



Rethinking circulatory management in thoracoabdominal aortic repair: split-body perfusion for continuous end-organ flow

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Abstract: Thoracoabdominal aortic aneurysm (TAAA) repair involving the proximal descending thoracic aorta remains among the most technically demanding operations in cardiovascular surgery. Conventional approaches may require systemic hypothermia and periods of circulatory arrest to facilitate proximal aortic reconstruction, potentially exposing the brain, spinal cord, and abdominal viscera to ischemic injury. Strategies that permit complex proximal reconstruction while maintaining continuous perfusion to multiple vascular territories remain limited. We describe a split-body circulation technique designed to preserve uninterrupted upper- and lower-body perfusion during open TAAA repair. Split-body cardiopulmonary bypass is established using separate upper- and lower-body perfusion circuits, permitting independent control of cerebral and distal systemic blood flow. The operative strategy incorporates temporary left common carotid chimney graft for initial systemic and subsequently selective cerebral perfusion, distal-first aortic reconstruction, and selective visceral perfusion during sequential reimplantation of critical perivisceral vessels. Following completion of the distal reconstruction, proximal aortic replacement is performed while continuous selective cerebral perfusion is maintained. This video demonstrates the principal operative steps, circuit configuration, perfusion transitions, and technical considerations required to coordinate aortic reconstruction with continuous end-organ perfusion. The split-body configuration enables maintenance of cerebral, spinal cord, visceral, and distal systemic perfusion throughout the major phases of reconstruction while avoiding full-body deep hypothermic circulatory arrest. Independent upper- and lower-body circuits provide flexibility in adjusting regional flow according to the requirements of each operative phase and allow sequential reconstruction without complete interruption of systemic perfusion. This technique is particularly applicable to complex TAAA pathology extending proximally into the proximal descending aorta/distal aortic arch, where conventional proximal reconstruction may otherwise necessitate prolonged deep hypothermic circulatory arrest. Split-body circulation provides a reproducible perfusion framework for selected complex open TAAA repairs requiring proximal descending thoracic aortic reconstruction. By combining separate upper- and lower-body perfusion with selective cerebral and visceral perfusion, this strategy prioritizes continuous end-organ blood flow while facilitating extensive aortic reconstruction. Further experience is required to define optimal patient selection, reproducibility, and comparative clinical outcomes.

Keywords: Thoracoabdominal aortic aneurysm (TAAA); split-body circulation; selective cerebral perfusion; circulatory arrest; cardiopulmonary bypass

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Highlight box

Surgical highlights

- Split-body circulation enables complex open thoracoabdominal aortic aneurysm (TAAA) reconstruction while maintaining continuous perfusion to the brain, spinal cord, abdominal viscera, and distal body.
- Separate upper- and lower-body cardiopulmonary bypass circuits permit independent regional perfusion and facilitate sequential aortic reconstruction without full-body deep hypothermic circulatory arrest.

What is conventional and what is novel/modified?

- Conventional open TAAA repair may require deep systemic hypothermia, periods of circulatory arrest, and sequential interruption of regional blood flow during extensive proximal and distal reconstruction, all associated with high risk of stroke and perivisceral and spinal cord ischemia.
- The modified strategy combines temporary cervical chimney grafts for selective cerebral perfusion with a separate lower-body circuit and selective visceral perfusion, creating an integrated split-body perfusion platform that maintains continuous end-organ blood flow during distal-first reconstruction followed by proximal aortic replacement.

What is the implication, and what should change now?

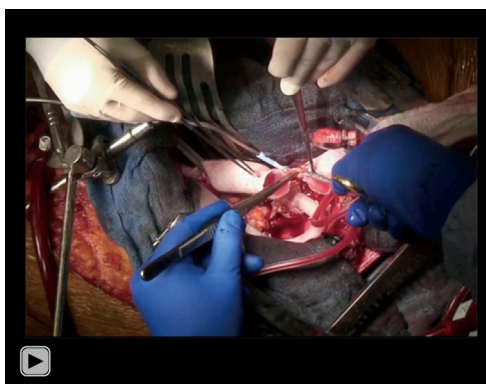
- Split-body circulation provides a reproducible perfusion framework for

Introduction

Open repair of thoracoabdominal aortic aneurysms (TAAAs) involving the proximal descending thoracic aorta requires balancing adequate operative exposure and proximal aortic control with protection of the brain, spinal cord, abdominal viscera, and myocardium. Despite advances in operative technique and perioperative management, open TAAA reconstruction remains associated with substantial risks of neurologic injury, renal dysfunction, visceral ischemia, bleeding, and cardiopulmonary complications (1). Establishing a durable proximal anastomosis in this region remains particularly challenging because conventional strategies may require deep systemic hypothermia and periods of regional or global circulatory arrest.

