

TABLE I
Mean Peak Systolic Velocity and End-Diastolic Velocity of Normal Intercostal Arteries

Spinal Level	Right Intercostal Artery		Left Intercostal Artery	
	PSV(cm/sec)	EDV(cm/sec)	PSV(cm/sec)	EDV(cm/sec)
Th4	22.8 ± 7.5	2.8 ± 0.7	25.1 ± 5.6	3.6 ± 1.3
Th5	22.2 ± 6.4	2.8 ± 0.7	27.6 ± 5.4	3.2 ± 1.2
Th6	26.7 ± 7.8	3.6 ± 1.0	29.8 ± 10	3.6 ± 1.2
Th7	28.7 ± 6.8	3.0 ± 0.9	32.9 ± 9.7	3.5 ± 1.4
Th8	33.4 ± 5.6	3.3 ± 1.2	38.2 ± 9.5	4.1 ± 1.0
Th9	36.8 ± 6.8	3.8 ± 1.7	43.3 ± 10.1	3.9 ± 1.3
Th10	36.5 ± 7.1	3.8 ± 1.6	40.4 ± 7.8	4.5 ± 1.4
Th11	34.5 ± 7.6	4.1 ± 2.1	40.1 ± 10.6	4.8 ± 1.8
Th12	25.5 ± 10.6	3.8 ± 1.7	31.8 ± 9.2	4.9 ± 1.7
L1	20.8 ± 6.9	2.5 ± 1.3	28.8 ± 13.7	2.9 ± 3.0
L2	20.3 ± 10.1	2.1 ± 2.3	21.4 ± 5.6	1.7 ± 1.2
L3	19.0 ± 5.3	2.1 ± 1.1	23.5 ± 13.5	1.9 ± 1.9
L4	24.3 ± 9.6	2.2 ± 2.2	23.2 ± 8.2	2.2 ± 1.6

PSV = peak systolic velocity; EDV = end-diastolic velocity.

complications, and ARM is thought to play the most important role in the pathology. Selective angiography,⁴ magnetic resonance angiography (MRA),⁵ and multidetector row CT (MD-CT)^{6,7} are reported to have practical uses in the identification of the ARM. Recently, the ICA for ARM is identified by MD-CT or MRA, and the vessel is reimplanted to prevent paraplegia due to spinal cord ischemia in descending thoracic or thoracoabdominal aortic repair.^{1,2} The successful identification frequency of ARM improves year by year and gets closer to 100%.^{1,2,4-7} However, a practical method in order to quantify the blood flow or to demonstrate the reduction in bloodstream in cases of paraplegia is currently not available. The cause of postoperative paraplegia cannot be explained with the use of CTA or MRA.

With our echo technique, the identification of each segmental artery from Th4 to L4 and the quantification of the blood flow become possible, except

the identification of the artery of ARM. However, the blood flow of the ARM can be measured indirectly granting that the ARM is initially identified by MRA or MDCT. In essence, the ICA arises from the descending aorta, and divides into the anterior and posterior branches, in which the posterior branch subdivides into the ARM. Therefore, a normal blood flow of the ICA for ARM equates to a normal blood flow of the ARM.

In physically unimpaired young persons, the blood flow of the ICA is measurable bilaterally from Th4 to L4 almost without exception. This fact means that this echo method covers all the segmental arteries, which may diverge to the ARM. In descending thoracic or thoracoabdominal aortic aneurysm patients, the frequency that the ARM diverges in left Th9 is high.^{1,2} The fact that the velocity was the fastest in Th9 is an interesting conformance. We must take this into consideration to diagnose ICA flow as normal by this Doppler technique. In other words, blood flow of the ICA will be normal when the PSV is 20 cm/sec at L1, but blood flow may be reduced when PSV is 20 cm/sec at Th9. The measurement of the flow volume by the echo is calculated with various suppositions. Flow volume is calculated by multiplication of velocity-time integral, square of inner diameter, and heart rate. Therefore, measurement error must be considered.⁸ In this study, the maximum blood flow at left Th11 was 169 mL/min and the minimum was 47 mL/min. Therefore, it is difficult to diagnose whether ICA flow is normal or not by virtue of PSV or flow volume alone. Further evaluation on qualitative analysis of the ICA is necessary.

