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Strategy for Thoracic Endovascular Aortic Repair Based on Collateral Circulation to the Artery of Adamkiewicz

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Abstract

Purpose: Spinal cord ischemia (SCI) is a serious complication of thoracic endovascular aortic repair (TEVAR). The purpose of this study was to establish if preoperative identification of the artery of Adamkiewicz (AKA) can help prevent post-TEVAR SCI.

Methods: Of 74 post-TEVAR patients, 51 had the critical segmental artery (CSA) to the AKA pre-identified to help the surgeon deploy stent-grafts.

Results: None of these 51 patients suffered permanent paraplegia postoperatively, but 5 (23.8%) of the remaining 23 patients (2 of whom had pre-existing paraplegia) did suffer permanent SCI. The CSA/AKA was preserved in 43 patients with pre-identification of the CSA/AKA; however, in 8 patients, the CSA was completely or partially occluded by a stent-graft. Transient SCI developed in one patient from each group, but both of these patients recovered fully before discharge. No change in the anatomical route was identified in 29 of the patients who had postoperative evaluation of the CSA/AKA. Five of eight patients whose CSA was completely occluded had new collateral circulation to the AKA.

Conclusions: None of the 51 patients with the CSA/AKA identified before TEVAR suffered permanent paraplegia, whereas 5 of the 23 without pre-identification did suffer permanent SCI. Thus, careful identification of the CSA/AKA may prove useful for preventing postoperative SCI. Preservation of potential collateral circulation may also reduce the risk of postoperative SCI.

Introduction

Spinal cord ischemia (SCI) is a serious complication of thoracic endovascular aortic repair (TEVAR), stent-graft implantation for thoracic descending aortic aneurysm (TAA), and thoracoabdominal aortic aneurysm (TAAA). It occurs in 2.5% to 10.3% [1-7] of these patients and seriously compromises their quality of life. Risk factors associated with postoperative SCI include female gender [1], an unrepaired abdominal aortic aneurysm (AAA) [2], a history of AAA repair [2], coverage of the hypogastric artery [3,8], a long length of aortic coverage by a stent-graft [1,4,5], blockage of the left subclavian artery without revascularization [6], perioperative hypotension [7,9], and chronic renal insufficiency [10]. However, the precise mechanisms underlying the development of postoperative SCI remain unclear.

In general, the artery of Adamkiewicz (AKA) supplies blood to the spinal cord via the critical segmental artery (CSA). The anatomical definition of the AKA has been reported in detail previously, using computed tomography (CT) or magnetic resonance images (MRI) [11]. In patients with TAA or TAAA, the CSA can become occluded spontaneously at the ostium because of arteriosclerosis, and alternative collateral circulation may develop to maintain blood supply to the AKA [12]. This collateral circulation to the AKA could be extremely important to prevent postoperative SCI when the original CSA is occluded. However, to our knowledge, there has been no comprehensive investigation or evaluation of the collateral circulation to the AKA in association with TEVAR. We use computed tomography angiography (CTA) to identify the CSA/AKA before TEVAR to enable the safe placement of stent-grafts. The purpose of this study was to assess the efficiency of identifying the CSA/AKA before TEVAR to prevent postoperative SCI.

Methods

Study population

Between June, 2002 and June, 2014, 74 patients underwent TEVAR at our institution, 51 of whom (38 men, 13 women; mean age 72.0 ± 10.6 years [range, 31–87 years]) had undergone preoperative CTA to identify the CSA/AKA. Of the other 23 patients who did not have the CSA/AKA pre-identified, 9 underwent emergency surgery (including 1 who already had paraplegia as a result of spinal cord infarction) while the remaining 14 (including 1 who already had paraplegia as a result of spinal cord infarction) did not undergo preoperative CSA/AKA evaluation because the thoracic aneurysms were located in the distal arch, which is far from the distal edge of the stent-graft. The aneurysms in these 51 patients included true degenerative aneurysms in 35, dissecting aortic aneurysms in 11 (including the thrombosed type (n=8) and the double-barrel type (n=3)), and pseudoaneurysm at the anastomotic site after previous open surgery in 5. Table 1 summarizes the patients' clinical characteristics.