Several adjunctive strategies have evolved to mitigate ischemic injury, including extracorporeal bypass, distal aortic perfusion, cerebrospinal fluid drainage, selective visceral and renal perfusion, and deep hypothermic cardiopulmonary bypass with circulatory arrest (2-5). These approaches have substantially advanced organ protection during open thoracic and thoracoabdominal aortic reconstruction; however, proximal reconstruction may still expose individual vascular territories to periods of interrupted perfusion.

In this video (*Video 1*), we describe a split-body circulation strategy, defined as a temporary extracorporeal perfusion configuration in which systemic circulation is functionally separated into independently perfused upper- and lower-body territories during aortic reconstruction. Using separate arterial inflow circuits, dedicated cerebral/upper-body and visceral/lower-body perfusion are maintained during the critical phases of reconstruction.



Video 1 Split-body circulation for continuous end-organ perfusion during TAAA repair. TAAA, thoracoabdominal aortic aneurysm.

selected complex TAAA repairs involving the proximal descending thoracic aorta and may reduce reliance on systemic circulatory arrest.

- This strategy shifts the operative paradigm from tolerating defined periods of end-organ ischemia toward maintaining continuous regional perfusion throughout reconstruction. Further clinical experience should evaluate reproducibility, patient selection, and comparative neurologic and end-organ outcomes.

The technique is designed to facilitate controlled proximal thoracoabdominal aortic reconstruction under moderate systemic hypothermia while potentially limiting periods of regional ischemia and avoiding the need for full-body deep hypothermic circulatory arrest. This report is intended as a technical proof-of-concept demonstrating the operative configuration, physiologic rationale, and technical considerations of this strategy rather than evidence of clinical superiority over established perfusion techniques. We present this article in accordance with the SUPER reporting checklist (available at <https://jovs.amegroups.com/article/view/10.21037/jovs-2026-0039/rc>).

Preoperative preparations and requirements

The index patient was a 56-year-old man with a history of prior hemiarch repair for acute Stanford type A aortic dissection who subsequently developed rapid aneurysmal degeneration of the residual chronically dissected thoracoabdominal aorta, resulting in a Crawford extent II post-dissection TAA. The maximum aortic diameter was 57.9 mm at aortic zone 3. The perivisceral aorta measured 54.3 mm, with severe compression of the true lumen to a maximal diameter of 8.9 mm.

The proximal extent of the aneurysmal disease necessitated reconstruction of the proximal descending thoracic aorta with creation of an open proximal anastomosis. Given the extent and anticipated complexity of the reconstruction, a split-body perfusion strategy was selected to provide independent cerebral and lower-body/visceral perfusion during the critical phases of the repair, thereby permitting reconstruction under moderate systemic hypothermia.

Preoperative planning requires detailed review of cross-sectional imaging of the entire thoracoabdominal aorta and supra-aortic vessels. Particular attention is directed toward the intended carotid inflow vessel, the proximal and distal sites of reconstruction, visceral and renal arterial anatomy, true- and false-lumen relationships in chronic dissection, and potentially important intercostal arteries. Significant carotid or supra-aortic occlusive disease, dissection involving the intended carotid inflow vessel, unfavorable cervical anatomy, or pathology requiring independent reconstruction of the supra-aortic vessels may limit applicability or require modification of the technique.

The operative sequence and planned perfusion transitions should be reviewed by the surgical, anesthesia, perfusion, and neuromonitoring teams before incision. The perfusion system must permit independently controlled upper- and lower-body arterial inflow as well as selective visceral perfusion. Bilateral upper- and lower-extremity arterial pressure monitoring, transesophageal echocardiography, continuous electroencephalography, and motor-evoked potential monitoring are used throughout the procedure.

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Declaration of Helsinki and its subsequent amendments. Written informed consent was obtained from the patient for the publication of this article and accompanying video. A copy of the written consent is available for review by the editorial office of this journal.

