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Cool-shot Technique to Protect Spinal Cord During Thoracoabdominal Aortic Replacement

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Conflict of Interest: The authors declare that they have no conflict of interest.

Abstract:
Deep hypothermia helps protect the spinal cord, but is invasive. Here, we present a method to avoid reperfusion injury by selectively circulating cold blood under high pressure to the intercostal artery during reperfusion after intercostal artery reconstruction. Of the 23 patients who underwent thoracoabdominal aortic aneurysm open repair, one died. The motor evoked potential disappeared during aortic clamping in nine patients. Six patients recovered completely from aortic clamping release, two showed recovery >50% and one achieved full recovery three months later. Permanent motor impairment did not occur. This method could prevent reperfusion injury and paraplegia following thoracoabdominal aortic aneurysm surgery.

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Contributors' Statement: (I) Conception and design: TY and DE.
(II) Administrative support: TM supervised the study design and advised on the study's progress and potential resolution of issues.
(III) Provision of study materials or patients: TY was the first operators of the thoracoabdominal aortic surgery in this team. DE and YY performed perioperative management according to this strategy. ED was mainly responsible for outpatient follow-up.
(IV) Collection and assembly of data: TY and DE collected the data retrospectively and assembled it.
(V) Data analysis and interpretation: TY, and DE analyzed and interpreted the data, and all of them confirmed this data analysis and interpretation at the meeting.
(VI) Manuscript writing: All the authors participated in the research meetings, drafted the manuscript, and each critically revised it for important intellectual content, completing the manuscript.
(VII) Final approval of manuscript: All the authors have read and approved the final manuscript.

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Cool-shot Technique to Protect Spinal Cord During Thoracoabdominal Aortic Replacement

Abstract

Deep hypothermia helps protect the spinal cord, but is invasive. Here, we present a method to avoid reperfusion injury by selectively circulating cold blood under high pressure to the intercostal artery during reperfusion after intercostal artery reconstruction. Of the 23 patients who underwent thoracoabdominal aortic aneurysm open repair, one died. The motor evoked potential disappeared during aortic clamping in nine patients. Six patients recovered completely from aortic clamping release, two showed recovery >50% and one achieved full recovery three months later. Permanent motor impairment did not occur. This method could prevent reperfusion injury and paraplegia following thoracoabdominal aortic aneurysm surgery.

Keywords: Thoracoabdominal aortic aneurysm, Cool-shot technique, Spinal cord protection, reperfusion injury

Introduction

Spinal cord injury (SCI) is one of the complications that surgeons must seriously avoid in patients undergoing thoracic and abdominal aortic aneurysm (TAAA) repair, causing permanent paralysis at a rate of 2.0–10.8% [1-4].

We have used cold blood reperfusion as a method of protection against spinal cord ischemia to prevent spinal cord nerve tissue reperfusion injury. We have found this technique to be particularly useful when intraoperative motor evoked potential (MEP) monitoring showed a weak response and spinal cord perfusion failure was strongly suspected. Herein we present a case series wherein this technique was performed.

Patients and Methods

We performed open aortic surgery with intercostal artery (ICA) reconstruction in 23 patients at our hospital from January 2016 to December 2022. All patients underwent preoperative multislice CT scan angiography of the Adamkiewicz artery (AKA) [5].

We inserted a cerebrospinal fluid drainage (CSFD) catheter between the lumbar vertebral bodies one day preoperatively. Muscle MEPs (using a MEE-2000; Nihon Kohden, Tokyo, Japan) were recorded intraoperatively. Muscle MEPs were obtained in the abductor pollicis brevis and abductor hallucis muscles of the feet using subcutaneous needle electrodes. A 50% decrease in MEP amplitude from the baseline amplitude obtained immediately before the interventions was considered a significant change; MEP-amplitude loss was deemed an alarm signal for spinal ischemic changes [6]. No neuromuscular blocking agents were administered during MEP monitoring.

We conducted partial cardiopulmonary bypass through cannulation of the left femoral artery and femoral vein (Figure 1a). We routinely used mild-to-moderate hypothermia (32–34°C, rectal temperature). Circulating flow during cardiopulmonary bypass was slowly titrated up to 3.5 L/min and maintained after aortic clamping. Subsequently, we used segmental-staged aortic clamping to execute cross-clamping, first clamping the proximal side of the left subclavian artery and middle descending aorta. The abdominal aorta was clamped above the celiac artery branches. We measured

MEPs 5 min after aortic clamping. Of these, the intercostal artery between Th8 and Th12 was selected for reimplantation based on preoperative diagnosis.