Assessment of the CSA/AKA using CTA

CTA was used to evaluate the CSA/AKA before TEVAR by scanning from the level of Th7 to the level of L2. The CSA is defined as the intercostal or lumbar artery with a continuous vascular route from the anterior spinal artery, the AKA, the radiculomedullary artery, the posterior branch of the intercostal artery, the intercostal artery, and the aorta. In evaluating the AKA, we confirmed that, in addition to the characteristic hairpin turn, the continuity of the vascular route from the aorta to the anterior spinal artery is also important. Therefore, for the purposes of this study, when multiple continuities existed in one patient, all are referred to as the CSA [12].

To evaluate blood supply (the CSA/AKA) in each patient, we used a 4-channel multi-detector helical row CT scanner (Aquilion 4; Toshiba, Tokyo, Japan) between March, 2002 and May, 2003; a 16-channel multi-detector helical row CT scanner (Aquilion 16; Toshiba, Tokyo, Japan) between June, 2003 and February, 2005, (reported in detail elsewhere [11,12]; a 64-channel multi-detector helical row CT (Aquilion 64, Toshiba, Tokyo, Japan) between February, 2005 and January, 2008; and a 320-row multi-detector CT (Aquilion ONE, Toshiba Medical Systems Corporation, Tochigi, Japan) after January 2008. The scanning parameters were as follows: 120 kV, 400 mA, 0.5-mm section thickness, 0.75-second rotation speed, and 64-slice helical with 0.641 pitch factor. We administered 2.0 mL/kg body weight of high-osmolarity iopamidol (370 mg/mL) at a rate of 3.5 mL/s with a power injector, followed by a 30-mL saline flush.

The CSA/AKA was identified using CTA, 76.6 ± 62.7 days (range, 4–298 days) preoperatively. The following parameters were also examined in detail: the level of the thoracic or lumbar vertebra where the CSA arose from the aorta, the presence or absence of stenosis and obstructing lesions in the CSA, and the presence or absence of collateral circulation to the AKA. The image data were analyzed using a workstation (Zio M900; Ziosoft, Tokyo, Japan), whereby multiplanar reformatted, curved planar reformatted, and volume-rendering images were obtained. These images were then interpreted by two radiologists with more than 10 years' experience, who were in agreement.

TEVAR and post-procedure assessment

Operations were performed under local anesthesia for the initial two patients and under general anesthesia for the other 49 patients. The device used for TEVAR was a hand-made stent-graft in 17 patients and Gore TAG (W. L. Gore and Associate, Flagstaff, AZ, USA) in 34 patients. The access route during TEVAR was as follows: a femoral artery in 38, an iliac artery in 11, and a leg of the Y-graft, which was used for the abdominal aortic aneurysm repair in 2 patients. A concomitant procedure during TEVAR was required in 10 patients, as summarized in Table 2. The mean operation time was 175.3 ± 91.4 min (range, 60–510 min).

When conducting TEVAR, information regarding the CSA/AKA was used to help guide stent-graft deployment, paying particular attention to the position of the distal landing zone, in order to preserve CSA/AKA flow as much as possible. The CSA/AKA had to be completely or partially occluded by a stent-graft when the CSA/AKA arose from the aortic aneurysm itself; otherwise, an adequate sealing zone would not have been secured, and a type I endoleak would have occurred. If an adequate sealing zone could not be ensured, we explained the risks of spinal cord ischemia to the patient and performed TEVAR after obtaining informed consent. Partial occlusion of the CSA was defined as follows: the CSA was partially occluded by a stent-graft, one of the CSAs was completely occluded by a stent-graft in a patient who had two CSAs, or one of the collateral routes to the CSA was occluded by a stent-graft in a patient whose CSA had already occluded. In these cases, all efforts were made to preserve the adjacent intercostal artery (ICA), which was adjacent to the preoperatively identified CSA, and the left subclavian artery.

CTA was performed on postoperative day (POD) 15.7 ± 19.7 (range, 5–114). Similar to the preoperatively, we evaluated the level of the thoracic or lumbar vertebra where the CSA/AKA arose and the presence or absence of new stenosis or occluded lesions in the CSA. When the preoperatively identified CSA was occluded by a stent-graft during TEVAR, the presence or absence of a new collateral circulation to the AKA was also assessed.

