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Institutional report - Vascular thoracic

Spinal cord protection with selective spinal perfusion during descending thoracic and thoracoabdominal aortic surgery☆

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Abstract

Open repair of aortic aneurysm causes spinal cord perfusion pressure to decrease due to the steal phenomenon from the bleeding of intercostal arteries and cross-clamping of the aorta. We attempted to perfuse the intercostal arteries for preoperative detection of the artery of Adamkiewicz using newly developed catheters. Fifteen patients underwent selective spinal perfusion with our original catheter as spinal protection during the procedure of distal descending thoracic aneurysm (DTA) or thoracoabdominal aortic aneurysm (TAAA) repair. Seven patients had distal DTA and eight had TAAA. Monitoring of motor evoked potential (MEP) was performed in all patients throughout the operation. The perfusion flow was 30–40 ml/min for each intercostal artery and was adjusted to keep the proximal circuit pressure at 150–200 mmHg. The average number of perfused intercostal arteries was 2.3 per patient and the number of intercostal arteries reimplanted per patient was 2.5. Intercostal arteries were reimplanted using an interpositional graft. MEPs were still observable after graft replacement in all patients and there were no cases of paraparesis/paraplegia. All patients were discharged ambulatory. Selective spinal perfusion maintains the quantity of total blood flow in the spinal cord and is very useful for reducing the incidence of ischemic injury of the spinal cord during operation.

Keywords: Aneurysm; Motor evoked potential; Spinal cord; Selective spinal perfusion

1. Introduction

Postoperative paraplegia or paraparesis is a serious complication of reconstructive surgery on the thoracoabdominal or descending thoracic aorta, wherein the major cause is thought to be spinal cord ischemia during and after the procedure. Due to advances in anesthetic and surgical techniques, the incidence of intractable neurological complications has declined, but the rate of paraplegia or paraparesis is still within the range of 4–16% [1, 2]. In the thoracolumbar region, it is known that the great anterior medullary artery [artery of Adamkiewicz or arteria radicularis magna (ARM)] is the dominant feeder of the spinal cord. One cause of paraplegia after aortic operations is the failure to re-establish the spinal cord blood supply.

Consequently, it has been suggested that reattachment of the intercostal and lumbar arteries during replacement of a descending thoracic or thoracoabdominal aorta could minimize such complications [3]. The importance of reattachment of the intercostal artery related to the ARM has been stressed in many reports. To avoid neurological complication, it is useful to know the level of the intercostal artery from which the ARM originates before reconstructive aortic surgery [4]. Even when the important segmental artery is successfully preserved, transient ischemia may occur during reimplantation and cause spinal cord injury. Thus, when reattachment of the segmental arteries is necessary, perfusion of these vessels during anastomosis will reduce spinal cord ischemia.

We investigated the outcome of thoracoabdominal or descending thoracic aortic aneurysm repair after selective perfusion to the intercostal arteries during operation and preoperative detection of the ARM by magnetic resonance angiography (MRA) or multi-detector-row computed tomography (MDCT) to prevent neurological deficit.

2. Materials and methods

2.1. Patients

Between February 2007 and March 2009, 15 patients underwent selective spinal perfusion with original catheters as spinal protection during the surgery of distal descending thoracic aneurysm (DTA) or thoracoabdominal aortic aneurysm (TAAA) repair. A retrospective review on selective spinal perfusion procedure in the management of DTA or TAAA was performed. Data from the hospital records of the patients were obtained from our departmental registry.

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2.2. Detection of the artery of Adamkiewicz

Eleven patients underwent MRA for detection of the ARM in this study. The MRAs were performed with a 1.5-T unit SIGNA Infinity Excite (GE Medical Systems, Milwaukee, WI). Four patients were imaged in the supine position with a 64-detector CT system (LightSpeed VCT, GE Health care, Milwaukee, WI, USA) from the apex of the lungs to the pubic symphysis.

2.3. Surgical technique

Arterial pressure was monitored at the right radial artery and at the dorsalis pedis artery opposite the femoral artery that was cannulated for the bypass. After induction of general anesthesia, patients were placed in the left lateral decubitus position with hips swiveled posteriorly. A double-lumen endotracheal tube was used in all patients, allowing collapse of the left lung. Left thoracotomy was performed through the fifth, sixth or seventh intercostal space. Some patients with type I and II TAAA were treated according to a previously reported procedure [5]. The entire aorta was exposed with dissection of the retroperitoneal space and division of the costal cartilage and diaphragm. Cardiopulmonary bypass was established by means of cannulation of the right femoral artery and the right femoral vein basically, after the administration of heparin (2 ml/kg). The femoral venoarterial bypass circuit used for the procedure included a centrifugal pump and a membrane oxygenator with heat exchanger. The circuit was branched for selective perfusion of the segmental arteries and major abdominal vessels. Selective perfusion of intercostal arteries using newly developed catheters was performed with a roller pump independent of systemic circulation. The perfusion flow was 30–40 ml/min for each intercostal artery and was adjusted to keep the proximal circuit pressure at 150–200 mmHg with a roller pump, independent of the cardiopulmonary bypass circuit (Figs. 1 and 2, Video 1). After the intercostal arteries were reconstructed, the visceral and renal arteries were also reimplanted. During reconstruction of the visceral and renal arteries, selective visceral and renal perfusion with 10–12 F balloon catheters connected to the systemic circuit was performed. Each artery was perfused at a flow rate of 200–300 ml/min.

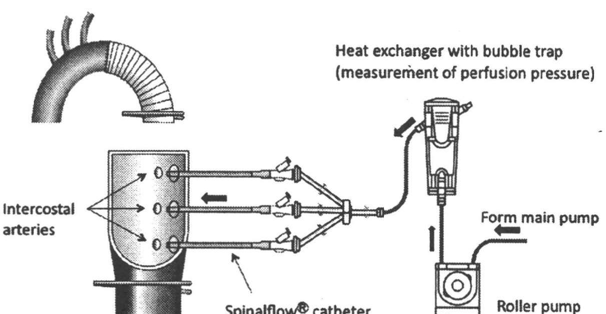


Fig. 1. Selective perfusion of the intercostal arteries using newly developed catheters was performed with a roller pump independent of systemic circulation. The perfusion flow was 20–30 ml/min for each intercostal artery and was adjusted to keep the proximal circuit pressure at 100–200 mmHg with a roller pump, independent of the cardiopulmonary bypass circuit.

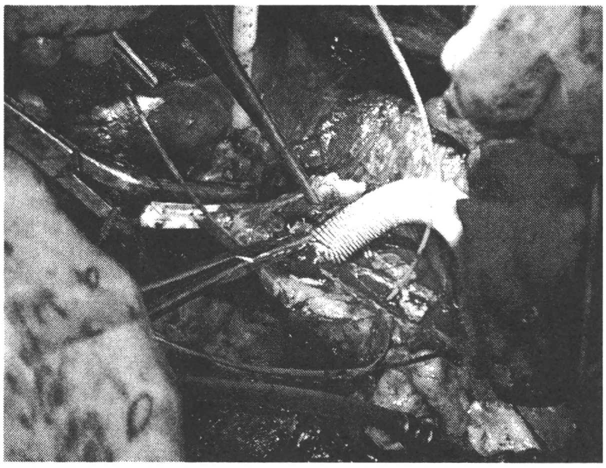
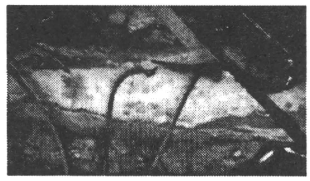


Fig. 2. Intercostal arteries were reattached by separate tube graft under selective perfusion of the intercostal arteries using newly developed catheters for the purpose of maintaining spinal cord perfusion pressure during the cross-clamping of the aorta.



Video 1. Catheters (Spinalflow®, Fuji Systems Co, Ltd, Tokyo, Japan) used in this study are made from polyurethane with a total length of 40 cm, size of 4.4 F, and balloon volume of 0.06 ml. Perfusion flow rates through these catheters measured by blood (Hct: 20%) under 150 and 200 mmHg perfusion pressure were approximately 30 and 40 ml/min, respectively. During reimplantation, we attempted to perfuse the intercostal arteries in all patients.

2.4. Catheters for selective perfusion of intercostal arteries

Catheters (Spinalflow®, Fuji Systems Co, Ltd, Tokyo, Japan) used in this study are made from polyurethane with a total length of 40 cm, size of 4.4 F, and balloon volume of 0.06 ml. Perfusion flow rates through these catheters measured by blood (Hct: 20%) under 150 and 200 mmHg perfusion pressure were approximately 30 and 40 ml/min, respectively [6] (Fig. 3). During reimplantation, we attempted to perfuse the intercostal arteries in all patients.

2.5. Monitoring technique for transcranial motor evoked potentials (Tc-MEPs)

Tc-MEPs were elicited by using a multiple electrical transcranial stimulator (Digitimer D185 cortical stimulator, Digitimer Ltd, Welwyn Garden City, UK). Stimuli were applied to the skull with the anode placed in the C3 position and the cathode in the C4 position (International 10–20 system for the placement of electroencephalogram electrodes). The stimulus consisted of a series of five pulses. Each

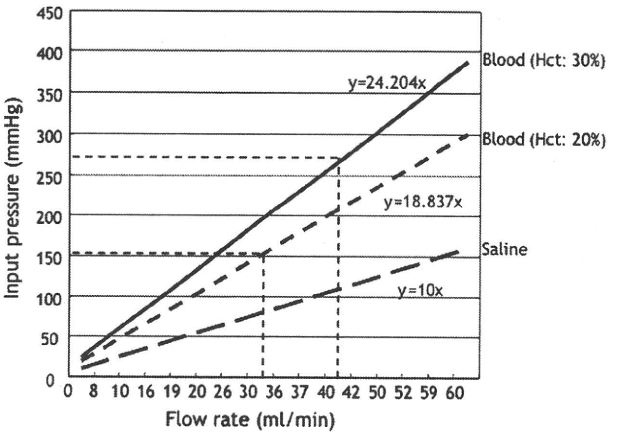


Fig. 3. Pressure loss of Spinalflow® catheter. Perfusion flow rates through these catheters measured by blood (Hct: 20%) under 150 and 200 mmHg perfusion pressure were approximately 30 and 40 ml/min, respectively.

individual stimulation lasted 50 ms, and the interstimulus interval between pulses was 2.0 ms. The output voltage was set at 500 V. Compound muscle action potentials were recorded from the skin over the right flexor hallucis brevis muscle and the right flexor pollicis brevis muscle using adhesive gel Ag/AgCl electrodes. Signals were recorded every 100 ms, passed through a bandpass filter of 10–1000 Hz, and amplified 5000–20,000 times. Data acquisition, processing, analysis, and saving required a personal computer system (Neuropak MEB-2200, Nihon Koden, Tokyo, Japan). An average of three consecutive amplitudes recorded before aortic cross-clamping was defined as the baseline. A reduction of motor evoked potential (MEP) amplitude of the flexor hallucis brevis muscle to <50% of baseline was considered to be a sign of spinal cord ischemia.