We adopted the following strategies:

1. Upper body circulation was maintained at 80–100 mmHg at radial artery pressure with autologous cardiac output, while lower body circulation was maintained at hypothermic blood flow (1.0–1.5 L/min) with cardiopulmonary bypass circulation.

2. We reperfused the AKA from a 9 mm branch of an artificial graft with a blood temperature of 20°C and perfusion pressure of 80–100 mmHg. We raised blood temperature to 34°C within approximately 15 min (cool-shot technique) (Figure 1a).

3. Mean blood pressure of 100 mmHg was enforced if MEPs weakened or disappeared during clamping (Figure 1b).

CSFD was continued for 24 h postoperatively.

Table 1 presents patient characteristics. One patient (4.5%) died postoperatively due to pneumonia caused by multidrug-resistant *Pseudomonas aeruginosa*.

During intercostal artery reconstruction, MEP was attenuated or absent in nine patients. However, MEP improved in all but one case (case 1: Figure 2a-d). Although MEP did not improve in one patient intraoperatively, it improved one month later. This patient underwent coronary artery bypass surgery via the left internal thoracic artery, aortic arch replacement, and Y-grafting for an abdominal aortic aneurysm (case 2: Figure 3a-d). Moreover, the patient experienced severe hypotension due to a postoperative blood transfusion allergy and difficulty maintaining blood pressure. Nevertheless, motor palsy improved after one month, with a slight depth perception abnormality remaining. We attributed the leading cause of spinal cord failure paralysis to the lack of collateral blood flow during aortic clamping and failure to maintain blood pressure after reconstruction.

Although we used the CSFD during surgery, we were unable to prove its efficacy in this study because we were not able to use it in all patients based on the established criteria; it was only used according to the protocol after surgery.

Discussion

Excellent results were achieved with this technique; there were no instances of post-discharge paraplegia, despite momentary MEP loss in some patients. Although hypothermia is helpful for spinal cord protection, whole-body hypothermia during thoracoabdominal aortic aneurysm surgery is invasive. Hence, we employed the cool-shot technique for local cooling of the spinal nerves.

The degree of hypothermia employed may be mild (30–34°C) or severe (15–20°C) depending on the institution. Deep hypothermic circulatory arrest (DHCA) is typically reserved for complex thoracic aortic procedures. In large centers where DHCA is routinely performed, patient outcomes are comparable to those of endovascular repair [7-9]. However, adapting DHCA in older patients is challenging and may increase blood loss. Therefore, we devised a method in which surgery is performed under mild hypothermia, with only the spinal cord under deep hypothermia.

Although epidural cooling to prevent reperfusion injury is effective, it is invasive and complex [10]. Hence, we investigated a strategy commencing with local cooling perfusion after intercostal artery reconstruction and gradually raising spinal cord blood delivery temperature.

This study has certain limitations. First, the sample size was small. Second, only results in cases of reconstructed intercostal arteries were reported; the extent of spinal cord cooling using the cool-shot technique after reconstruction remains unknown.

Conclusions

We devised a regional spinal-cord cooling technique using the spinal cool-shot technique following intercostal artery reconstruction that is effective in additional spinal-cord protection. This technique may prevent reperfusion injury, and early and delayed postoperative paralysis in patients with intraoperative MEP loss during thoracoabdominal aortic aneurysm surgery.

Data Availability

The data associated with this manuscript are not publicly available; however, they can be provided by the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this article.

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Figure 1. Mechanical cardiopulmonary support during surgery for thoracoabdominal aortic aneurysm. (a) Modification of the cardiopulmonary bypass during surgery for thoracoabdominal aortic aneurysm. (b) The end-to-side anastomosis is created between the Bentall graft and abdominal Y-shaped graft. Reperfusion methods after Adamkiewicz artery reconstruction are as follows. Blood cooled to 20°C is perfused from the artificial vascular side branch before releasing the proximal aortic clamp following intercostal artery reconstruction. The distal anastomosis or abdominal organ branches are reconstructed during 15–20 min of rewarming, and the proximal clamping is subsequently released. Red, black, yellow, and blue arrows indicate the proximal aortic clamping, distal aortic clamping, site of intercostal artery reconstruction, and abdominal vessel branching, respectively. White and purple arrows indicate the site of blood delivery and direction of cooled blood delivery to the intercostal artery, respectively.