Data were collected from the patients' medical records. The institutional review board of our hospital approved this retrospective study and waived patient consent on the condition that the patients were not identified.

Results

Table 3 shows the level of the thoracic or lumbar vertebra where the CSA to the AKA arose, as identified on the preoperative CTA. Two CSAs were found in four patients (7.8%). In seven patients (13.7%), the original CSA to the AKA was already occluded at the origin of the aorta and alternative continuity to the AKA through the collateral circulation was observed. These routes of collateral circulation are summarized in Table 4. The routes of the collateral circulation were grouped into two main types: (1) from the ICA adjacent to the ICA that was originally identified as the CSA via bridging arteries such as a muscular branch; and (2) from the arteries that were branches of the left subclavian artery, such as the internal thoracic artery and the thoracodorsal artery.

During TEVAR, the preoperatively identified CSA/AKA was preserved in 43 patients (84.3%). On the other hand, the CSA/AKA was occluded completely or partially by a stent-graft in five and three patients, respectively. Of the 50 patients who underwent postoperative conventional thoracoabdominal contrast-enhanced CT (contraindicated in one patient because of postoperative respiratory failure), one and five had type I (from the proximal side) and type II endoleaks, respectively.

None of the 51 patients suffered permanent postoperative paraplegia. The two patients who did suffer postoperative transient SCI underwent spinal fluid drainage after the onset of symptoms, followed by steroids and naloxone, resulting in complete resolution before discharge. Of the remaining 23 patients who did not have their CSA/AKA identified prior to TEVAR, two already had paraplegia caused by spinal cord infarction before TEVAR, and five (23.8%) suffered permanent SCI postoperatively.

Of the 51 study patients, 37 (72.5%) underwent postoperative CTA to evaluate the

CSA/AKA. The other 14 patients (27.5%) did not undergo postoperative CTA to evaluate their CSA/AKAs because of renal dysfunction or low postoperative activity. Of these 37 patients, 29 received a stent-graft with preservation of the CSA/AKA, and the other eight patients had occlusion of the CSA by the stent-graft during TEVAR. The postoperative CTA showed no change in the anatomical route of the CSA/AKA in any of these 29 patients: however, 1 suffered transient delayed paraparesis postoperatively. An aneurysm was located in the descending thoracic aorta in this patient, who was not examined using the Gore TAG. The stent-graft was deployed from zone 4 to the level of Th9, with a length of aortic coverage of 12.1 cm. The CSA (right Th10 ICA) was completely preserved during TEVAR in this patient.

In five patients with a CSA identified preoperatively, which had to be completely occluded by a stent-graft, postoperative CTA revealed the formation of new collateral circulation to the AKA. In four of these patients, the new route of the collateral circulation to the AKA was confirmed in detail as shown in Fig. 1 and Table 5. One patient (the second patient in Table 5) was previously reported in detail [13].

Of the remaining three patients with partially occluded CSAs identified preoperatively (Table 5), one suffered transient paraplegia postoperatively. This patient had two CSAs (right Th9 ICA and right Th11 ICA), and the ostium of the right Th9 ICA was almost occluded by the distal edge of the stent-graft. The characteristic “hairpin turn” appearance at its junction with the anterior spinal artery was obscured in the postoperative CTA. Apparent new collateral routes were not identified. Postoperative MRI revealed no evidence of spinal cord infarction (Table 5).

Discussion

Kawaharada et al. [14] reported that none of their patients with patency of the ICA following TEVAR suffered postoperative SCI, but that the incidence of postoperative SCI was 9.1% when the CSA was occluded by a stent-graft. Thus, it seems that occlusion of the CSA by a stent-graft is one of the major factors contributing to the development of postoperative SCI.