2.6. Statistical analysis

Statistical analyses were performed using the SPSS 11.0 software (SPSS Inc, Chicago, IL). All values were expressed as mean±standard deviation (S.D.).

3. Results

The patients included 12 males and 3 females with a mean age of 65 years (range, 52–79 years). Aortic pathology included five atherosclerotic aneurysms and ten dissecting aneurysms. The maximal aortic diameters ranged from 55 to 79 mm (mean, 65 mm). The patients' characteristics are summarized in Table 1. Seven patients had distal DTA and eight had TAAA (Crawford's classification revealed type 1 in two patients, type 2 in four patients, and type 3 in two patients with prior descending or abdominal aortic repair) (Table 1).

ARMs were detected in 13 (87%) of 15 patients. All 13 patients had vessels that coursed toward the anterior spinal artery and were supplied by the intercostal artery. The laterality of the arteries originated from the intercostal artery on the left side in 10 (77%) of the 13 ARMs. Cerebrospinal fluid (CSF) drainage was used intraoperatively in 10 patients (67%).

Table 1
Demographics and comorbidities of operation

Demographics	
No. of patients	15
Age (years)	62±9
Male gender (%)	12 (80)
Aneurysm diameter (mm)	65±7
Aneurysm type, *n* (%)	
Thoracic	7 (47)
Crawford type 1	2 (13)
Crawford type 2	4 (27)
Crawford type 3	2 (13)
Previous aortic procedure, *n* (%)	8 (53)
Infrarenal AAA, *n* (%)	4 (27)
Thoracic aortic aneurysm, *n* (%)	4 (27)
Comorbidities	
Hypertension, *n* (%)	13 (87)
Hyperlipidemia, *n* (%)	3 (20)
Smoking, *n* (%)	4 (27)
Chronic obstructive pulmonary disease, *n* (%)	2 (13)
Chronic renal insufficiency, *n* (%)	3 (20)
Pathology of aneurysmal dilatation, *n* (%)	
Aortic dissection	10 (67)
Non-dissection	5 (33)
Detection of ARM, *n* (%)	13 (87)

ARM, arteria radicularis magna; AAA, abdominal aortic aneurysm.

3.1. Selective perfusion and reconstruction of intercostal arteries

The average number of perfused intercostal arteries was 2.3 per patient and the number of intercostal arteries reimplanted per patient was 2.5. Intercostal arteries were reimplanted using an interpositional graft (8 mm or 10 mm). The average perfusion time of intercostal artery (ICAs) with the catheters or through the implanted interpositional grafts was 64 min (Table 2).

3.2. Changes in MEP after aortic cross-clamp

MEPs were still observable after graft replacement and no case of paraparesis/paraplegia happened. In two patients, MEPs were not observed directly after aortic cross-clamp. The ARM was located in the RT8 and LT10, including the cross-clamp area, in these patients. The changes in MEPs amplitude after cross-clamping were recovered by selective intercostal arteries perfusion (Fig. 4).

Table 2
Intraoperative details

Cardiopulmonary bypass time (min)	214±100
Aortic cross-clamp time (min)	162±80
Distal aortic perfusion, *n* (%)	15 (100)
Distal perfusion time (min)	167±71
Visceral perfusion, *n* (%)	8 (53)
Visceral perfusion time (min)	138±50
Mean selective spinal perfusion time (min)	
With catheter	31.7 (5–77)
With catheter and tube graft	64.1 (5–121)
Perfused ICAs/pt, *n* (range)	2.3 (1–4)
Reimplanted ICAs/pt, *n* (range)	2.5 (0–4)
Open proximal anastomosis, *n* (%)	5 (33)
CSF drainage, *n* (%)	10 (67)
MEP monitoring, *n* (%)	12 (80)

CSF, cerebrospinal fluid; MEP, motor evoked potential; ICA, intercostal artery.

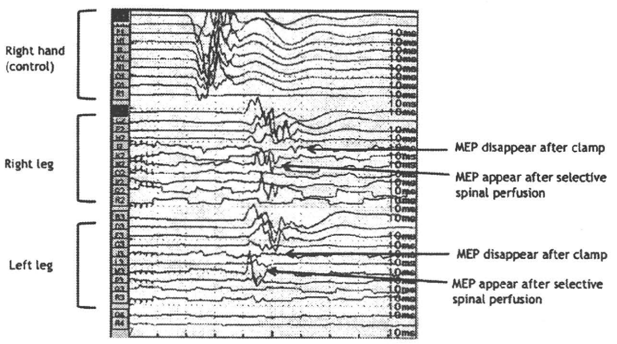


Fig. 4. MEPs were not observed in two patients directly after aortic cross-clamp. The changes of MEPs amplitude after cross-clamp were recovered by selective intercostal arteries perfusion.

3.3. *Morbidity and mortality*

There was no early mortality. There were no paraparesis/paraplegia, bleeding complications requiring reoperation, and postoperative renal insufficiency. All patients were discharged ambulatory.

4. Discussion

Postoperative paraplegia and paraparesis are devastating complications of DTA or TAAA repair. These pose not only the present physical disability but also a higher mortality rate among patients [1]. Repair of DTA or TAAA is a meticulous procedure, such as that a large number of segmental intercostal and lumbar arteries providing spinal cord perfusion may be disrupted, especially in patients with more extensive aneurysms. The presence of paraplegia immediately upon emergence from anesthesia suggests that an irreversible ischemic injury to the spinal cord occurred, perhaps related to the interruption of its vascular supply.

Spinal cord injury generally happens during temporary or permanent interruption of spinal cord blood supply. The pathophysiology of spinal cord injury in DTA or TAAA surgery is essentially an ischemia-infarction model. Thoracic aortic clamping reduces arterial blood supply to the spinal cord, increases spinal fluid pressure [7], and produces inadequate tissue oxygen delivery and ischemia [8]. Reperfusion after ischemia can further damage neuronal cells [9].

We have previously demonstrated the usefulness of preoperative detection of the intercostal artery supplying the Adamkiewicz artery for the reduction of the incidence of ischemic injury of the spinal cord [4]. This procedure establishes the best operational strategy for descending thoracic aortic aneurysm or TAAA repair. Surgical repair can be performed while the intercostal and lumbar arteries can be revascularized at or near the level of Adamkiewicz artery; thereby, spinal cord injury can be reduced. In our institute, we have routinely reconstructed or preserved an intercostal artery that may be related to the preoperatively detected Adamkiewicz artery during repair of thoracoabdominal or descending thoracic aortic aneurysm. However, even when the important segmental artery is successfully preserved, transient ischemia may occur during reimplantation, and thus cause spinal cord injury. Maintaining blood pressure within the aortic segment isolated by double cross-clamping has been shown experimentally to improve spinal cord blood flow [10].

We have previously reported that many patients do not have spinal cord ischemia even if the internal artery to Adamkiewicz artery is occluded after endovascular stent-graft repair [11]. Endovascular repair avoids aortic cross-clamping and may significantly decrease perioperative complications because of the minimally invasive nature of the procedure, avoidance of ischemia/reperfusion, and the associated changes in hemodynamics that occur during proximal aortic cross-clamping. In other words, patients are still at risk for paraplegia/paraparesis whether the procedure involves no aortic cross-clamping or no open aortic aneursym, even if the intercostal artery to Adamkiewicz artery is occluded after endovascular stent-graft repair. It seems that the intercostal artery supplying the Adamkiewicz artery is not solely responsible for the total blood flow quantity to the spinal cord.

We believe that no single artery is so important in many patients, but rather it is the total amount of blood flow through all intercostal and lumber arteries or vertebral arteries from the subclavian artery or pelvic vascular plexus that determines adequacy of spinal cord perfusion during operation. However, dependence on the Adamkiewicz artery for the total amount of blood flow to the spinal cord is a reality in a patient.

Based on the above-mentioned theory, we attempted to perfuse the intercostal arteries mainly on the Adamkiewicz artery for the purpose of maintaining spinal cord perfusion pressure during the cross-clamping of the aorta. By this technique, total blood flow quantity in the spinal cord becomes equal to or more than a certain constant level. Below the constant level, patients will suffer spinal cord ischemia.

MEP changes during the cross-clamping of the aorta have been used to evaluate spinal cord perfusion pressure. The observed changes in MEPs indicate that selective perfusion of the segmental arteries was not sufficient to maintain adequate spinal perfusion. We experienced cases in which MEP amplitude disappeared after open aneurysm, but recovery of the amplitude after perfusion to the intercostal arteries was noted. MEPs are known to be very sensitive to spinal cord ischemia [12] and MEP changes clearly overpredict the number of ICAs that must be reimplanted to prevent infarction.

Safi and colleagues [13] determined that a lack of segmental arterial reattachment at various thoracolumbar levels resulted in specific early or delayed deficits. Jacobs and associates [14] used MEP changes to indirectly evaluate segmental spinal cord blood supply; in which they contended that a diffuse collateral network provided spinal cord blood supply in those with degenerative TAAAs. Wong and colleagues [15] suggested that reattaching a greater number of segmental arteries increased the likelihood of maintaining this rich collateral network. These papers show that it is very important to maintain total blood flow quantity from the intercostal and lumbar arteries or vertebral arteries or pelvic vascular plexus and other collateral arteries.

Many surgeons think that distal perfusion prevents spinal cord ischemia in an operation of DTA or TAAA. We think that perfusion to the intercostal arteries is the same as the distal perfusion under open aneurysms this method is very useful to prevent spinal cord ischemia.

We believe that selective spinal perfusion for spinal cord protection is a similarly effective method as in many operative repairs of the aortic arch. The principle is similar to selective cerebral perfusion for brain protection.

5. Conclusion

Selective spinal perfusion maintains the total blood flow quantity in the spinal cord and is very useful for reducing the incidence of ischemic injury of the spinal cord during operation.

References

[1] Svensson LG, Crawford ES, Hess KR, Coselli JS, Safi HJ. Experience with 1509 patients undergoing thoracoabdominal aortic operations. J Vasc Surg 1993;17:357–370.

[2] Coselli JS, LeMaire SA, Miller CC 3rd, Schmittling ZC, Koksoy C, Pagan J, Curling PE. Mortality and paraplegia after thoracoabdominal aortic aneurysm repair: a risk factor analysis. Ann Thorac Surg 2000;69:409–414.

[3] Acher CW, Wynn MM, Mell MW, Tefera G, Hoch JR. A quantitative assessment of the impact of intercostal artery reimplantation on paralysis risk in thoracoabdominal aortic aneurysm repair. Ann Surg 2008;248:529–540.

[4] Kawaharada N, Morishita K, Hyodoh H, Fujisawa Y, Fukada J, Hachiro Y, Kurimoto Y, Abe T. Magnetic resonance angiographic localization of the artery of Adamkiewicz for spinal cord blood supply. Ann Thorac Surg 2004;78:846–852.