Step-by-step description

Step 1: left common carotid chimney graft construction

The patient is initially positioned supine. Bilateral brachial and femoral arterial pressure monitoring is established, and a double-lumen endotracheal tube is placed to permit subsequent single-lung ventilation. Continuous electroencephalographic and motor-evoked potential monitoring are used throughout the operation.

The left common carotid artery is exposed through a cervical incision. After proximal and distal control, 5,000 IU of intravenous heparin are administered. The carotid artery is temporarily occluded while maintaining a mean systemic arterial pressure of approximately 90 mmHg to minimize transient cerebral hypoperfusion.

An 8-mm Dacron graft is beveled and anastomosed end-to-side to the left common carotid artery using a bovine pericardial-reinforced technique. Following meticulous deairing, the graft is secured and temporarily positioned within the cervical incision. This conduit subsequently provides arterial inflow for selective upper-body and cerebral perfusion.

Careful graft orientation is essential because redundancy, torsion, or kinking may compromise cerebral inflow after initiation of extracorporeal circulation.

Step 2: positioning and thoracoabdominal exposure

The patient is subsequently repositioned into a partial right lateral decubitus position while maintaining access to the left neck and femoral vessels. The patient is prepped and draped to maintain simultaneous access to the cervical incision, thorax, abdomen, and groin.

Single-lung ventilation is established. A left posterolateral thoracotomy is performed, with rib division as necessary to optimize exposure of the descending thoracic aorta. We routinely perform T3–T9 intercostal nerve cryoablation as part of the perioperative pain-management strategy.

Aortic exposure proceeds from the diaphragmatic hiatus proximally toward the left subclavian artery, which is circumferentially controlled for subsequent temporary occlusion. Particular attention is directed toward identification and preservation of the vagus and recurrent laryngeal nerves.

The perivisceral segment is exposed, and the celiac artery, superior mesenteric artery, and left renal artery are individually controlled with vessel loops. We preferentially maintain the left kidney in its native anatomic position to minimize unnecessary dissection and reduce the potential for vessel or graft distortion if dedicated renal reconstruction is required.

Before systemic anticoagulation and initiation of cardiopulmonary bypass, meticulous hemostasis is obtained throughout the operative field.

Step 3: initiation of cardiopulmonary bypass and preparation for left ventricular decompression

Venous drainage is established through percutaneous cannulation of the left femoral vein under transesophageal echocardiographic guidance. The previously constructed

carotid chimney graft is brought into the operative field, meticulously deaired, and connected to one arterial limb of the cardiopulmonary bypass circuit.

Cardiopulmonary bypass is initiated, and systemic cooling begins to a target bladder temperature of approximately 28 °C. During cooling, the heart may transition to ventricular fibrillation. Left ventricular size and distention are continuously assessed using transesophageal echocardiography.

Left ventricular venting was not required in any patient in this series. However, a purse-string suture is routinely placed in the left inferior pulmonary vein before initiation of bypass to permit rapid placement of a left ventricular vent should significant ventricular distention develop during cooling or fibrillatory arrest. Direct apical left ventricle (LV) venting represents an alternative when pulmonary venous access is limited by anatomy or dense intrapericardial adhesions.

This anticipatory strategy permits LV decompression to be instituted promptly when required while avoiding routine cardiac manipulation when adequate ventricular decompression is maintained.

Step 4: establishment of split-body perfusion

While systemic cooling continues, the mid-descending thoracic aorta is cross-clamped and the distal thoracoabdominal aorta is opened. In patients with chronic dissection, the true and false lumens are carefully identified, and the origins of the visceral vessels are directly inspected.

Selective visceral perfusion is established using 4–8 Fr balloon perfusion catheters placed into the celiac artery, superior mesenteric artery, and both renal arteries. These catheters are supplied by a dedicated pump head from the extracorporeal circuit, permitting continued perfusion of the visceral organs during distal reconstruction.

The distal aortic anastomosis is constructed first using a reinforced technique with felt or bovine pericardium as appropriate. A side-arm graft incorporated into the distal reconstruction subsequently serves as the definitive inflow conduit for lower-body perfusion.

Following completion of the distal anastomosis, the graft is meticulously deaired and connected to the second arterial limb of the extracorporeal circuit. Lower-body perfusion is then established through the distal side-arm graft.

At this stage, extracorporeal circulation is functionally separated into two independently perfused territories: upper-body and cerebral perfusion are supplied through the left common carotid chimney graft, while visceral and lower-body perfusion are maintained through the distal reconstruction. We define this temporary parallel extracorporeal configuration as split-body circulation.