Figure 2. Case 1: A 72-year-old man presenting with a chronic type IIIb dissecting aortic aneurysm (Crawford type II). (a) Preoperative findings (Crawford type II). The thoracic descending aorta has a maximum diameter of 63 mm, while the abdominal

aorta shows a diameter of 48 mm. The Adamkiewicz artery branches off the descending aorta at the 11th–12th thoracic vertebral level (black arrow). (b) First post-operative three-dimensional CT. We opt for descending aortic replacement as our first procedure (light blue line coverage). (c) 3DCT following the final surgery. We perform artificial vascular replacement for the thoracoabdominal aortic aneurysm in the second surgery (yellow-green line). The intercostal artery is reconstructed as an island between the 8th and 12th thoracic vertebrae. The black arrows indicate the reconstructed Adamkiewicz artery. (d) Alteration in motor response evoked potential (MEP): MEP in the right leg is lost during reconstruction of the intercostal artery (red arrow), but recovered after revascularization (blue arrow).

Figure 3. Case 2: A 73-year-old man with Behçet's disease and multiple aortic saccular aneurysms. (a) Preoperative findings. The coronary arteries show 90% stenosis in the left anterior descending branch and an aneurysm in the left subclavian artery. The Adamkiewicz artery is branched from the 10th–11th intercostal artery (black arrow). The patient also undergoes artificial vascular replacement (Y-graft) for an abdominal aortic aneurysm. (b) First post-operative three-dimensional CT. We initially perform total arch aortic replacement and coronary artery bypass (left internal thoracic artery-left anterior descending branch: light blue arrow). (c) 3DCT following the final surgery. Artificial vessel replacement is performed for the thoracoabdominal aortic aneurysm in the second surgery (yellow-green line). The intercostal artery is reconstructed as an island between the 9th and 12th thoracic vertebrae. Black arrows indicate the reconstructed Adamkiewicz artery. (d) Alterations in motor response evoked potentials