[5] Morishita K, Yokoyama H, Inoue S, Koshino T, Tamiya Y, Abe T. Selective visceral and renal perfusion in thoracoabdominal aneurysm repair. Eur J Cardiothorac Surg 1999;15:502–507.

[6] Koyanagi T, Kawaharada N, Kurimoto Y, Ito T, Baba T, Nakamura M, Watanebe A, Higami T. Examination of intercostal arteries with transthoracic Doppler sonography. Echocardiography 2009 Aug 31 [Epub ahead of print].

[7] Marini CP, Levison J, Caliendo F, Nathan IM, Cohen JR. Control of proximal hypertension during aortic cross-clamping: its effect on cerebrospinal fluid dynamics and spinal cord perfusion. Semin Thorac Cardiovasc Surg 1998;10:52–56.

[8] Rokkas C, Cronin C, Nitta T, Helfrich LR Jr, Lobner DC, Choi DW, Kouchoukos NT. Profound systemic hypothermia inhibits the release of neurotransmitter amino acids in spinal cord ischemia. J Thorac Cardiovasc Surg 1995;110:27–35.

[9] Allen BT, Davis CG, Osborne D, Karl I. Spinal cord ischemia and reperfusion metabolism: the effect of hypothermia. J Vasc Surg 1994;19:332–339.

[10] Dapunt OE, Midulla PS, Sadeghi AM, Mezrow CK, Wolfe D, Gandsas A, Zappulla RA, Bodian CA, Ergin MA, Griepp RB. Pathogenesis of spinal cord injury during simulated aneurysm repair in a chronic animal model. Ann Thorac Surg 1994;58:689–697.

[11] Kawaharada N, Morishita K, Kurimoto Y, Hyodoh H, Ito T, Harada R, Kuwaki K, Higami T. Spinal cord ischemia after elective endovascular stent-graft repair of the thoracic aorta. Eur J Cardiothorac Surg 2007;31:998–1003.

[12] Meylaerts SA, Jacobs MJ, van Iterson V, De Haan P, Kalkman CJ. Comparison of transcranial motor evoked potentials and somatosensory evoked potentials during thoracoabdominal aortic aneurysm repair. Ann Surg 1999;230:742–749.

[13] Safi HJ, Miller CC III, Carr C, Iliopoulos DC, Dorsay DA, Baldwin JC. Importance of intercostal artery reattachment during thoracoabdominal aortic aneurysm repair. J Vasc Surg 1998;27:58–66.

[14] Jacobs MJ, Mess W, Mochtar B, Nijenhuis RJ, Statius van Eps RG, Schurink GW. The value of motor evoked potentials in reducing paraplegia during thoracoabdominal aneurysm repair. J Vasc Surg 2006; 43:239–246.

[15] Wong DR, Coselli JS, Amerman K, Bozinovski J, Carter SA, Vaughn WK, LeMaire SA. Delayed spinal cord deficits after thoracoabdominal aortic aneurysm repair. Ann Thorac Surg 2007;83:1345–1355.

Conference discussion

Dr. D. Pacini *(Bologna, Italy)*: Thoracic and thoracoabdominal aortic aneurysm repair still represents a challenge for cardiovascular surgeons, and paraplegia and paraparesis remain the major devastating and unpredictable complications. Multiple factors contribute to these complications, but the principal one is represented by the temporary or permanent interruption of blood supply to the spinal cord.

Efforts to reduce the risk of ischemic spinal cord injuries have appropriately focused largely on intraoperative management approaches. Alternative perfusion strategies ranging from deep hypothermia and circulatory arrest to partial left heart bypass have been successfully advocated by various authors. Intercostal artery reimplantation has also been promoted by some, although not all, authors.

Moreover, monitoring of motor-evoked potentials was successfully introduced to assess spinal cord ischemia during surgery. All these efforts have reduced the reported incidence of postoperative paraparesis and paraplegia to a range of approximately 3–15% in recent series.

The present study described the experience with thoracic and thoracoabdominal aortic aneurysm repair with the aid of cardiopulmonary bypass. Monitoring of motor-evoked potentials was performed in all patients, and in all patients the spinal cord blood supply was guaranteed during cross-clamping by perfusion of the intercostal arteries. A mean of 2.3 intercostal arteries were perfused in each patient. The results were excellent without any death or any spinal cord injury. I totally agree with the authors' conclusion that perfusion of the spinal cord should be considered similarly effective as cerebral perfusion during aortic arch surgery. And in this way spinal cord ischemia is considerably reduced during the operation.

An important finding of the study was that the Adamkiewicz artery was preoperatively detected in 87% of the patients with CT or MRI. And so this is my first question. Could you tell us just a little bit more about the technical aspect. How were you able to detect this artery before operation?

Dr. Kawaharada: We believe that no single artery is so important in many patients, but rather it is important for patients that the total amount of blood flow through all intercostal arteries or vertebral arteries from the subclavian artery or pelvic vascular plexus determines adequacy of spinal cord perfusion during operation.

But a few patients depend on one important intercostal artery to the Adamkiewicz artery for the total amount of blood flow to the spinal cord. We try to detect these intercostal arteries for Adamkiewicz artery in preoperative examination, CT or MRI. Our process is to perfuse intercostal arteries, this critical artery, and next to its upper intercostal artery and lower intercostal artery on the same side. If we have no information preoperatively to detect these Adamkiewicz arteries, we will have scheduled reconstruction of intercostal arteries at Th9, 10, 11, which may need perfusion.

Dr. Pacini: And my second question addresses cerebrospinal fluid drainage that was not used in all patients. So in which patients do you recommend it? And additionally, there is some controversy with the use of CSF drainage in fully heparinized patients. Could you elaborate this concept?

Dr. Kawaharada: The CSF drainage, our patients had inserted the day before the operation day. I think this CSF drainage may be very useful. We don't think it is a problem to insert the CSF drainage.

Dr. Pacini: But you use it only in 10 patients. So what are your current indications for using it? Because you didn't use the drainage in all patients.

Dr. Kawaharada: We try to insert CSF drainage tube in all thoracoabdominal aneurysm patients. But we could not insert in some patients because of deformity of vertebral body.

Dr. Pacini: So you recommend its use in all patients?

Dr. Kawaharada: Yes.

Dr. Pacini: And finally, I noticed that in five patients you performed an open proximal anastomosis that of course required deep hypothermic circulatory arrest, but you did not mention anything about temperature. So what degree of hypothermia have you used in case of circulatory arrest, and also in the other cases?

Dr. Kawaharada: I usually operated the thoracoabdominal aneurysm repairs under the normal body temperature. But in five cases in this series, I operated open proximal anastomosis under deep hypothermic circulatory arrest. That temperature is about 20°. When I finished the open proximal anastomosis, we recovered the normal body temperature to the patient.

Dr. Pacini: So if you are able to perform the proximal anastomosis during clamping, you don't cool the patient: do I understand right?

Dr. Kawaharada: Yes, when I do not use open proximal anastomosis, I usually operate under normothermia.

Dr. J. ***Bachet*** *(Abu Dhabi, United Arab Emirates)*: I'm a little intrigued by a few features. First of all, half of your patients had a replacement of the descending aorta and not of the thoracoabdominal aorta. We know that patients with replacement of the descending aorta alone are not very prone to spinal cord ischemia. The attrition rate is rather low.

But more importantly, your study relied on the old vision that the most important thing is the anatomical vascularization. We know now after the work by Griepp and his group that the physiologic view, that is, the pattern of the collateral network, may be much more important.

I used to belong to a group that was assessing the Adamkiewicz artery before surgery. And it happened that it was useless. First of all, because when we opened the aorta in the operating theater, often we could not decide exactly which was the right artery that we had seen in radiology before surgery; secondly, because the results were exactly the same, whether we had assessed the Adamkiewicz artery or not.

So to make it short, my question is: do you really think that the important thing here was to perfuse the intercostal arteries or just to occlude them to prevent backflow and steal syndrome from the spinal cord?

Dr. Kawaharada: This intercostal arteries perfusion technique is the same as distal perfusion procedure. Therefore to perfuse intercostal arteries under open aneurysm is same condition as distal perfusion in aneurysm under cross-clamp. For example many surgeons try to do selective cerebral perfusion with balloon catheter in operation of arch aneurysm. And the concept of this intercostal artery perfusion is the same. Our aim is to keep the total blood flow to the spinal cord, to keep the anterior spinal artery blood pressure due to intercostal artery perfusion. We know that there are patients in whom spinal cord ischemia is not reversed during operation by stopping back-bleeding.

Report

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MAJOR PAPER

MR Angiography for Detecting the Artery of Adamkiewicz and Its Branching Level from the Aorta

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Purpose: We evaluated the efficacy of magnetic resonance angiography (MRA) for detecting the artery of Adamkiewicz (AKA) and the vertebral level of its feeding arteries branching from the aorta.

Materials and Methods: Eighty-two patients (67 men, 15 women; aged 34 to 86 years, mean age 68.6 years) with thoracic descending and thoracoabdominal aortic lesions (aneurysm in 55, dissection in 25, coarctation in 2) underwent MRA to detect AKA. MRA was performed using 6-phase, dynamic-enhanced, 3-dimensional, fast spoiled gradient recalled acquisition in steady state (GRASS) on a 1.5-tesla (T) system, with double-dose bolus contrast injection. The vertebral levels of AKA branching and the AKA feeder artery branching from the aorta were determined.

Results: The AKA was detected in 67 patients (81.7%). Branching of AKA occurred at levels T7 to T12 on the left side (n = 52) and on the right (n = 15). Vascular continuity from the aorta to the anterior spinal artery was demonstrated in 55 patients (67.1%). Comparing the vertebral level of arterial branching from the aorta to that of the AKA at the intervertebral foramen, the AKA branched at the same vertebral level in 44 patients (80.0%), one vertebral level above/below in 10 (18.2%), and 2 vertebral levels above in one (1.8%).

Conclusion: MRA can be useful in the preoperative work-up of patients with thoracoabdominal aortic lesions to localize AKA and the segmental trajectories of vessels supplying blood to the AKA.

Keywords: ***aortic aneurysm, aortic dissection, artery of Adamkiewicz, MR angiography (MRA), surgery***

Introduction

Postoperative paraplegia/paraparesis is a serious complication of reconstructive surgery for thoracic descending and thoracoabdominal aortic lesions, i.e., aneurysm, dissection, or coarctation. The major cause of spinal complication is thought to be spinal cord ischemia during and/or after the procedure. Owing to advances in anesthetic and surgical techniques, the frequency of severe neurologic complications has declined, but the rate of postoperative spinal complication remains high, in the range of 5 to 10%.[1-3] Maintaining blood supply to the spinal cord is thought to be a key factor in reducing the risk of spinal complications. Recent studies have reported that the rate of spinal cord ischemia was significantly decreased in patients who underwent successful preoperative identification of the artery of Adamkiewicz (also known as the great anterior radiculomedullary artery and the dominant arterial feeder of the spinal cord) compared to patients in whom this artery was not identified.[4,5]

Greenberg's group reported on neurologic deficit caused by spinal cord ischemia in 3 of 25 patients (12%) undergoing endovascular thoracoabdominal aneurysm repair, with long-segment thoracic aortic coverage found to be a significant risk factor in predicting clinically evident spinal cord ischemia.[6]

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It has been suggested that reattachment of the intercostal arteries during repair of the descending thoracic or thoracoabdominal aorta could minimize the occurrence of such complications.[7] Before reconstructive aortic surgery, knowledge of the branching level of the intercostal artery from which the artery of Adamkiewicz originates would be useful in preventing neurologic complications. Therefore, we prospectively evaluated detection of the artery of Adamkiewicz[7] by MR angiography (MRA) that included an additional scan that visualized the aorta to determine the vertebral level of feeding arteries branching off from the aorta and the branching trajectory to the anterior spinal artery.