In the current study, none of the 51 patients who underwent preoperative evaluation of the CSA/AKA suffered permanent paraplegia postoperatively. In contrast, 23.8% of those who had not had preoperative evaluation of the CSA/AKA, did suffer permanent SCI. This implies that our strategy to reduce postoperative SCI following TEVAR is effective; namely: using CT (or similar) to preoperatively identify the CSA/AKA preoperatively; positioning the stent-graft placement to preserve the CSA/AKA to the greatest extent possible, with full consideration of the planned stent-graft placement position and the anatomical relationship of the CSA/AKA as identified preoperatively; and when occlusion of the preoperatively identified CSA/AKA is necessary, planning stent-graft placement with consideration of the potential collateral circulation pathways after stent-graft placement.

Only 1 of 43 patients with the CSA/AKA preserved suffered delayed and transient SCI postoperatively. This patient experienced hypotension during the operation, which we attributed as the cause of transient SCI through a temporary decrease spinal blood flow. In the present study, the CSA/AKA was completely occluded in five patients and partially occluded in three, resulting in postoperative transient paraplegia in one patient. In this patient, one of the two CSA/AKAs was partially occluded during TEVAR, and the characteristic hairpin-turn appearance at a junction with the anterior spinal artery was obscured in the postoperative CTA. Thus, apparent new collateral pathways were not identified. In the other seven patients who had no postoperative SCI despite CSA occlusion, new collateral circulation pathways to the AKA were confirmed using postoperative CTA.

Schurink et al. [15] speculated that the presence of intersegmental collaterals decreased the risk of SCI during TEVAR, which concurs with the current results. Nevertheless, it is still difficult to predict in advance the route of the collateral circulation to the AKA in case of occlusion of the CSA. The muscular branch of the ICA was reported as one of the common sources of collaterals [12,16]. The left internal thoracic artery [17, 18] and the left thoracodorsal artery [19], which are branches of the left subclavian artery, were also reported as routes of collateral circulation to the AKA when the original CSA was occluded. In our study, patients with the CSA occluded by a stent-graft showed new collateral circulation from the ICA adjacent to the CSA. Therefore, preservation of the ICA at one level distal to the original CSA might increase the possibility of collateral development to the AKA and thereby reduce the risk of postoperative SCI if occlusion of the CSA is necessary during TEVAR.

It remains controversial whether occlusion of the left subclavian artery without revascularization increases the risk of postoperative SCI after TEVAR [4,6,20,21,22,23]. The left subclavian artery is the source of the left vertebral artery and the cervical radicular arteries, both of which supply the cervical spinal cord and contribute to the blood flow of the thoracic spinal cord through a narrowed segment of the anterior spinal artery, as visualized in this study. This might be similar to the contribution of the hypogastric artery, which predominantly supplies the cauda equina but may provide blood flow to the lumbar and distal thoracic spinal cord. In the present study, the collateral circulation originated from the thoracodorsal artery [13] and the internal thoracic artery in some patients whose CSA was occluded by a stent-graft. In the present study, CTA was conducted within about 2 weeks postoperatively, rather than immediately after the operation; therefore, the exact time of occurrence of the collateral pathways to the AKA could not be identified. The possibility that the adjacent segmental arteries and the extrathoracic collateral source occur at different times cannot be ignored; however, the relative contribution of each collateral pathway is not fully understood. Thus, when preoperatively identified CSA and AKA are occluded with a stent-graft, a deployment plan that preserves at least the adjacent segmental artery or left subclavian artery and takes into account the potential collateral circulation is important to prevent postoperative SCI. This practice will decrease the risk of postoperative SCI in patients who require CSA occlusion.

This study has several limitations. First, it was a retrospective, single-center study. Second, the number of subjects was relatively small and 14 of the 51 subjects did not have postoperative CTA assessment of the CSA/AKA. However, the distal edge of the stent-graft did not reach the level of the vertebra from which the CSA arose in any of the patients, suggesting that the CSA/AKA was most likely preserved.

Conclusion

Careful identification of the CSA/AKA before TEVAR can help guide the surgeon to maneuver into a safe stent-graft landing zone. When the preoperative identified CSA is occluded by a stent-graft during TEVAR, preservation of the potential collateral circulation route to the AKA might reduce the risk of postoperative SCI.

Conflict of interest statement: We have no conflicts of interest to declare.

Figure legend

Figure 1.

(a) The critical segmental artery to the artery of Adamkiewicz, identified preoperatively, arose from the right Th10-intercostal artery.