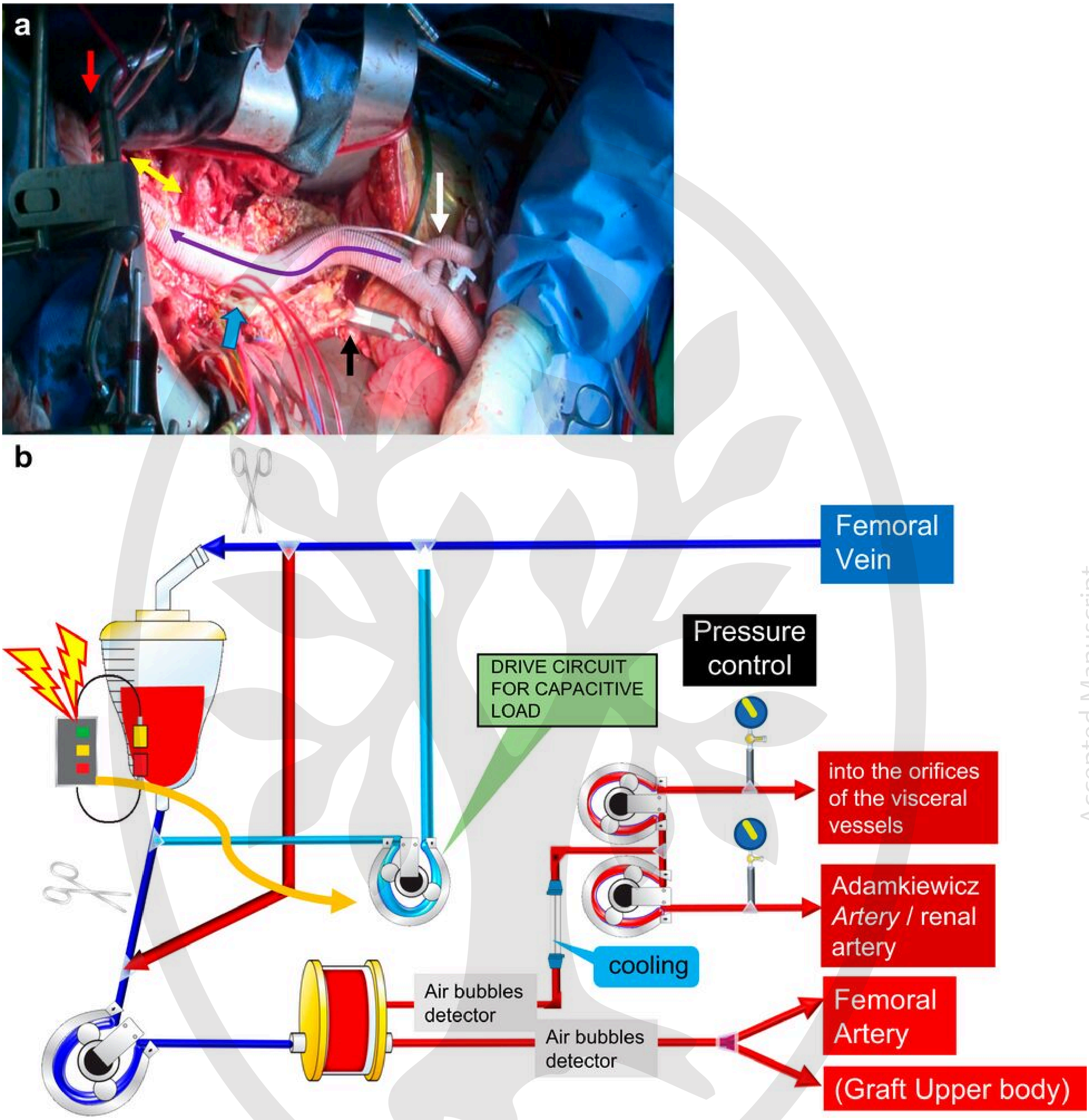
(MEPs): MEPs in the left leg disappear during intercostal artery reconstruction (red arrow) and, unfortunately, they do not recover after revascularization (blue arrows).

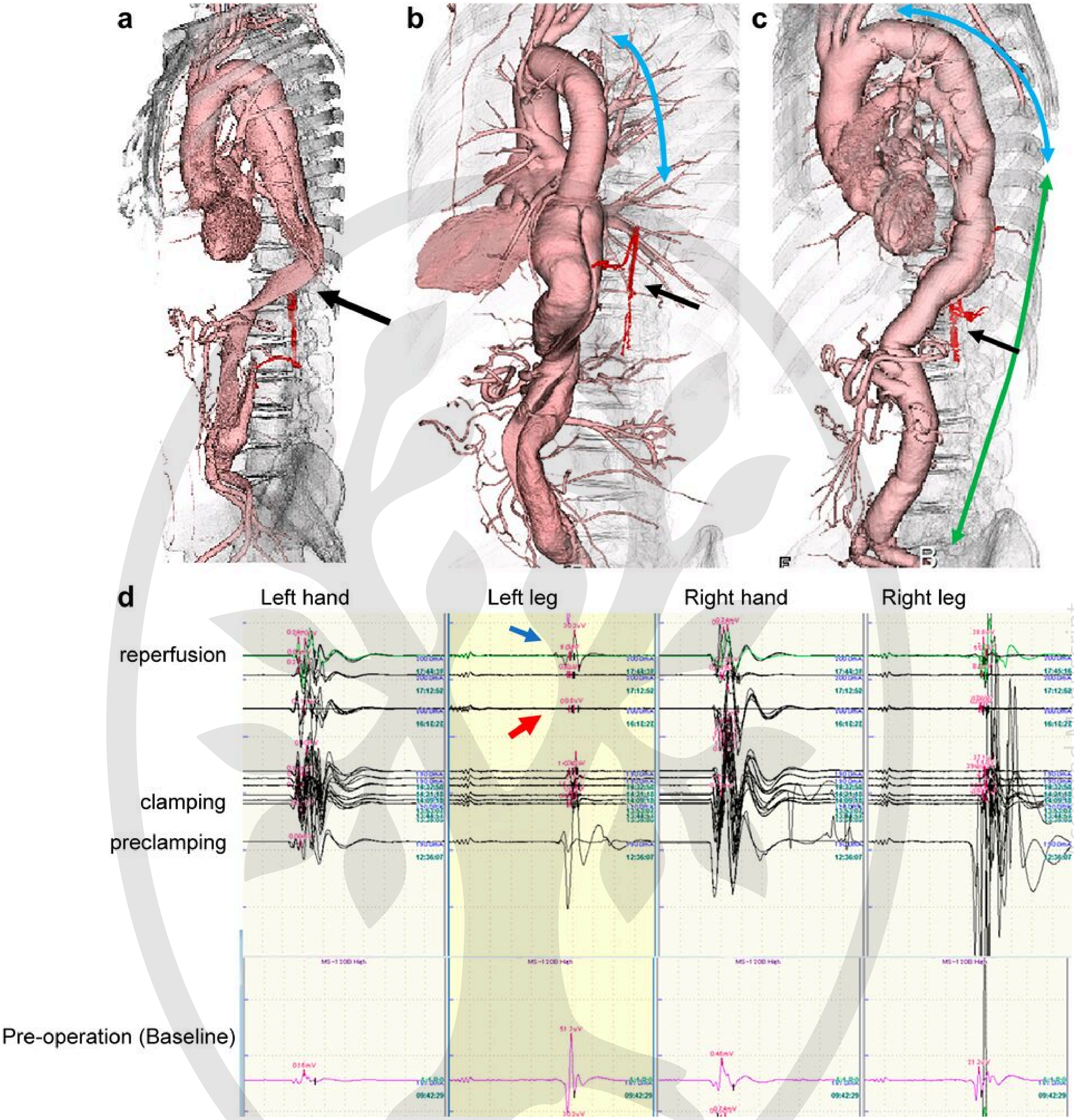
Table 1. Preoperative baseline characteristics

