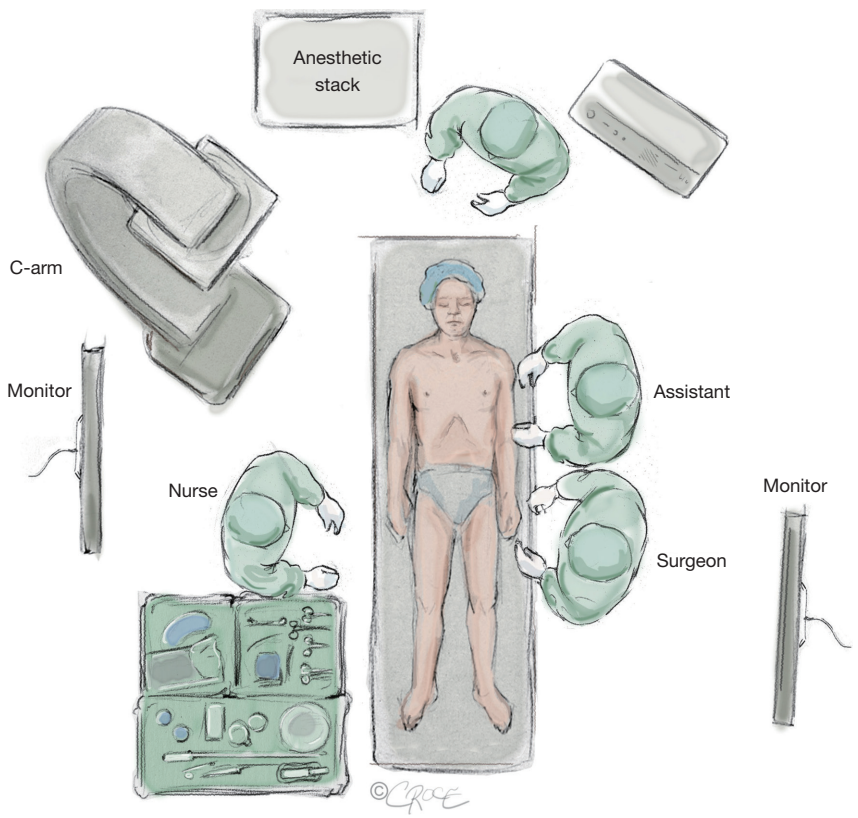


Figure 5 Overhead (bird's eye) view of layout of hybrid operating room, including the C-arm for radiation and the fixed imaging system with large flat panel detector.

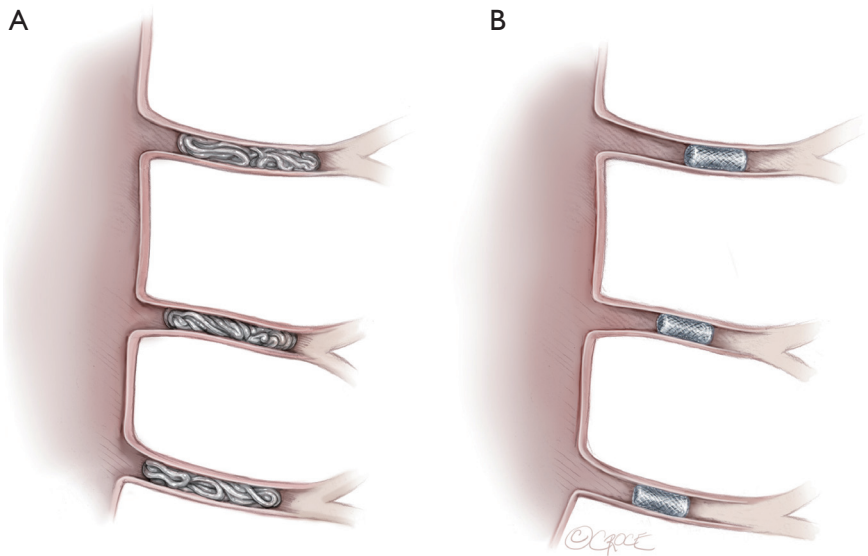


Figure 6 Different methods of segmental artery occlusion (A) coil embolization (B) plug embolization.