(b) Postoperative collateral circulation (arrow) from the right Th11-intercostal artery after occlusion of the preoperatively identified critical segmental artery.

ICA: intercostal artery; CSA: critical segmental artery, AKA: artery of Adamkiewicz

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Table 1. Clinical characteristics of the patients

Type of aneurysm	True aneurysm: 35 cases Dissection: 11 cases Pseudoaneurysm: 5 cases
Gender	Male: n=38 (74.5%)
Age (years)	72.0±10.6 (31～87)
Hypertension	n=44 (86.3%)
Hyperlipidemia	n=10 (19.6%)
Diabetes mellitus	n=6 (11.8%)
History of aortic surgery	Total arch replacement: n=10 Hemi arch replacement: n=1 Descending thoracic aneurysm repair: n=2 Bentall procedure: n=1 Abdominal aortic aneurysm repair: n=4 Patch aortoplasty for PDA: n=1

PDA: Patent Ductus Arteriosus

Table 2. Concomitant operative procedure during thoracic endovascular aortic repair *(TEVAR)*

Concomitant procedure during TEVAR	Number of cases
Left axillo-right axillo bypass Coil embolization for the left subclavian artery	n=3
Y graft replacement for abdominal aortic aneurysm	n=1
Left CIA-EIA graft replacement Left IIA reconstruction	n=1
PTA for bilateral CIA Left EIA-CFA bypass Right femoral-left femoral bypass	n=1
PTA for the iliac artery	n=2
PTA for the left subclavian artery	n=1
PTA for left CIA-EIA Left CFA graft replacement	n=1

CIA: common iliac artery; EIA: external iliac artery; IIA: internal iliac artery;

CFA: common femoral artery; PTA: percutaneous transluminal angioplasty

Table 3. Level of the thoracic or lumbar vertebra at which the critical segmental artery (CSA) to the artery of Adamkiewicz (AKA) arose.

	Left	Right	Unknown
Th7	1	1	
Th8	4	1	
Th9	10	2	1
Th10	12	7	
Th11	4	4	
Th12	3		
L1	4		
L2	1		

Th: thoracic vertebra level; L: lumbar vertebra level; CSA: critical segmental artery; AKA: artery of Adamkiewicz

Table 4. Preoperative evaluation of collateral circulation to the artery of Adamkiewicz (AKA)