Materials and Methods

Patient population

This study was approved by the institutional review board. All patients who participated provided written informed consent.

From March 2006 through May 2008, 82 patients (67 men, 15 women; aged 34 to 86 years, mean age, 68.6 years) underwent MRA to detect the artery of Adamkiewicz. Patients included 55 with thoracoabdominal aortic aneurysm (Crawford type I, 26 patients; II, 3 patients; III, 3 patients; IV, 2 patients; and arch, 21 patients), 25 with thoracoabdominal aortic dissection (DeBakey type I, 3 patients; II, 0 patients; IIIa, 5 patients; and IIIb, 17 patients), and 2 with coarctation.

MRA protocol

MRA was performed with a 1.5T system (Signa Infinity Excite; GE Medical Systems, Milwaukee, WI, USA). Because reconstruction of the radiculomedullary artery is considered an essential part of aortic graft implantation at our institution, a 24-cm field of view (FOV) from above the second lumbar (L2) vertebral level was examined in each patient. We used the L5 vertebra and the twelfth thoracic (T12) rib to localize the L2 vertebra as the lower boundary of the FOV on a positioning scan. As in the previously reported protocol,[7] a dynamic study was performed by enhanced, 3-dimensional (3D), fast spoiled gradient recalled acquisition in steady state (GRASS) method (spine phased-array coil; repetition time, 5.9 ms; echo time, 2.4 ms; flip angle, 25 degrees; number of excitations, 2; matrix size, 256×128; slice thickness, 1.6 mm; number of slices, 12; zero-fill interpolation [section ZIP 4, in-plane ZIP 512] providing 48 slices), with no phase wrap, FOV of 24 cm, and oblique-coronal section along the posterior line of the vertebral body. The MR input/output gain was standardized (mean $\pm$ standard deviations, $155.0 \pm 7.3/13.0 \pm 0.0$, respectively).

The contrast agent, gadopentetate dimeglumine (Omniscan; Daiichi-Sankyo, Tokyo, Japan), was injected into the median cubital vein (0.2 mmol/kg, 4 mL/s) with a saline flush (20 mL). A power injector (SONIC SHOT 50, Nemoto Kyorindo, Tokyo, Japan) was used in all patients. By using first-phase acquisition synchronized to the start of the injection, 5 dynamic scans were obtained (first to fifth consecutive scan phases). Each scan time was 23 to 25 s. After 5 dynamic scans, an additional scan was obtained (sixth phase) with an adjusted FOV to cover the posterior half of the aorta to detect the branching level of the feeding artery. After data acquisition, the images were stored as digital imaging and communications in medicine (DICOM) datasets and displayed on a diagnostic monitor (Flexscan L365; EIZO NANAO, Ishikawa, Japan) at a 0.4-mm reconstruction pitch.

Image reconstruction

Image reconstruction was the same as previously reported.[7] The acquired datasets were transmitted to a workstation (Advantage Windows, GE Medical Systems). A 3D maximum intensity projection (MIP) image[8] in the anteroposterior direction was reconstructed for each of the 5 phases. The resulting five 3D-MIP source images were used for subtraction. The 3D-MIP phase-2 to -5 source images were subtracted from the phase-1 image for noise reduction. A partial MIP image was also used for subtraction. The resulting five 3D-MIP source images were used for double-subtraction (i.e., subtraction of the venous-phase 3D-MIP image from the arterial-phase 3D-MIP image yielded a double-subtracted arterial 3D-MIP image).[7,9] The curved multi-planar reconstruction (MPR) image was reconstructed and combined with the arterial-phase image and phase-6 image to evaluate the arterial continuity from the aorta to the anterior spinal artery via the artery of Adamkiewicz (Fig. 1).

Detection criteria

The criteria for detection of the artery of Adamkiewicz in both the original and the 3D-MIP images were as previously reported:[5,7] 1) depiction of a clearly defined blood vessel connected to the radiculomedullary or lumbar artery in the early phase, 2) depiction of a blood vessel running toward the anterior spinal cord with a hairpin-turn connection in the early phase, and 3) diminished signal intensity of this vessel in the late phase. Using curved MPR images, the vertebral level of ar-

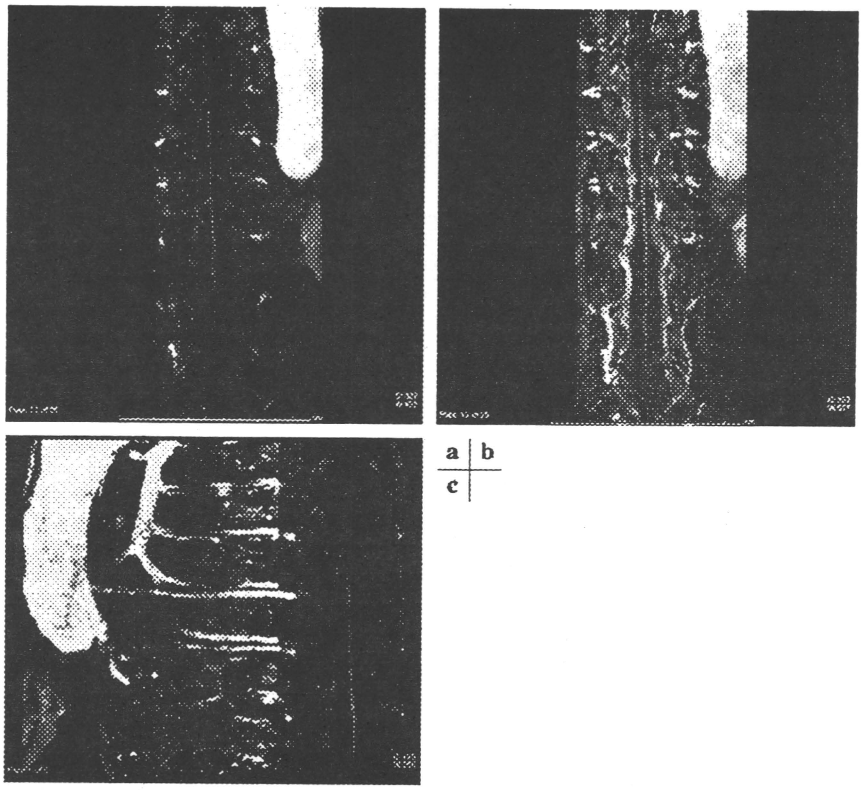

Fig. 1. Magnetic resonance angiography (MRA) images of a 78-year-old man with a Crawford I aneurysm: **(a)** arterial phase, **(b)** venous phase, and **(c)** curved multi-planar reconstruction (MPR). MRA demonstrated the artery of Adamkiewicz in the arterial phase **(a)**. The artery's signal intensity diminished in the venous phase **(b)**. The artery of Adamkiewicz branched from the right side at the intervertebral foramen T9, and its feeding artery branched at the same level from the aorta **(c)**.

terial branching from the aorta and the level at the intervertebral foramen were also evaluated.

Two MRA readers independently judged all images according to these criteria to detect the artery of Adamkiewicz and determine the branching levels; disagreements about any aspect, i.e., branching level, side of origin [laterality], or number of vessels, were settled by consensus.

Statistical analysis

Detectability of the artery of Adamkiewicz was compared between the patients with aneurysm versus those with dissection by Mann-Whitney U test. $P<0.05$ was considered significant (StatView ver 4.58; Abacus Concepts Inc., Berkeley, CA, USA).

Results

The artery of Adamkiewicz was detected in 67 (81.7%) of the 82 patients. All of those 67 had vessels that coursed toward the anterior spinal cord and were supplied by the intercostal artery (Fig. 1). Branching of the artery of Adamkiewicz occurred either on the left side of the body (n = 52; 77.6%) at T7 (n = 6), T8 (n = 5), T9 (n = 13), T10 (n = 19), T11 (n = 7), or T12 (n = 2) or on the right side (n = 15; 22.4%) at T7 (n = 1), T8 (n = 2), T9 (n = 7), T10 (n = 1), T11 (n = 3), or T12 (n = 1) (Fig. 2).

The artery of Adamkiewicz was detected clearly along its entire course (starting with feeding arteries branching from the aorta and ultimately feeding into the anterior spinal artery) in 55 (67.1%) of the 82 patients, with aneurysm diagnosed in 44/55 patients (80.0%) and dissection in 21/25 (84.0%). Branching of the intercostal artery from the aorta occurred on the left side of the body at T7 (n = 3), T8 (n = 4), T9 (n = 10), T10 (n = 17), or T11 (n = 7), on the right side at T8 (n = 1), T9 (n = 5), T10 (n = 2), T11 (n = 3), or T12 (n = 1), or as an anastomosis at T10–11 (n = 2). There was no statistical difference in the rate of detecting the artery of Adamkiewicz between the patients with aneurysm and with

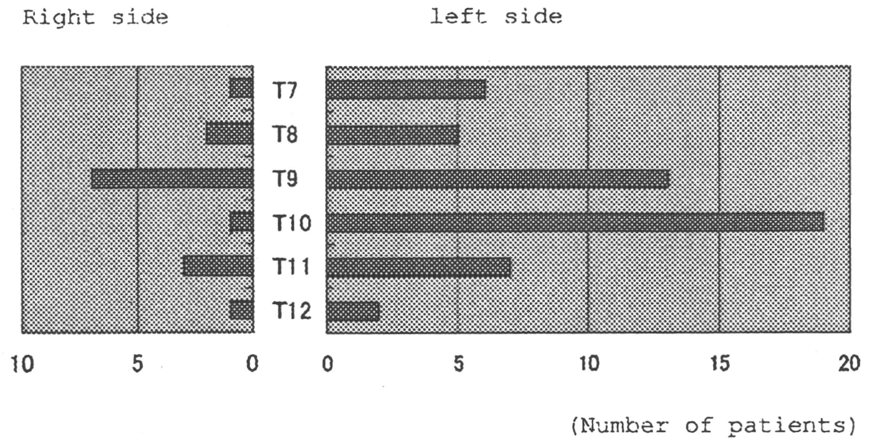

Fig. 2. Frequencies of the vertebral level of arterial branching and of the laterality of the artery of Adamkiewicz in 67 patients.

dissection ($P=0.673$). No cases of collateral blood supply to the artery of Adamkiewicz were found in this study.