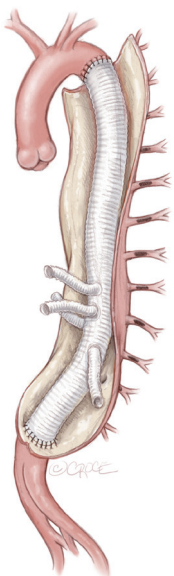


Figure 7 Schematic drawing of a final repair in open surgical technique with previously occluded segmental arteries.

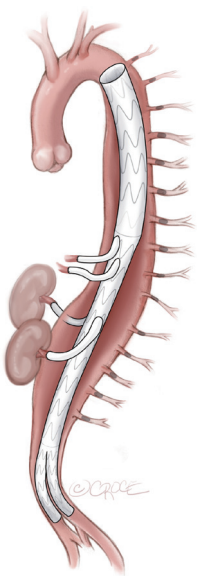


Figure 8 Schematic drawing of a final repair in endovascular technique with previously occluded segmental arteries.

Completion

After a minimum of 5 days after the last MIS²ACE procedure, final aneurysm repair can be performed, either as open thoracoabdominal repair (see *Figure 7*) or endovascular procedure (see *Figure 8*). MIS²ACE back-bleeding in open repair is reduced and risk of type II endoleak is significantly lower in endovascular repair.

Comments

Clinical results

MIS²ACE has been proven to be an effective tool for reducing the incidence of SCI, by priming the paraspinous collateral network prior to complete thoracoabdominal aortic repair. Large animal experiments, various clinical

pilot studies, and numerous retrospective clinical series have shown the benefits of "staging" (6). It is currently being evaluated in a large, international, randomized, controlled multicenter clinical trial (1,4,12). The first preliminary clinical results, gathered before the initiation of the PAPAartis trial, seem promising, and endovascular staging using stent grafts is also already being performed by many leading endo/vascular specialists in the field (5,6,11). The clinical implementation of MIS^{2}ACE was performed in two very high-risk patients—one 45-year-old man receiving MIS^{2}ACE of two unilateral lumbar SAs four weeks prior to open repair of a Crawford Extent III aortic aneurysm, and in one 66-year-old woman receiving bilateral MIS^{2}ACE of the 4th lumbar SA and the inferior mesenteric artery eight weeks prior to endovascular aortic repair of a Crawford Extent II aneurysm (10). Both patients were eventually successfully treated without any signs of neurological impairment. These first two patients were followed by a single-center case series from Branzan *et al.* including 50 patients, mainly Crawford Extent II and III (72%), receiving MIS^{2}ACE prior to endovascular repair. No neurological deficit occurred, however, 24% of patients developed backpain during the procedure as sign of serious muscle ischemia (4). Recently, Addas *et al.* presented a retrospective analysis of 17 patients receiving MIS^{2}ACE prior to endovascular repair, also mainly Extent II and III aneurysms. In this analysis, prior SA embolization was successful in 14 patients, and a mean of three arteries were occluded, mainly between T9 and T12 (11). In those patients with MIS^{2}ACE, two patients still developed paraparesis, potentially due to incomplete embolization and therefore insufficient priming of the collateral network (may be due to short interval) or insufficient blood pressure management.

One of the three patients with attempted but unsuccessful MIS^{2}ACE experienced paraplegia. Another case report of insufficient collateral network preparation was published by Doukas *et al.* involving a 54-year-old man in need for a Crawford Extent II repair after acute type A aortic dissection with ascending and arch replacement, as well as frozen elephant trunk implantation 4 years earlier (17). In three MIS^{2}ACE sessions, a total of eight SAs were occluded (T8 and T9 right sided, T11, L1 and L2 bilateral). However, during open repair, a significant decrease of motor-evoked potentials (MEPs) occurred and the surgeons found two small SAs at T12, which then were revascularized with an 8-mm polyester graft, and MEPs were reported to have been restored. The patient was discharged with no neurological deficits (17). This case demonstrates the know-how and expertise needed for sufficient occlusion of all available SAs, especially in the highly relevant, so called 'watershed area', between T12 and L2, prior to the repair as demonstrated in a chronic large animal experiment on the optimal occlusion pattern (12).