This configuration permits progression of the reconstruction while maintaining dedicated perfusion to the principal proximal and distal vascular territories. Meticulous deairing before initiation of lower-body perfusion is essential because the distal circuit directly supplies the abdominal viscera and lower extremities.

Step 5: proximal reconstruction under split-body perfusion

After reaching the target bladder temperature of approximately 28 °C, the proximal left common carotid artery is temporarily occluded so that flow delivered through the carotid chimney graft is directed toward the intracranial circulation. The left subclavian artery is also temporarily occluded. Cerebral perfusion is monitored using bilateral arterial pressure monitoring, continuous electroencephalography, and motor-evoked potentials.

Simultaneously, the abdominal viscera and lower body remain perfused through the distal graft circuit. This split-body configuration permits the proximal descending thoracic aorta to be opened while maintaining dedicated cerebral and distal perfusion.

The proximal aortic cross-clamp is removed and the proximal descending thoracic aorta is opened. In patients with chronic dissection, the true and false lumens are again carefully identified.

Myocardial protection is achieved using standard del Nido cardioplegia. Following opening of the proximal aorta, a balloon occlusion catheter (LeMaitre Vascular, Burlington, MA, USA) is positioned within the aortic root, and 1,300 mL of del Nido cardioplegia is delivered antegrade. A single dose provided adequate myocardial protection throughout proximal reconstruction in all patients, and no additional cardioplegia was required.

The innominate artery is neither dissected, manipulated, nor occluded during this phase. It remains open, allowing controlled back-bleeding during proximal reconstruction. Blood return is managed with operative suction as necessary to maintain visualization. Although this configuration provides continuous blood return through the open arch, its potential effect on embolic clearance or neurologic protection has not been established and is not assumed to represent a clinical benefit of the technique.

The proximal aortic anastomosis is then constructed while selective cerebral perfusion is maintained through the left common carotid chimney graft and visceral/lower-body perfusion continues through the distal graft circuit.

Thus, during open proximal reconstruction, the principal proximal and distal vascular territories remain supported by dedicated perfusion circuits: cerebral perfusion through the carotid chimney graft and visceral/lower-body perfusion through the distal graft. This configuration permits proximal reconstruction under moderate hypothermia without full-body deep hypothermic circulatory arrest.

Step 6: reperfusion and completion of reconstruction

Following completion of the proximal anastomosis, the proximal graft is meticulously deaired and arterial flow is established through its side branch.

Upper-body systemic perfusion is then transferred from the carotid chimney circuit to the proximal aortic graft. The carotid chimney graft is clamped and excluded from the extracorporeal circuit, while lower-body perfusion continues through the distal side-arm graft.

Continuity of the reconstructed aorta is subsequently established through a graft-to-graft anastomosis between the proximal and distal graft components, thereby restoring continuity of the reconstructed neo-aorta.

When indicated, selected intercostal arteries are reimplanted as a patch. The intercostal patch may be incorporated directly into the main aortic graft or reconstructed using an interposition/C-loop configuration according to individual anatomy and operative requirements.

Systemic rewarming is initiated. Following restoration of native cardiac rhythm and satisfactory cardiac function, the patient is separated from cardiopulmonary bypass. Anticoagulation is reversed, cannulas are removed, and meticulous hemostasis is obtained.

Thoracotomy closure is completed with rib stabilization when appropriate to optimize postoperative respiratory mechanics and recovery.

Postoperative considerations and tasks

Postoperative management follows established principles for complex open TAAA repair, with particular emphasis on neurologic surveillance, spinal cord protection, hemodynamic optimization, renal and visceral function, respiratory recovery, and early recognition of bleeding.

Frequent neurologic examinations should be performed as soon as sedation permits, with particular attention to lower-extremity motor function. Hemodynamic management should prioritize adequate spinal cord and end-organ perfusion [mean arterial pressure (MAP) >85 mmHg] while avoiding excessive hypertension that may increase bleeding risk. When cerebrospinal fluid drainage is used as part of the institutional spinal cord protection strategy, drainage should be managed according to cerebrospinal fluid pressure, hemodynamic status, and neurologic findings (2,4).

Renal function, urine output, serum lactate, acid-base status, hepatic indices, and peripheral perfusion should be followed closely as indicators of end-organ recovery. Because the procedure incorporates multiple perfusion territories and transitions between selective and systemic circulation, unexpected postoperative metabolic abnormalities or organ dysfunction should prompt evaluation for regional malperfusion or ischemic complications.