The advantage and purpose of this ultrasound method are to examine the dynamic blood flow of sacrificed ICAs and the correlation with postoperative paraplegia from other aspects of still images of MRA or MDCT. Examining the relation between the change in ICA flow from pre- to postoperation of descending thoracic or thoracoabdominal aortic aneurysm repair and postoperative spinal cord

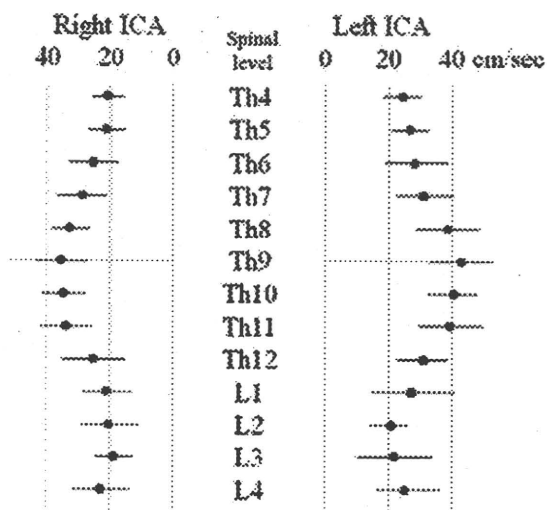


Figure 3. Peak systolic velocity of the intercostal arteries. The velocity of the left Th9 was the fastest at 43.3 10.1 cm/sec, and the velocity of the ICAs gradually decreased as the distance from Th9 increased.

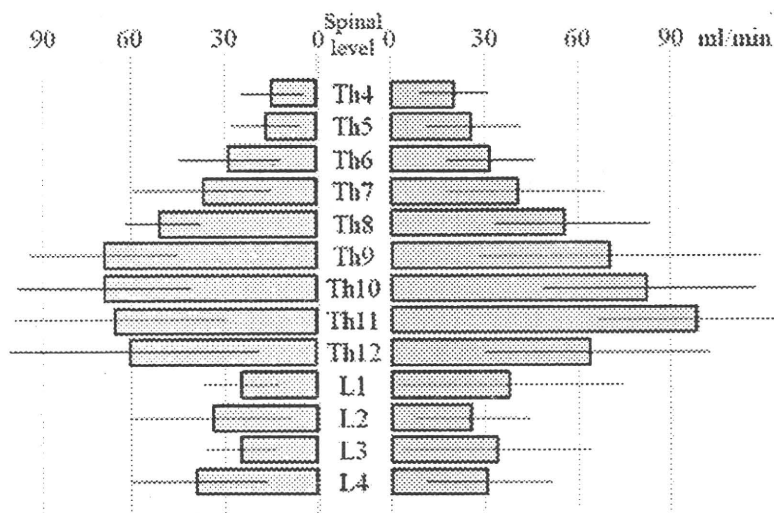


Figure 4. Flow volume of the intercostal arteries.

TABLE II

Mean VTI, Inner Diameter, and Flow Volume of Normal Intercostal Arteries

Spinal Level	Right Intercostal Arteries			Left Intercostal Arteries		
	VTI(cm)	D(cm)	Q(mL/min)	VTI(cm)	D(cm)	Q(mL/min)
Th4	5.0 ± 1.5	0.23 ± 0.04	16.3 ± 8.4	6.0 ± 1.9	0.26 ± 0.04	23.9 ± 9.8
Th5	5.5 ± 1.2	0.24 ± 0.06	19.5 ± 11.7	6.2 ± 1.9	0.27 ± 0.07	28.7 ± 14.9
Th6	6.2 ± 1.5	0.28 ± 0.06	29.8 ± 16.3	6.5 ± 1.6	0.30 ± 0.05	33.6 ± 14.3
Th7	6.5 ± 1.6	0.31 ± 0.07	39.0 ± 22.6	7.2 ± 2.0	0.32 ± 0.06	45.5 ± 25.8
Th8	7.2 ± 1.3	0.36 ± 0.03	53.4 ± 10.6	8.5 ± 1.9	0.33 ± 0.05	54.2 ± 23.3
Th9	8.2 ± 1.7	0.38 ± 0.04	69.7 ± 25.3	9.5 ± 2.9	0.36 ± 0.05	73.2 ± 46.4
Th10	8.1 ± 1.8	0.38 ± 0.04	70.0 ± 30.4	9.5 ± 1.9	0.40 ± 0.07	86.4 ± 36.2
Th11	7.7 ± 2.3	0.38 ± 0.07	65.8 ± 37.3	9.8 ± 2.6	0.42 ± 0.06	99.5 ± 33.9
Th12	6.2 ± 3.1	0.38 ± 0.09	60.6 ± 45.9	8.4 ± 2.1	0.35 ± 0.08	65.9 ± 38.1
L1	4.2 ± 2.3	0.36 ± 0.07	26.2 ± 9.0	5.8 ± 3.3	0.33 ± 0.09	42.3 ± 37.0
L2	4.0 ± 2.8	0.36 ± 0.09	34.9 ± 30.1	4.0 ± 2.2	0.33 ± 0.06	26.1 ± 19.6
L3	4.0 ± 1.4	0.33 ± 0.07	24.6 ± 11.0	4.7 ± 3.4	0.36 ± 0.08	36.8 ± 31.2
L4	4.9 ± 2.6	0.36 ± 0.09	38.2 ± 24.1	4.6 ± 2.0	0.32 ± 0.09	28.1 ± 18.0