When comparing the branching level of the artery of Adamkiewicz at the intervertebral foramen with that of its feeding artery from the aortic wall, the same vertebral level of branching was found in 44 of the 55 patients (80.0%; mean age ± standard deviation, 67.8 ± 11.4 years), and a difference of one level (above or below the other vertebral level) was detected in 10 of 55 patients (18.2%; mean age 70.5 ± 8.6 years). Only one patient (1.8%) had a difference of 2 vertebral levels between the level at the intervertebral foramen versus the level at the aortic wall (Fig. 3). No patient had compression fracture or vascular anomalies.

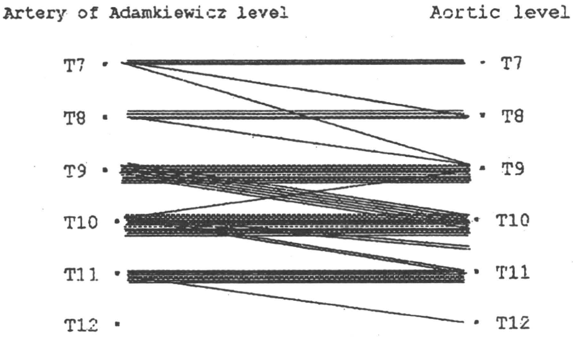

Fig. 3. Comparison of the vertebral level of arterial branching: artery of Adamkiewicz at the intervertebral foramen versus intercostal/lumbar feeding artery branching from the aorta.

Discussion

The artery of Adamkiewicz can now be detected noninvasively with MR angiography.[4,5,10-13] The use of these imaging techniques for preoperative analysis and surgical planning enables selective reconstruction of the feeding radiculomedullary artery.[4,5,14] However, it is difficult to reconstruct the artery of Adamkiewicz itself because of its small size (about 0.5 mm in diameter) and its branching from the intercostal/lumbar artery at the intervertebral foramen. Therefore, in the surgical approach, 2 methods are used to maintain the blood flow to the artery of Adamkiewicz. First is to reconstruct the intercostal/lumbar artery feeding the blood flow to the artery of Adamkiewicz, which is the method used when its branching origin is within the vertebral level of the aortic graft replacement. The other method is to adjust the cross-clamping level according to the vertebral level to maintain the flow to the artery of Adamkiewicz, which is used when its branching level is above/below the aortic graft replacement level.

In our review of the literature, we found no report discussing the difference in branching level between the artery of Adamkiewicz at the intervertebral foramen and the feeding artery originating from the aortic wall. In this study, we detected the same vertebral level of branching in 80.0% and a difference of only one vertebral level in 18.2%.

In patients in whom MRA could detect the entire trajectory of the artery of Adamkiewicz and its feeding arteries from the aorta, the critical intercostal/lumbar arterial reconstruction proved adequate to maintain the blood flow to the spinal cord. However, the overall rate of detection of the artery of Adamkiewicz was limited to 81.7% of patients, and we were able to evaluate the entire continuity of the vasculature from the aorta to the anterior spinal artery in only 67.1%. We considered 4 factors that might affect the branching level difference: aortic elongation, decreasing vertebral height, vascular formative anomalies, and collateral supply. In our case series, there was no evidence of vertebral compression nor vascular formative anomalies. The group of patients with a different vertebral level of branching had a slightly higher mean age than those with the same branching level, but this difference was not statistically significant. We hypothesized that aortic elongation is the factor most likely to affect the branching level and thus contribute to a difference in the branching level in individual patients.

Our study limitations included difficulties in detecting all collateral arteries feeding into the artery of Adamkiewicz because of the limited FOV and difficulties in differentiating this artery from veins. Collateral arteries feeding into the artery of Adamkiewicz may enhance the detection of the arterial vasculature branching from the aorta. It is still controversial that the collateral vessels can feed blood into the spinal cord,[13,15] and occlusion of the artery of Adamkiewicz may not be the only causative factor affecting spinal ischemia.[16] However, actual cases of spinal cord ischemia after endovascular repair of the aorta continue to be reported,[17] and increase in biochemical markers of ischemic spinal cord injury was documented in an experimental canine study of stent-graft implantation at a critical aortic segment.[18] Our study demonstrated that the artery of Adamkiewicz can be detected at a high rate preoperatively, allowing evaluation of the risk of occlusion of this artery, which could affect the likelihood of spinal complications.

We used a double dose of contrast to visualize the artery of Adamkiewicz. According to recent reports, nephrogenic systemic fibrosis can develop and cause severe damage in patients with renal insufficiency who undergo contrast-enhanced MR imaging,[19,20] so use of a high dose of contrast has a disadvantage in terms of patient safety. However, in our study population, no patient had renal insufficiency and no case of nephrogenic systemic fibrosis was reported in the follow-up period. It has been shown that the renal artery can still be detected without contrast enhancement.[21] Using this MRA technique with high spatial resolution, the artery of Adamkiewicz could potentially be detected without contrast enhancement. Further evaluation will be needed to demonstrate useful noncontrast MRA in patient with severe renal damage.

Conclusions

Double-subtraction MRA is a useful noninvasive technique for detecting the artery of Adamkiewicz and the vertebral level of its feeding arteries branching from the aorta. Using this information to plan surgical strategy, it is possible to reconstruct the artery of Adamkiewicz to reduce the risk of spinal complications. In particular, for clinical use in patients with thoracoabdominal aortic lesions, MRA can be included in the preoperative work-up to localize the segmental trajectories of vessels supplying blood to the artery of Adamkiewicz.

Acknowledgments

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References

1. Coselli JS, LeMaire SA, Miller CC 3rd, et al. Mortality and paraplegia after thoracoabdominal aortic aneurysm repair: a risk factor analysis. Ann Thorac Surg 2000; 69:409–414.
2. Estrera AL, Miller CC 3rd, Huynh TT, Porat E, Safi HJ. Neurologic outcome after thoracic and thoracoabdominal aortic aneurysm repair. Ann Thorac Surg 2001; 72:1225–1230.
3. Cambria RP, Clouse WD, Davison JK, Dunn PF, Corey M, Dorer D. Thoracoabdominal aneurysm repair: results with 337 operations performed over a 15-year interval. Ann Surg 2002; 236:471–479.
4. Kawaharada N, Morishita K, Fukada J, et al. Thoracoabdominal or descending aortic aneurysm repair after preoperative demonstration of the Adamkiewicz artery by magnetic resonance angiography. Eur J Cardiothorac Surg 2002; 21:970–974.
5. Hyodoh H, Kawaharada N, Akiba H, et al. Usefulness of preoperative detection of artery of Adamkiewicz with dynamic contrast-enhanced MR angiography. Radiology 2005; 236:1004–1009.
6. Greenberg R, Resch T, Nyman U, et al. Endovascular repair of descending thoracic aortic aneurysms: an early experience with intermediate-term follow-up. J Vasc Surg 2000; 31:147–156.
7. Hyodoh H, Shirase R, Akiba H, et al. Double-subtraction maximum intensity projection MR angiography for detecting the artery of Adamkiewicz and differentiating it from the drainage vein. J Magn Reson Imaging 2007; 26:359–365.
8. Huang Y, Webster CA, Wright GA. Analysis of subtraction methods in three-dimensional contrast-enhanced peripheral MR angiography. J Magn Reson Imaging 2002; 15:541–550.
9. Watanabe Y, Dohke M, Okumura A, et al. Dynamic subtraction contrast-enhanced MR angiography: technique, clinical applications, and pitfalls. Radiographics 2000; 20:135–152.

10. Yamada N, Takamiya M, Kuribayashi S, Okita Y, Minatoya K, Tanaka R. MRA of the Adamkiewicz artery: a preoperative study for thoracic aortic aneurysm. J Comput Assist Tomogr 2000; 24:362–368.
11. Yoshioka K, Niinuma H, Ohira A, et al. MR angiography and CT angiography of the artery of Adamkiewicz: noninvasive preoperative assessment of thoracoabdominal aortic aneurysm. Radiographics 2003; 23:1215–1225.
12. Nijenhuis RJ, Jacobs MJ, van Engelshoven JM, Backes WH. MR angiography of the Adamkiewicz artery and anterior radiculomedullary vein: postmortem validation. AJNR Am J Neuroradiol 2006; 27:1573–1575.
13. Backes WH, Nijenhuis RJ, Mess WH, Wilmink FA, Schurink GW, Jacobs MJ. Magnetic resonance angiography of collateral blood supply to spinal cord in thoracic and thoracoabdominal aortic aneurysm patients. J Vasc Surg 2008; 48:261–271.
14. Kawaharada N, Morishita K, Hyodoh H, et al. Magnetic resonance angiographic localization of the artery of Adamkiewicz for spinal cord blood supply. Ann Thorac Surg 2004; 78:846–851.
15. Yoshioka K, Niinuma H, Kawazoe K, Ehara S. Three-dimensional demonstration of the Adamkiewicz artery and its collateral supply with contrast-enhanced magnetic resonance angiography. Eur J Cardiothorac Surg 2004; 26:440–441.
16. Etz CD, Halstead JC, Spielvogel D, et al. Thoracic and thoracoabdominal aneurysm repair: is reimplantation of spinal cord arteries a waste of time? Ann Thorac Surg 2006; 82:1670–1677.
17. Kawaharada N, Morishita K, Kurimoto Y, et al. Spinal cord ischemia after elective endovascular stent-graft repair of the thoracic aorta. Eur J Cardiothorac Surg 2007; 31:998–1003.
18. Bashar AH, Suzuki K, Kazui T, et al. Changes in cerebrospinal fluid and blood lactate concentrations after stent-graft implantation at critical aortic segment: a preliminary study. Interact Cardiovasc Thorac Surg 2008; 7:262–266.
19. Cowper SE, Robin HS, Steinberg SM, Su, LD, Gupta S, LeBoit PE. Scleromyxoedema-like cutaneous diseases in renal-dialysis patients. Lancet 2000; 356:1000–1001.
20. Collidge TA, Thomson PC, Mark PB, et al. Gadolinium-enhanced MR imaging and nephrogenic systemic fibrosis: retrospective study of a renal replacement therapy cohort. Radiology 2007; 245:168–175.
21. Utsunomiya D, Miyazaki M, Nomitsu Y, et al. Clinical role of non-contrast magnetic resonance angiography for evaluation of renal artery stenosis. Circ J 2008; 72:1627–1630.