Early respiratory management should emphasize lung recruitment, pulmonary toilet, multimodal analgesia, and timely liberation from mechanical ventilation when clinically appropriate. Particular attention should be given to recurrent laryngeal nerve function because of the extensive proximal thoracic dissection. The cervical carotid graft site and thoracoabdominal operative field should be monitored for bleeding, hematoma, thrombotic complications, and evidence of malperfusion.

Tips and pearls

- Plan the complete perfusion sequence before incision. The operation depends on coordinated transitions between carotid inflow, selective visceral perfusion, distal graft perfusion, and restored systemic perfusion.
- Maintain meticulous carotid graft orientation. Redundancy, torsion, or kinking of the chimney graft may compromise cerebral inflow.
- Deair every circuit transition deliberately. This is particularly important before initiating carotid or distal graft perfusion.

- Monitor cerebral perfusion continuously. Bilateral arterial pressure monitoring, electroencephalography, and motor-evoked potentials provide complementary information during selective cerebral perfusion.
- Prepare for left ventricular decompression before bypass. Placement of a left inferior pulmonary vein purse-string permits immediate vent insertion if ventricular distention develops without requiring routine venting.
- Avoid unnecessary innominate artery manipulation. In this configuration, the innominate artery can remain undissected and unclamped during proximal reconstruction.
- Construct the distal reconstruction first. Establishing the distal side-arm graft creates a durable lower-body inflow source before opening the proximal descending thoracic aorta.
- Maintain explicit surgeon-perfusionist communication. Independent perfusion territories increase flexibility but also circuit complexity; each change in clamp position, flow distribution, and reconstruction phase should be coordinated.
- Individualize application of the technique. Carotid disease, supra-aortic anatomy, chronic dissection morphology, visceral vessel anatomy, and previous operations may require modification or preclude use of the strategy.

Discussion

Open TAAA repair remains among the most physiologically demanding procedures in cardiovascular surgery. Despite substantial advances in operative technique and perioperative management, extensive open reconstruction continues to carry important risks of neurologic injury, spinal cord ischemia, renal dysfunction, visceral ischemia, bleeding, and cardiopulmonary complications (1). Contemporary organ-protection strategies therefore rely on combinations of distal aortic perfusion, extracorporeal bypass, systemic hypothermia, sequential aortic clamping, selective visceral and renal perfusion, cerebrospinal fluid drainage, and, in selected circumstances, hypothermic cardiopulmonary bypass with circulatory arrest (2-5).

Extracorporeal perfusion has become an important component of contemporary open thoracic and thoracoabdominal aortic reconstruction. Distal aortic perfusion combined with cerebrospinal fluid drainage has contributed substantially to spinal cord and end-organ protection (2), while hypothermic cardiopulmonary bypass and circulatory arrest remain valuable alternatives when anatomy or the extent of reconstruction precludes conventional sequential clamping (3). Mohebbi and colleagues reported an association between extracorporeal bypass and improved outcomes during open thoracic and TAAA repair (6). Nevertheless, contemporary population-level data continue to demonstrate the substantial morbidity associated with thoracoabdominal aortic disease and its surgical treatment (7).

The split-body circulation strategy described here extends these established principles by integrating perfusion architecture directly into the sequence of aortic reconstruction. Rather than relying predominantly on systemic hypothermia to increase tolerance of temporary ischemia, the circulation is temporarily divided into independently perfused upper- and lower-body territories. This configuration allows the sequence of reconstruction and the distribution of extracorporeal blood flow to evolve together throughout the operation.

The central physiologic objective is straightforward: to maintain active perfusion to critical vascular territories whenever technically feasible rather than relying on their tolerance of interrupted blood flow. During distal reconstruction, selective visceral perfusion maintains blood flow to the abdominal organs. Once the distal anastomosis is completed, the distal graft side arm becomes a dedicated lower-body inflow source. During subsequent open proximal reconstruction, cerebral perfusion is maintained through the left common carotid chimney graft while visceral and lower-body perfusion continue through the distal graft circuit. Consequently, the proximal descending thoracic aorta can be reconstructed under moderate systemic hypothermia without full-body deep hypothermic circulatory arrest.