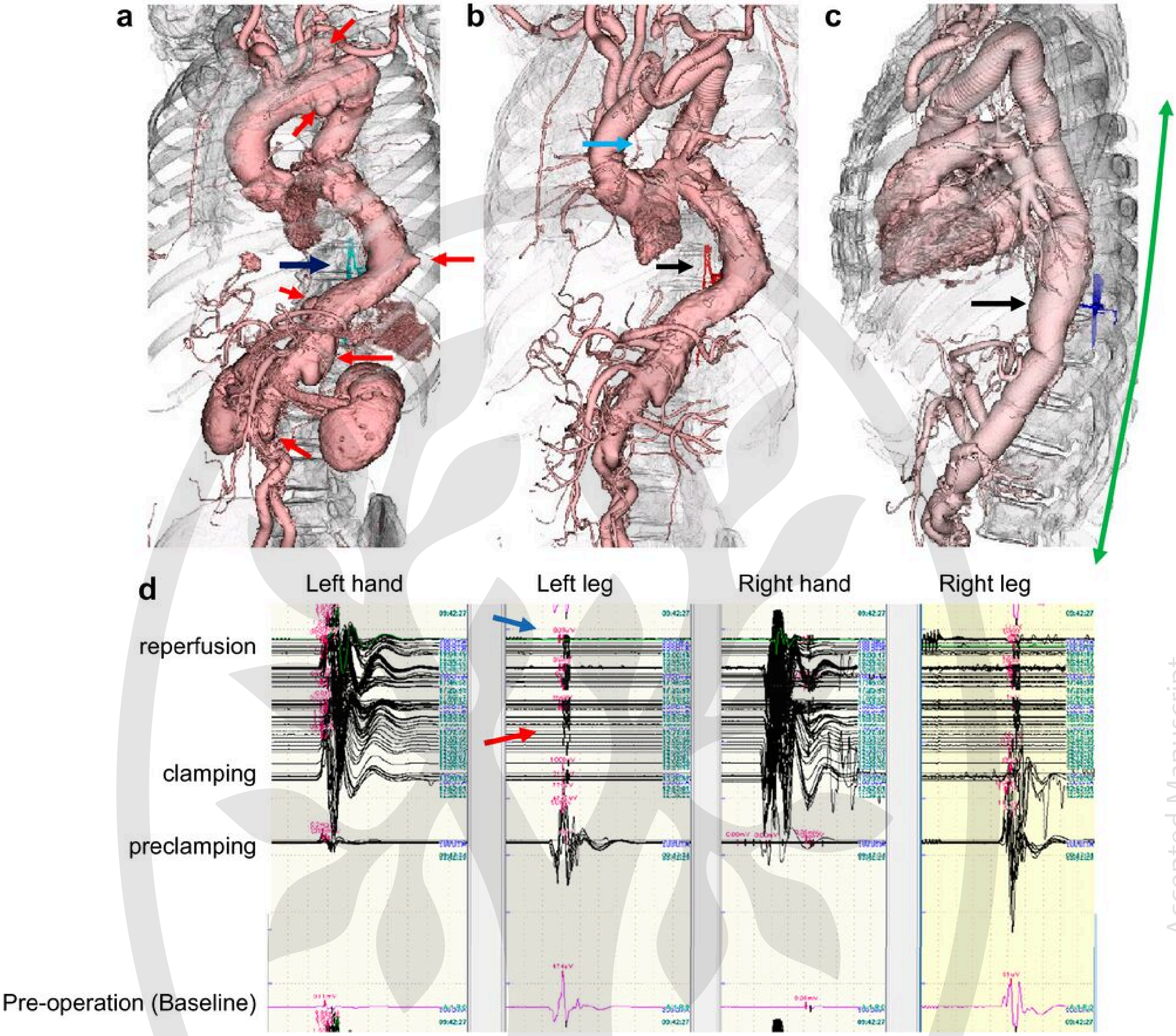
Age (year)	59.7±12.6 (28–74)
Male sex	20 (86.9%)
Heritable thoracic aortic disease: Marfan syndrome	3 (13.6%)
Hypertension	20 (90.9%)
Dyslipidemia	12 (54.5%)
Diabetes mellitus	3 (13.6%)
Estimated glomerular filtration rate (mL/min/1.73 m2)	71.9±20.6
Prior cerebrovascular accident	2 (9.1%)
Left ventricular ejection fraction (%)	69.5±4.7
EuroSCORE II	5.4±4.8
Type of aortic disease	
True aortic aneurysm	6 (27.3%)
Aortic dissection type I	8 (45.5%)
Aortic dissection type IIIb	6 (27.3%)
Type of Crawford's classification I	4 (18.2%)
II	10 (45.5%)
III	7 (31.8%)
IV	1 (4.5%)
Adamkiewicz artery branches at	
Th 7–9	3
Th 10–12	16
L1–2	3
Reattachment of intercostal arteries	22 (100%)
6^{th} to 12^{th} intercostal arteries	3 (13.6%)