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ORIGINAL ARTICLE

Endovascular stent-grafting of anastomotic pseudoaneurysms following thoracic aortic surgery

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Abstract
Purpose. Anastomotic pseudoaneurysm is a rare but life-threatening complication after thoracic aortic surgery. Endovascular stent-grafting is a less invasive treatment for thoracic aortic aneurysm; however, its clinical usefulness for anastomotic pseudoaneurysms following thoracic aortic surgery is unclear.
Methods. A series of 12 anastomotic pseudoaneurysms in 10 patients, which occurred following thoracic aortic surgery, underwent endovascular stent-grafting in our university hospital. Eight emergent endovascular stent-grafting cases were included in this study. A hand-made stent-graft, reconstructed by suturing graft material to an endoskeleton of modified Gianturco Z stents, was used in all cases.
Results. The delivery success rate was 91.7%, and the hospital mortality rate was 25.0%. Two cases were converted to open surgery during the postoperative phase because of a type I endoleak. Complete absorption or shrinkage of the anastomotic pseudoaneurysm was observed in seven of nine cases.
Conclusion. Endovascular stent-grafting for patients with anastomotic pseudoaneurysms of the thoracic aorta following thoracic aortic surgery has become a possible optimal treatment. However, long-term outcome remains unclear, and periodical follow-up is required.

Key words Endovascular stent-grafting · Anastomotic pseudoaneurysm · Thoracic aortic surgery

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Introduction

Anastomotic pseudoaneurysm is a rare but fatal complication after thoracic aortic surgery. Both asymptomatic and symptomatic cases, which present with hemosputum, hemoptysis, or hematemesis, expand with time unpredictably and result in rupture. Therefore, precise diagnosis and prompt surgical management are required. However, the conventional surgical repair is fraught with a risk of complications and even death. To avoid the morbidity and mortality associated with redo thoracic surgery, endovascular stent-grafting, which is a less invasive procedure, has been introduced. The aims of this study are to review the outcome of endovascular repair for anastomotic pseudoaneurysms following thoracic aortic surgery and to assess whether this procedure can be a treatment of choice.

Materials and methods

Patient population

From December 2001 to September 2007, a total of 232 cases of thoracic aortic aneurysm subjected to endovas-

Table 1 Patients' characteristics

No.	Age (years)/sex	Symptom	Primary disease	Initial surgery	Years to presentation
1	59/M	Hemoptysis	A-TAA	Descending aorta graft replacement	9.0
	63	Hemoptysis			13.0
2	17/M	No	CoA	Direct suture	11.6
3	75/M	No	A-TAA	Patch plasty	17.9
4	54/M	No	D-TAA	Total arch graft replacement	0.7
5	70/M	Hematemesis, shock	A-TAA	Total arch graft replacement	9.0
6	72/M	Hemosputum	A-TAA	Descending aorta graft replacement	6.0
	74	No			7.4
7	78/M	Hemoptysis, shock	D-TAA	Descending aorta graft replacement	13.0
8	73/M	Hemosputum	A-TAA	Total arch graft replacement	6.0
9	80/M	Hemosputum	A-TAA	Descending aorta graft replacement	6.6
10	68/M	No	A-TAA	Total arch graft replacement	12.0

A-TAA, atherosclerotic thoracic aortic aneurysm; CoA, coarctation of the aorta; D-TAA, dissecting aortic aneurysm

Table 2 Stent-grafting procedures: type and outcome

No.	Access artery	Type of stent-graft	Postoperative complication	Mortality	Primary endoleak	Course of pseudoaneurysm
1	Femoral a.	Nonfenestrated	None		No	Absorption
	Femoral a.	Nonfenestrated	ARDS		No	Shrinkage
2	Femoral a.	Fenestrated	None		No	Absorption
3	Femoral a.	Nonfenestrated	None		No	Enlargement
4	Femoral a.	Nonfenestrated	None		No	Shrinkage
5	Femoral a.	Nonfenestrated	—	1 Day (hemorrhagic shock)	—	—
6	Femoral a.	Nonfenestrated	None		No	Shrinkage
	Femoral a.	Fenestrated	None	3 Months (mediastinitis)	Type I	—
7	Iliac a.	Fenestrated	Acute renal failure	21 Days (rupture)	Type I	—
8	Femoral a.	Fenestrated	ARDS		No	No change
9	Iliac a.	Nonfenestrated	Accessed artery injury		No	Shrinkage
10	Femoral a.	Nonfenestrated	None		No	Absorption

ARDS, acute respiratory distress syndrome

cular stent-grafting in our university hospital were reviewed. Among them, 12 cases (5.2%) in 10 patients with anastomotic pseudoaneurysms that developed after thoracic aortic surgery were included as subjects in this study. The patients' characteristics are shown in Table 1. The mean age was 65.3 years, and 9 of 10 patients were male (90.0%). Patients 1 and 6 had pseudoaneurysms at both proximal and distal anastomotic sites that had occurred at different times. Five cases were asymptomatic and were treated electively. The clinical presentations of the cases treated emergently were hemosputum in three cases, hemoptysis in three cases, and hematemesis in one case. The mean time interval between the original procedure and the diagnosis of anastomotic pseudoaneurysm was 9.3 years (range 8 months to 17.9 years).

Stent-grafting procedure

Stent-grafting was performed under general anesthesia. Basically, the 20 F or 22 F delivery sheath was inserted from the common femoral artery (Table 2). In two patients (cases 7, 9), the femoral artery was too small to accommodate the delivery sheath; hence, a retroperitoneal incision was performed to insert the delivery sheath via the iliac artery. In the event that a stent-graft was placed on a proximal portion of the aortic arch, a fenestrated stent-graft was employed to preserve adequate blood flow to the brain (cases 2, 6, 7, 8). A hand-made stent-graft, which was reconstructed by suturing graft material (Ube Corp., Ube, Japan) to an endoskeleton of modified Gianturco Z stents (Cook, Bloomington, IN, USA), was used in all cases. It took 20–60 min to con-

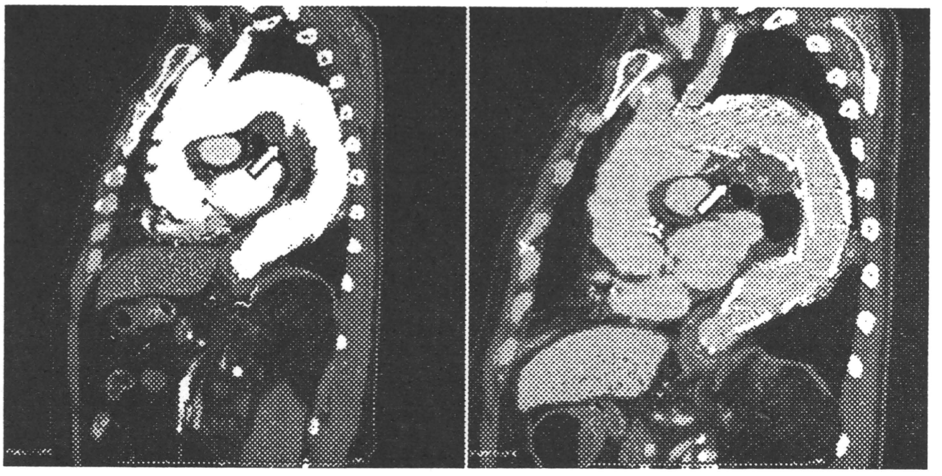

Fig. 1 *Left* Preoperative enhanced computed tomography (CT) shows that the anastomotic pseudoaneurysm occurred at the proximal descending aorta (*white arrow*). *Right* Postoperative enhanced CT shows the detached stent-graft from the proximal landing zone and type I endoleak in the aneurysm sac

struct a stent-graft for emergency use, depending on the complexity of the pseudoaneurysm. During deployment of the stent-graft, distal migration was prevented either by lowering systolic arterial blood pressure to 80 mmHg through intravenous administration of nicardipine hydrochloride or by inducing temporary cardiac arrest for several seconds through rapid intravenous administration of adenosine triphosphate disodium (ATP). This procedure, using stent-grafts made in-house, has been approved by the Ethics Committee at our institution. Written, informed consent for this procedure was obtained from the patients or their families.

Patient follow-up

Enhanced computed tomography (CT) was performed 1 week after stent-grafting if the patients' renal function was normal. After discharge, the patients were followed up within 2 weeks to assess the incision sites and overall health status. CT was usually obtained 6 months after stent-grafting and yearly thereafter.

Results

Early results

A stent-graft was deployed in 11 of 12 cases (91.7%). There was only one failure of deployment, which occurred in patient 5, who died of hemorrhagic shock related to an aortoesophageal fistula in the operating room. Massive bleeding could not be controlled by emergency endovascular stent-grafting. Hospital mortality rate was 25.0%. Two other patients (6, 7) died postoperatively while in the hospital. Patient 7, with hemorrhagic shock from hemoptysis related to an aortobronchial fistula, underwent emergent endovascular stent-grafting, and temporary hemostasis was achieved. Postoperative enhanced CT revealed type I endoleak from the proximal landing zone. However, conversion to open thoracic surgery could not be tolerated owing to the poor condition of the patient. He subsequently died of a ruptured aneurysm 3 weeks after the procedure. Patient 6, diagnosed with a proximal anastomotic pseudoaneurysm in the distal aortic arch 7.4 years after initial surgery (Fig. 1), then underwent elective endovascular stent-grafting. Postoperative enhanced CT showed detachment of the stent-graft to the proximal landing zone and type I endoleak in the aneurysm sac. Open conversion was readily conducted. However, his general condition did not improve postoperatively and he died of mediastinitis 2 months after the surgery.

Postoperative complications are shown in Table 2. Two patients suffered from respiratory failure, and one patient incurred injury of the accessed artery. Patient 7 had acute renal failure, and temporary hemodialysis was initiated.