This concept may be particularly relevant when disease extends proximally into the descending thoracic aorta and creation of a durable proximal anastomosis would otherwise require profound hypothermia or a period of global circulatory arrest. The distal-first sequence is integral to the strategy. Completion of the distal reconstruction establishes a definitive lower-body perfusion conduit before the proximal aorta is opened, thereby creating the two independently supported vascular territories required for split-body circulation.

Continuous distal perfusion may also have implications for spinal cord protection. Contemporary understanding emphasizes a dynamic collateral network involving segmental, paraspinal, subclavian, hypogastric, and other collateral arterial territories rather than dependence on a single dominant segmental vessel (4). Maintaining distal systemic perfusion throughout proximal reconstruction may therefore preserve components of this collateral network during a period in which conventional approaches can interrupt regional inflow. This represents a physiologically attractive feature of the technique; however, the present experience does not establish a reduction in spinal cord ischemia, and such a benefit should not be inferred without larger comparative studies.

A further technical advantage is that the innominate artery does not require dissection, cannulation, clamping, or balloon occlusion during proximal reconstruction. The vessel remains open, with controlled back-bleeding managed by operative suction. Avoiding additional manipulation simplifies the supra-aortic component of the reconstruction and eliminates the need for direct instrumentation of the innominate artery. However, whether this translates into reduced embolic or neurologic risk remains unknown and cannot be established from the present experience.

Similarly, routine left ventricular venting was not required. Ventricular dimensions and distention are continuously assessed with transesophageal echocardiography during cooling and fibrillatory arrest. Placement of a purse-string suture in the left inferior pulmonary vein before initiation of cardiopulmonary bypass provides immediate access for left ventricular decompression should distention develop, while avoiding routine cardiac manipulation when decompression is unnecessary. Direct apical venting remains an alternative when pulmonary venous access is unfavorable.

The potential advantages of split-body circulation must be considered alongside its additional technical and extracorporeal complexity. The strategy requires coordinated management of several perfusion phases and transitions, including selective visceral perfusion, distal graft perfusion, carotid inflow, selective cerebral perfusion, and ultimately restoration of conventional systemic circulation. Each transition introduces potential hazards related to flow distribution, pressure control, deairing, and cannula or graft position. Successful implementation therefore depends on close communication

among the operating surgeon, perfusionist, anesthesiology team, and neuromonitoring personnel. In this setting, meticulous deairing is not simply a routine technical consideration but a critical component of every transition between perfusion territories.

The temporary carotid chimney graft introduces additional considerations, including bleeding, thrombosis, embolization, carotid injury, graft kinking or torsion, and inadequate cerebral inflow. Careful graft orientation, meticulous deairing, and continuous assessment of cerebral perfusion are therefore essential. Patient selection is equally important. Significant carotid or supra-aortic occlusive disease, dissection involving the intended carotid inflow vessel, unfavorable cervical anatomy, or pathology requiring independent reconstruction of the supra-aortic vessels may limit applicability or require modification of the technique.

Accordingly, split-body circulation should presently be regarded as an advanced perfusion strategy for selected complex proximal TAAA reconstructions rather than a replacement for established approaches. Its principal contribution is conceptual: it reorganizes extracorporeal support around the anatomy and sequence of reconstruction, creating dedicated perfusion territories before the phase in which proximal aortic continuity must be interrupted. The present experience establishes technical feasibility and provides the physiologic rationale for this approach, but it does not establish clinical superiority. Larger clinical series and ultimately comparative investigation will be necessary to determine whether maintaining continuous regional perfusion translates into measurable reductions in neurologic injury, spinal cord ischemia, renal or visceral dysfunction, or mortality.

Conclusions

Split-body circulation provides a reproducible framework for maintaining dedicated cerebral and visceral/lower-body extracorporeal perfusion during selected complex TAAA repairs requiring open proximal descending thoracic aortic reconstruction. By establishing independent upper- and lower-body perfusion territories and integrating these circuits into a distal-first reconstructive sequence, extensive proximal reconstruction can be performed under moderate systemic hypothermia without full-body deep hypothermic circulatory arrest.

The key conceptual shift is from relying on hypothermia to increase tolerance of temporary end-organ ischemia toward designing the reconstruction to maintain continuous regional perfusion whenever technically feasible. This technical experience demonstrates the feasibility of that strategy but does not establish superiority over conventional approaches. Further clinical experience and comparative investigation are required to define optimal patient selection, reproducibility, safety, and its effect on neurologic and end-organ outcomes.

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Footnote

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