8th to 12th intercostal arteries	8 (36.4%)
9th to 12th intercostal arteries	2 (9.1%)
10th to 12th intercostal arteries (plus 1st lumbar artery)	4 (18.2%)
11th to 12th intercostal arteries	2 (9.1%)
12th intercostal artery to 2nd lumbar arteries	3 (21.1%)
Operative time (minutes)	539±114
Cardiopulmonary bypass time (minutes)	176±58
Aortic clamp time (minutes)	120±44
minimum rectal temperature	35.1±0.6
Operative death	1 (4.5%)
Cerebrovascular accident	4 (18.2%)
Acute renal failure	2 (9.1%)
Cardiac complication	0
Pulmonary complication	3 (13.6%)
Infection	3 (13.6%)
Bleeding requiring reoperation	0
Spinal cord injury	1 (4.5%)
Persistent paraparesis or paraplegia	0
Transient paraparesis	1 (4.5%)
Length of hospital stay (days)	25.8±19.4

EuroSCORE II, European System for Cardiac Operative Risk Evaluation


a
b
Femoral Vein
Pressure control
DRIVE CIRCUIT FOR CAPACITIVE LOAD
into the orifices of the visceral vessels
Adamkiewicz Artery / renal artery
cooling
Air bubbles detector
Air bubbles detector
Femoral Artery
(Graft Upper body)


a
b
c
d
Left hand
Left leg
Right hand
Right leg
reperfusion
clamping
preclamping
Pre-operation (Baseline)


a
b
c
d
Left hand
Left leg
Right hand
Right leg
reperfusion
clamping
preclamping
Pre-operation (Baseline)