Midterm results

The mean follow-up period was 22.8 months. Seven patients are currently alive. Only one patient (case 3) required open conversion. Patient 3 was diagnosed with a pseudoaneurysm about 18 years after patch plasty for a descending thoracic aortic aneurysm and underwent elective endovascular stent-grafting. There was no endoleak in the postoperative evaluation. However, enhanced CT 6 months later revealed the presence of an endoleak from the pseudoaneurysm (Fig. 2). Further enhanced CT 18 months postoperatively demonstrated

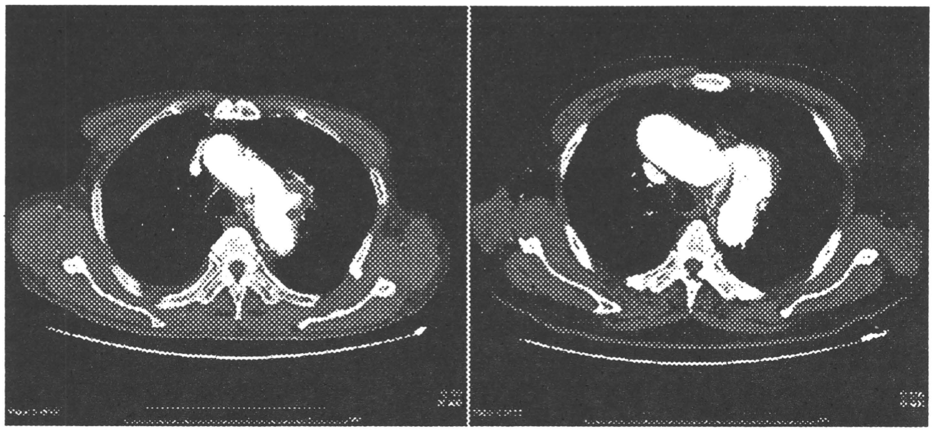

Fig. 2 *Left* Enhanced CT revealed that the endoleak was encountered in the pseudoaneurysm 6 months after endovascular stent-grafting. *Right* At 18 months after the operation, enhanced CT demonstrated that the pseudoaneurysm was extremely dilated and the stent-graft had migrated into it

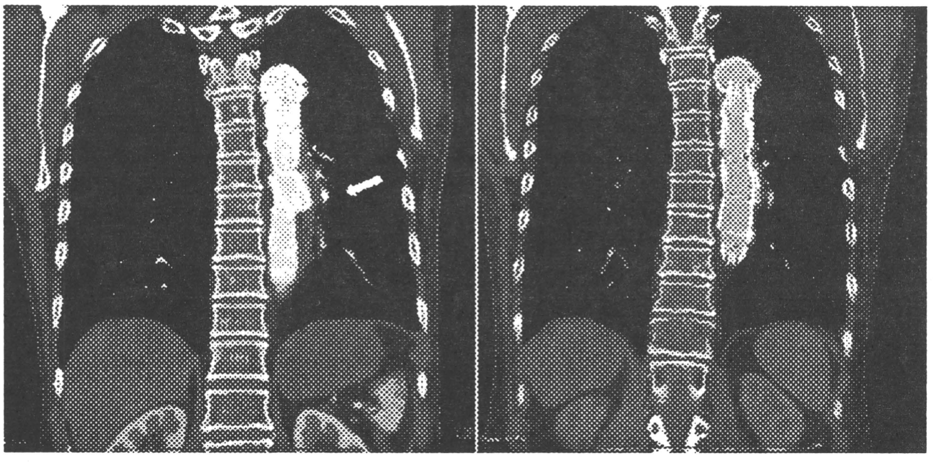

Fig. 3 *Left* Enhanced CT revealed that the distal edge of the stent-graft was protruding from the descending aorta (*white arrow*) and was located distal to the site of anastomosis of prior graft replacement. *Right* At 6 months after the operation, enhanced CT showed that the distal anastomotic pseudoaneurysm was obliterated

a widely dilated pseudoaneurysm and the stent-graft had migrated into it. Graft replacement of the total aortic arch was performed, and the postoperative course was uneventful.

The complete absorption or shrinkage of pseudoaneurysms was observed in seven of nine cases during the follow-up period.

Pseudoaneurysm possibly induced by stent-graft

A 63-year-old man (case 1) was admitted to our university hospital for hemoptysis. Four years prior to admission, he had undergone endovascular stent-grafting for a proximal anastomotic pseudoaneurysm following graft replacement of the descending thoracic aorta. Enhanced CT revealed the distal edge of the stent-graft protruding from the descending thoracic aorta, which was located distal to the anastomotic site prior to graft replacement (Fig. 3). Emergent endovascular stent-grafting was performed at the site of the distal anastomosis. Enhanced CT 6 months postoperatively showed a well-absorbed distal anastomotic pseudoaneurysm.

Discussion

Anastomotic pseudoaneurysm is a rare[1] but life-threatening complication after thoracic aortic surgery. Once diagnosed, it must be treated promptly. However, the morbidity and mortality of conventional surgical repair is still high.[1] Many promising results of endovascular repair on arteriosclerotic thoracic aortic aneurysms have been reported.[2,3] It is reasonable, then, that the endovascular repair is being considered as an essential treatment for anastomotic pseudoaneurysm. In fact, good results of endovascular repair for anastomotic pseudoaneurysm following an abdominal aortic surgery[4] and surgical repair of congenital aortic coarctation[5] were reported recently. In like manner, Wheatley et al. described three cases of successful endovascular repair of anastomotic pseudoaneurysms after thoracic aortic surgery.[6] Since 2002, when endovascular stent-grafts became available in our hospital, endovascular stent-grafting has become an essential therapy for patients with anastomotic pseudoaneurysm following thoracic aortic surgery because it is a less invasive procedure and redo thoracic aortic surgery can be avoided. If endovascular stent-grafting is not successful, open conversion can be performed. The stent-graft can prevent massive bleeding due to rupture of the aneurysm during division of the adhesion around the anastomotic pseudoaneurysm.

Technically, there is no major difference in treating anastomotic pseudoaneurysm versus the usual thoracic aortic aneurysm by endovascular stent-grafting. We had enough time to prepare hand-made stent-grafts, and the patients' conditions were almost stable. In detail, the length of the stent-graft deployed for anastomotic pseudoaneurysm is structurally shorter than that for the usual thoracic aortic aneurysm because it has to exclude only the disruption of the anastomosis between the aorta and the vascular prosthesis. We used hand-made stent-grafts for all cases in this study because construction of suitable forms for the patients' aortic dimensions was convenient. Moreover, fenestrated hand-made stent-grafts can preserve adequate blood flow to the brain. On the other hand, the quality of hand-made stent-grafts may not be uniform. A commercial stent-graft system has been available in Japan since 2008; hereafter, it will be applied for the treatment of anastomotic pseudoaneurysms as well as thoracic aortic aneurysms.

Among our 12 cases, 7 were symptomatic; thus, an emergent operation was done. Five of seven patients, who had not been on preoperative shock status, underwent successful emergent stent-grafting without endoleak. These results suggest that endovascular stent-grafting can be safely performed even during emergency conditions. Furthermore, patients with preoperative shock status can rarely be saved by either conventional open surgery or endovascular stent-grafting. However, patient 7 temporarily held on after hemorrhagic shock with endovascular stent-grafting, suggesting application of the procedure as a temporary treatment to achieve hemodynamic stability and as a bridge treatment to open thoracic surgery.

Anastomotic pseudoaneurysms are sometimes associated with infection. Therefore, endovascular stent-grafting remains controversial because there has been concern about persistent infection when the stent-graft is placed in the infected field. Kan et al. reviewed the outcome after endovascular stent-grafting for 48 mycotic aortic aneurysms.[7] The review showed that persistent infections occurred in 11 patients (22.9%). The 30-day and 2-year survival rates were 89.6% and 82.2%, respectively. They also concluded that persistent infection after endovascular stent-grafting was closely associated with a poor prognosis and that rupture of the aneurysm and fever at the time of the operation were identified as the most significant variables associated with persistent infection.

We basically excluded patients with anastomotic pseudoaneurysms caused by infection as candidates for endovascular stent-grafting. In fact, not one of the patients with an anastomotic pseudoaneurysm in our study manifested positive bacteriology culture, fever at the time of operation, or a local abscess around the pseudoaneurysm—to which we attributed our successful midterm results.

Aortobronchial fistula can induce infection per se by virtue of bronchial contamination. However, the outcome of endovascular stent-grafting for aortobronchial fistula was unexpectedly good. Wheatley reported that seven patients with aortobronchial fistula were successfully treated with endovascular stent-grafting, and the survival rate was 100% at 1 year.[6] A review of the literature also showed 30-day mortality of 8.3% for 36 cases of aortobronchial fistula. In our study, aortobronchial fistula was strongly suspected in three cases (patients 1, 7, 8). Except for patient 7, who died of a ruptured aneurysm 3 weeks after endovascular stent-grafting, three other patients are currently alive without occurrence of infection. It is unclear as to why the infection rate for endovascular stent-grafting is so low, but we considered that it might be due to the significant advantages of endovascular stent-grafting over open thoracic surgery: A large skin incision, extracorporeal circulation, interference with respiratory function, and massive blood transfusion are avoided.

The complete absorption or shrinkage of the pseudoaneurysm was observed in seven of nine patients during the follow-up period in this study. Only one patient (case 3) required conversion to open thoracic surgery due to enlargement of the pseudoaneurysm. This failure was possibly caused by a short proximal landing zone, leading to migration of the stent-graft into the anastomotic pseudoaneurysm. The use of a nonfenestrated stent-graft in case 3 is one of the reasons that the length of the proximal landing zone was insufficient. Moreover, the initial operation on patient 3 was patch plasty for a saccular type of thoracic aortic aneurysm. Both proximal and distal landing zones were composed of the native aorta, which was dilated during the follow-up period. Usually, either the proximal or distal landing zone of the anastomotic pseudoaneurysm is a vascular prosthesis sufficient in length and quality for attaching the stent-graft and is not dilated, causing detachment of the stent-graft. Furthermore, anastomotic pseudoaneurysms do not have any vessels with retrograde blood flow causing type II endoleak.[8] These factors may contribute to successful midterm results as well.

Spinal cord ischemia, which manifests as paraplegia or paraparesis, is one of the severe complications after endovascular stent-grafting in the thoracic aorta. We previously reported that prior aortic surgery was identified as a significant risk factor for spinal cord ischemia.[9] Based on our data, patients in this study must be at high risk for spinal cord ischemia because every patient with anastomotic pseudoaneurysm underwent open aortic surgery. In fact, we did not utilize spinal cord protection with spinal drainage or maintain a high systolic blood pressure; and there were no postoperative neurological complications, such as paraplegia or paraparesis in our study. The probable reason is the short length of the native aorta covered with the stent-graft.

Previous literature reported the formation of a false aneurysm at the proximal or distal end of a stent-graft.[10–12] This complication is thought to be attributed to weakness of the aortic wall, mechanical injury during balloon dilatation, or the mechanical stimulus of the stent-graft. We conducted 232 cases of endovascular stent-grafting for thoracic aortic aneurysms in our university hospital, and pseudoaneurysm induced by endovascular stent-grafting was first encountered in patient 1 only. The location of the distal end of the stent-graft at the anastomotic site may have caused the occurrence of stent-graft-induced pseudoaneurysm formation.

Conclusion

We undertook 12 cases of endovascular stent-grafting in patients with an anastomotic pseudoaneurysm of the thoracic aorta. Although the number of cases is small, no postoperative severe complications were encountered, and the midterm result was satisfactory. It is thought that endovascular stent-grafting is the optimal treatment for patients with anastomotic pseudoaneurysms of the thoracic aorta following thoracic aortic surgery. However, periodic follow-up is a requisite for anticipating possible complications during the late postoperative phase.