Advantages

The most significant advantage of MIS^{2}ACE, if confirmed by the ongoing PAPAartis trial, will be the reduction of paraplegia in the context of TAAA repair. The technique itself is easy to learn, however, is complicated by anatomical features of the individual patients. Up to now, no severe procedural complications have been reported by over 33 centers and over 150 MIS^{2}ACE procedures (4,11) and with advancing learning curve the amount of contrast agent and time of radiation is reduced. Furthermore, as the patient is awake, neurological symptoms, such as ischemic back pain or symptoms of sudden paralysis, can be reported immediately and the procedure can be interrupted. In contrast to staging by stenting, which should be applied cautiously as the regenerative potential of the paraspinous collateral network is unknown for the individual patient, and once the stent-graft is deployed and several SAs are occluded simultaneously, there is no option of reversal. One underestimated advantageous side-effect of MIS^{2}ACE is the reduction of back-bleeding. Segmental back-bleeding after opening of the aneurysm can worsen the overview of the operative field, and therefore back-bleeding can be a severe threat to the spinal cord as shown by an experimental study of our group (18). In endovascular repair, previous MIS^{2}ACE can reduce the incidence of type II endoleaks.

Caveats

However, MIS^{2}ACE is neither a diagnostic nor a therapeutic procedure itself. Therefore, safety of the patient has priority. In patients with a shaggy aorta, MIS^{2}ACE should be considered cautiously due to an increased embolic risk. Also, there is no room for MIS^{2}ACE in the case of emergency treatment of the aorta. In all patients, kidney and thyroid function requires testing due to the use of iodinated contrast agents. Furthermore, the individual timing for consecutive MIS^{2}ACE and the final repair remains to be investigated and depends on the individual regenerative potential of the paraspinal collateral network. Patient-associated risk factors, like age, sarcopenia, and other

co-morbidities are not only relevant for the success of the final repair, but also for priming of the paraspinous collateral network by MIS²ACE, since it is located in the paraspinal muscles (19). A recent study by Chatterjee *et al.* on 392 patients aged 60 years or older receiving open TAAA repair revealed that sarcopenia did not influence early mortality or midterm survival but was—not surprisingly—associated with an increased risk for permanent paraplegia [odds ratio (OR) =3.29, P=0.01] (19).

All other previously established neuroprotective adjuncts should be continued to be applied peri- and postoperatively (i.e., CSF drainage, permissive hypertension, sufficient hematocrit, monitoring of spinal cord oxygenation with collateral network) according to the individual patient. Maurel *et al.* demonstrated a ten-fold reduction in paraplegia rate from 14% to 1.2% by early restoration of blood flow via withdrawal of large sheaths and by optimizing the perioperative protocol (20), suggesting that safeguarding inflow to the collateral network, particularly during the perioperative period, is crucial. Any obstruction of large collateral network inflow vessels has to be avoided.

MIS²ACE and 'staging' are promising techniques in reducing the incidence of permanent spinal cord injury, by priming of the paraspinous collateral network and maintaining patient mobility and quality of life, thereby reducing long-term mortality. The technique is safe and may be trained on a vascular simulator. The learning curve is steep, leading to a reduction in amount of contrast agent and radiation time.

Acknowledgments

Funding: None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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Cite this article as: Haunschild J, Köbel T, Misfeld M, Etz CD. Minimally invasive staged segmental artery coil embolization (MIS^{2}ACE) for spinal cord protection. Ann Cardiothorac Surg 2023;12(5):492-499. doi: 10.21037/acs-2023-scp-21