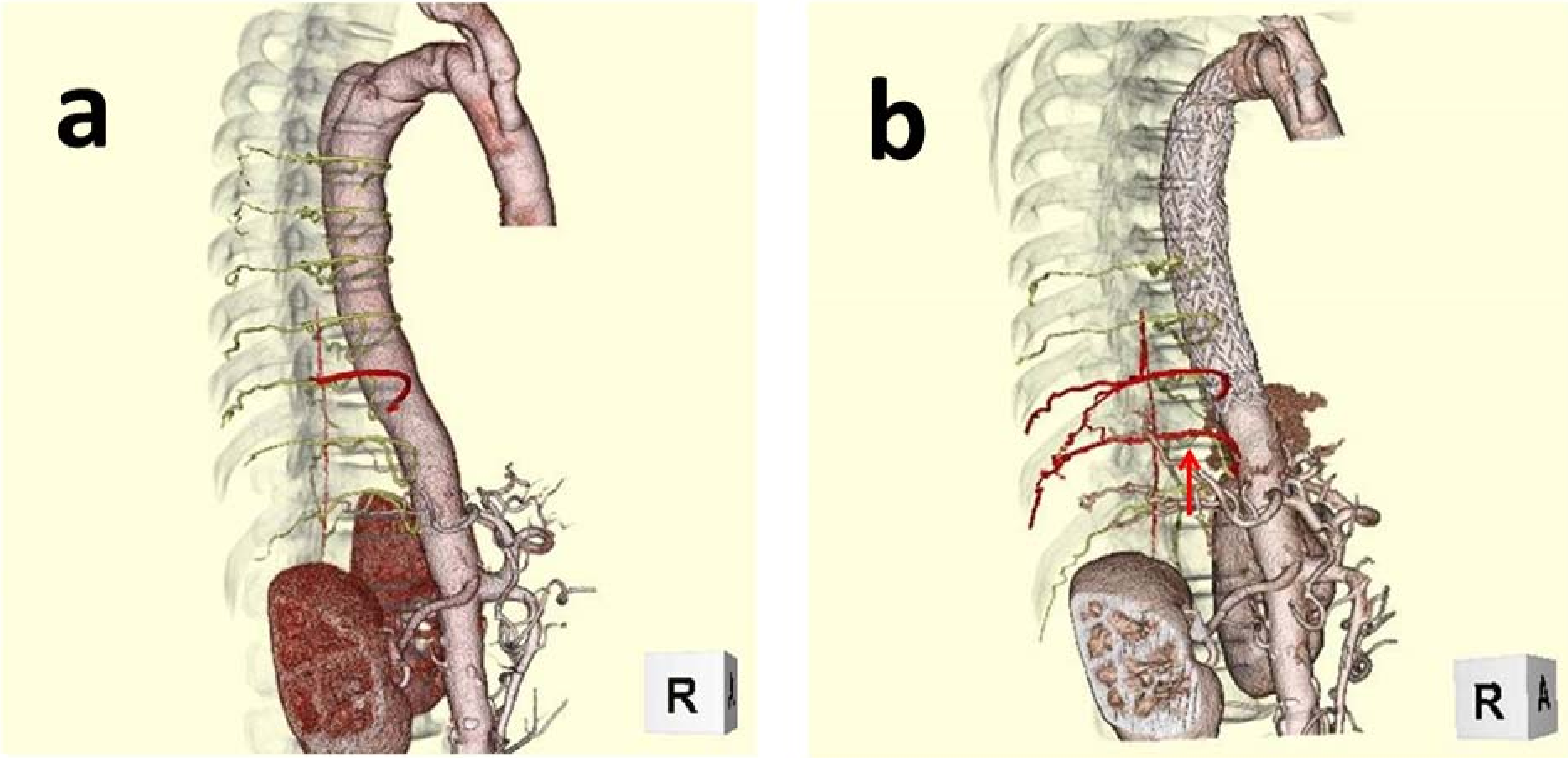
Patient NO.	Original CSA	Collateral circulation
1	Left Th 11-ICA	Th10-ICA and L1 lumbar artery
2	Left Th 10-ICA	Left Th 12-ICA
3	Left Th 9-ICA	Left Th 10-ICA
4	Left Th 9-ICA	Left Th 8-ICA and Th 10-ICA
5	Left Th 10-ICA	Left Th 11-ICA
6	Left Th 8-ICA	Left thoracodorsal artery
7	Left Th 7-ICA	Left internal thoracic artery and left Th 9-ICA

Th: thoracic vertebra level; L: lumbar vertebra level; CSA: critical segmental artery; AKA: artery of Adamkiewicz; ICA: intercostal artery

Table 5. Postoperative assessment of patients in whom the CSA identified preoperatively was occluded completely or partially by the stent-graft.

	Patient NO.	Preoperative CSA	SG proximal edge	SG distal edge	Postop SCI	Postop collateral circulation	Endoleak
Complete occlusion	1	Left Th 10-ICA	Zone 0	Th12	None	Unknown	None
	2	Left Th 9-ICA	Zone 3	Th12	None	Left and right lateral thoracic arteries, Left phrenic artery	Type II
	3	Right Th 10-ICA	Zone 4 (Elephant trunk)	Th11	None	Right Th11-ICA	None
	4	Left Th 10-ICA	Zone 4	Th10	None	Left Th11-ICA	None

	5	Left Th 9-ICA	Zone 4	Th10	None	Left Th 11-ICA	None
Partial occlusion	6	Left Th11 (occlusion) Collateral route from Th10, L1	Zone 4	Th11	None	Only from L1	None
	7	Right Th7 (stenosis) Left Th10 (continuity not determined)	Zone 0	Th8	None	Right internal thoracic artery, No change for left Th10	None
	8	Right Th11 (stenosis) Right Th9 (stenosis)	Zone 3	Th9	Transient paraplegia	None (preoperative hairpin turn also not determined)	None



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