References

1. Carrel T, Pasic M, Jenni R, Tkebuchava T, Turina MI. Reoperations after operation on the thoracic aorta: etiology, surgical techniques, and prevention. Ann Thorac Surg 1993;56:259–69.
2. Czerny M, Grimm M, Zimpfer D, Rodler S, Gottardi R, Hutschala D, et al. Results after endovascular stent graft placement in atherosclerotic aneurysms involving the descending aorta. Ann Thorac Surg 2007;83:450–5.
3. Riesenman PJ, Farber MA, Mendes RR, Marston WA, Fulton JJ, Mauro M, et al. Endovascular repair of lesion involving the descending thoracic aorta. J Vasc Surg 2005;42:1063–74.
4. James HM, Kathryn GD, Neil ES, Ali M, Zvonimir K. Endovascular repair of paraanastomotic aneurysms after aortic reconstruction. Tex Heart Inst J 2007;34:148–53.
5. Marcheix B, Lamarche Y, Perrault P, Cartier R, Bouchard D, Carrier M, et al. Endovascular management of pseudoaneurysms after previous surgical repair of congenital aortic coarctation. Eur J Cardiothorac Surg 2007;31:1004–7.
6. Wheatley GH, Nunez A, Preventza O, Ramaiah VG, Rodriguez-Lopez JA, Williams J, et al. Have we gone too far? Endovascular stent-graft repair of aortobronchial fistulas. J Thorac Cardiovasc Surg 2007;133:1277–85.
7. Kan CD, Lee HL, Yang YJ. Outcome after endovascular stent graft treatment for mycotic aortic aneurysm: a systemic review. J Vasc Surg 2007;46:906–12.
8. Marty B, Sanchez LA, Ohki T, Wain RA, Faires PL, Cynamon J, et al. Endoleak after endovascular graft repair of experimental aortic aneurysms: does coil embolization with angiographic "seal" lower intra-aneurysmal pressure? J Vasc Surg 1998;27:454–62.
9. Kawaharada N, Morishita K, Kurimoto Y, Hyodoh H, Ito T, Harada R, et al. Spinal cord ischemia after elective endovascular stent-graft repair of the thoracic aorta. Eur J Cardiothorac Surg 2007;31:998–1003.
10. Nishibe T, Moto A, Kondo Y, Sato M, Ando M. False aneurysm formation at proximal and distal ends of a stent graft: a rare complication in the repair of endovascular thoracic aortic aneurysm. Int Angiol 2006;25:228–30.
11. Chen FH, Shim WH, Chang BC, Park SJ, Won JY, Lee DY. False aneurysms at both ends of descending thoracic aortic stent-graft: complication after endovascular repair of penetrating atherosclerotic ulcer. J Endovasc Ther 2003;10:249–53.
12. Kato N, Hirano T, Kawaguchi T, Ishida M, Shimono T, Yada I, et al. Aneurysm degeneration of aorta after stent-graft repair of acute aortic dissection. J Vasc Surg 2001;34:513–8.

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Examination of Intercostal Arteries with Transthoracic Doppler Sonography

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Objective: There has been no study on the measurement of blood flow of the intercostal artery (ICA) or lumbar artery (LA) with the use of transthoracic Doppler sonography. Here, the method of the ICA depiction and flow measurement were described, and we suggested the clinical usage of this method. Methods: Twelve healthy subjects were examined. The performance of transthoracic Doppler sonography was approached from the back on lateral decubitus position. The intercostal artery was depicted by two-dimension mode with color flow, and the inner diameter was measured. Peak systolic velocity (PSV), end-diastolic velocity (EDV), velocity-time integral (VTI), and heart rate (HR) were measured with pulsed Doppler, and the blood flow was calculated. Results: Bilateral ICAs and LAs from Th4 to L4 were measurable with this method. The PSV of Lt Th9 was the fastest at 43.3 ± 10.1 cm/sec and the PSV of the ICAs gradually decreased as distance from Th9 increased. As for the flow volume, the left Th11 was the greatest at 99.7 mL/min, and the flow volume of the ICA gradually decreased as distance from Th11 increased. The velocity and blood flow of right ICA tended to be lower than the left in the same spinal level. Conclusions: Evaluation technique of serial ICAs and LAs was shown. We think that it may be a clinically useful method in the study of spinal cord circulation in the repair of cases of descending thoracic or thoracoabdominal aortic aneurysm. (Echocardiography 2010;27:17-20)

Key words: posterior intercostal artery, diagnostic imaging tools, ultrasound imaging

The examination of the intercostal artery (ICA) and lumbar artery (LA) by transthoracic Doppler sonography is not a routine procedure. To date, no report about the practical applications of the method has been published. Recently, in the repair of cases of descending thoracic or thoracoabdominal aorta, the ICA that feeds the artery of Adamkiewicz (arteria radicularis magna: ARM) is being identified with the use of magnetic resonance angiography (MRA) and multidetector row CT (MDCT) for the purpose of preventing spinal cord ischemia.[1,2] However, the quantity of the blood flow has not been evaluated. The reasons for the reduction in the amount of blood flow of the ARM are potential stenosis or occlusion of the ICA for ARM due to arteriosclerosis of the aortic wall, aortic dissection, and sacrifice of the ICA for ARM during surgical repair of thoracic aneurysms. Because the ARM is a branch of the ICA or the LA, we consider that the quantity of the blood flow of the ARM could reflect the amount of blood flow to the ICA for ARM. Here, we describe the technique of examining the ICAs and LAs using noninvasive transthoracic Doppler sonography.

Material and Method:

We studied the intercostal arteries in 12 young male healthy subjects. Age, height, and weight were 26.5 ± 2.7 years, 170 ± 8.0 cm, and 67.5 ± 5.0 kg, respectively. In this study, the examination was performed using a commercially available echocardiography system. Left lateral decubitus is the most suitable position for the procedure in consideration of muscle tonus and the presence of operative wounds. Measurable ICAs and LAs are from levels Th4 to L4. Identification of ICAs can be facilitated by first locating the twelfth rib by two-dimensional mode with color flow. There is a window (Fig. 1) that is suitable for scanning at about 4 cm lateral from the midline of the back. The frequency of pulsed Doppler is from 4.5 to 6.0 MHz. Decreasing the Doppler velocity range below 20 cm/sec facilitates easier detection of ICA flow. There is usually an intercostal vein right under a rib, and there is an ICA in the tail side. Flow velocity is measured with pulsed Doppler signals. The ultrasound beam is aligned as parallel as possible to the ICA flow. The Doppler sample volume is set on the ICA as deep as possible.

Flow signals of the intercostal veins are sometimes detected simultaneously, but the said flow is

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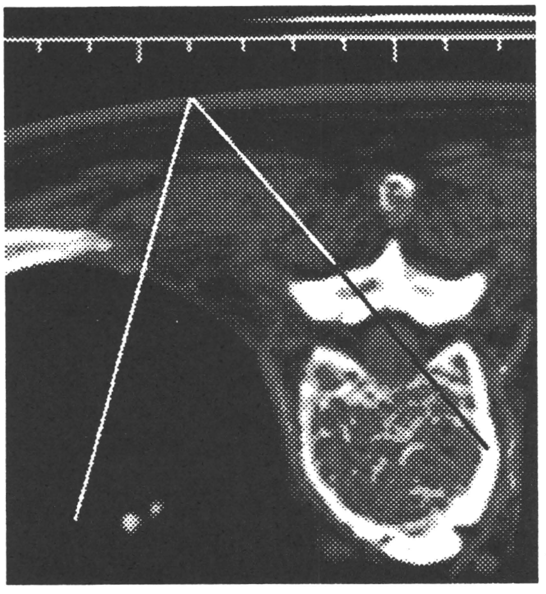

Figure 1. A suitable window for the scanning is at about 4 cm outside of the midline of the back. (Please compare it with Fig. 2.) Posterior branch of intercostal artery is diverged in the depth of about 5 cm.

distinct from the ICA because the flow pattern is different and the velocity changes with respiration. The pulsed Doppler pattern of ICA consists of systolic, dicrotic notch, and diastolic (Fig. 2). Peak systolic velocity (PSV), end-diastolic velocity (EDV), and velocity-time integral (VTI) of the ICAs are measured by pulsed Doppler in the long axis. The inner diameter is measured by color flow mode in the short axis. An estimate of the ICA flow volume is calculated from the following equation:

$$Q = (\Pi D^2 / 4)\ \text{VTI HR}$$

where Q is the flow volume, D is the inner diameter of the ICA, VTI is the velocity time integral of the ICA flow, and HR is heart rate.

Results:

In normal subjects, bilateral velocities of ICAs and LAs from Th4 to L4 levels were measurable (Table I) with pulsed Doppler. We got clear ICA images in this study population. The ultrasound beam could be aligned almost parallel to the ICA flow. Therefore, the angle correction was not necessary. Peak systolic velocity of the ICAs was shown in Figure 3. The velocity of the left Th9 was the fastest at 43.3 ± 10.1 cm/sec, and the velocity of the ICAs gradually decreased as the distance from Th9 increased. The velocity of left Th4 was 25.1 ± 5.6 cm/sec and left L4 was 23.2 ± 8.2 cm/sec. The velocity of the right ICA was slower than the left ICA at the same level. The velocity of right Th9 was the fastest in the right side at 36.8 ± 6.8 cm/sec. VTI of left Th9 was the longest at 9.5 cm, in which there was gradual reduction as the distance from Th9 increased. Inner diameter from Th8 to Th12 was larger than the other spinal levels. Inner diameter of LAs was larger than upper ICAs (Th4–7). The flow volume of the ICAs was shown in Figure 4. The left Th11 demonstrated the greatest flow volume as influenced by inner diameter and VTI, and flow volume of the ICA gradually decreased as the distance from Th11 increased (Table II). Flow volume of the right ICA was lesser than the left.

Discussions:

Ravi et al. previously reported a study on the ICA using transesophageal echocardiography.[3] In addition, there are few reports about evaluation of the ICA by sonography. Initially, the clinical significance on the measurement of the blood flow of the ICA is not appreciated. We believe that the ICA echo method may be useful for the diagnosis and prevention of spinal cord ischemia in cases of descending thoracic or thoracoabdominal aortic repair. Spinal cord injuries leading to paraplegia and paraparesis are the most devastating

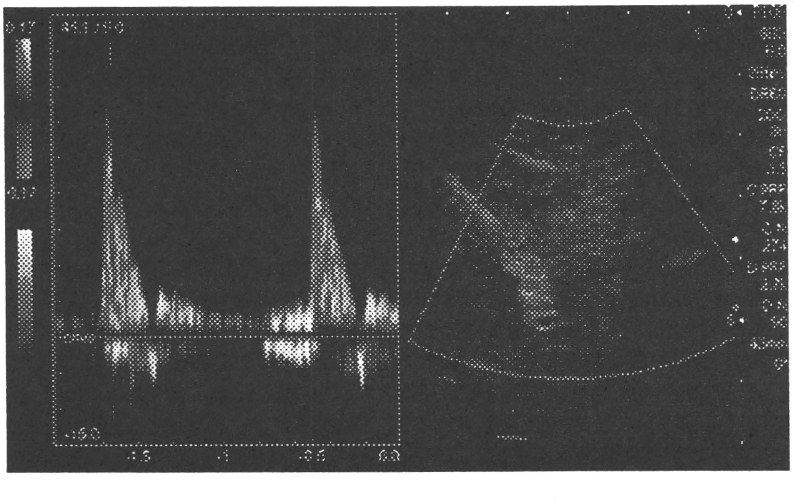

Figure 2. The image of the intercostal artery (right), and the pulsed-Doppler pattern consists of systolic, dicrotic notch, and diastolic (left).