PSV = peak systolic velocity; EDV = end-diastolic velocity; VTI = velocity-time integral; D = inner diameter of intercostal artery; Q = flow volume of intercostal artery.

ischemia may clarify the possibility of the indirect quantification of ARM flow, hence the significance of this method is elaborated. However, postoperative paraplegia or paraparesis is regarded as multifactorial⁹ and it is likely that the condition is not simply affected by the blood flow of the postoperative ARM.

Conclusions:

A new method on assessment of the intercostal artery is shown in this study. This method enabled us to quantify the intercostal artery flow, and may bring important information as regards spinal cord circulation. Further investigation about this new method will be necessary.

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Fenestrated Stent-Graft Facilitates Emergency Endovascular Therapy for Blunt Aortic Injury

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Background: Endovascular stent-grafting with intentional coverage of the left subclavian artery may be used to treat aortic isthmus injury, but this procedure may have serious neurologic sequelae and may not provide an adequate proximal landing zone. In 2005, in an effort to mitigate these problems, we began to use fenestrated stent-grafts for emergency repair of blunt aortic injury (BAI).

Methods: Between 2005 and 2007, all patients in our practice with a BAI with mediastinal hematoma (except young patients without an associated critical injury) were treated with immediate endo-

vascular stent-grafting, if anatomically possible. A fenestrated stent-graft was placed from the aortic arch, if the BAI was less than 20-mm distal of the left subclavian artery. The records of the 13 patients in the series were reviewed retrospectively.

Results: The BAI treatment was successful in all 13 patients. Eight patients (61.5%) were given a fenestrated stent-graft, placed distal to either the ascending aorta (n = 2), brachio-cephalic artery (n = 4), or left common carotid artery (n = 2), without concomitant bypass grafting or transposition of the head ves-

sels. Two patients died of an associated critical brain injury (hospital mortality rate, 15.4%). There were no perioperative complications related to stent-graft usage and no unintentional occlusions of the head vessels by a fenestrated device. One patient underwent open repair of a newly developed type Ia endoleak 7 months after placement of a nonfenestrated stent-graft.

Conclusion: Fenestrated stent-grafts can be used to treat BAI, without any concomitant procedures to provide an adequate proximal landing zone.

Key Words: Aorta, Blunt trauma, Endovascular therapy, Stent-graft, Fenestration.

J Trauma. 2009;66:974–979.

A major change in the treatment of blunt thoracic aortic injury (BAI) has occurred in the past 10 years.¹ According to a 2007 report by the multi-institutional thoracic aortic injury study group of the American Association for the Surgery of Trauma, the initial treatment for 65% of BAI cases in 2005 to 2007 was endovascular stent-graft placement rather than open surgical repair.² In addition, a recent meta-analysis of the use of stent-grafts for BAI revealed that early and mid-term results with these devices were better than those with conventional open surgery.³ However, some problems specifically associated with thoracic endovascular aortic repair (TEVAR) of BAI have been reported—difficulties that rarely occur in TEVAR in elderly patients with degenerative thoracic aortic lesions. One of these problems is that because relatively young patients are more likely to have such anatomic features as an acutely

angulated distal aortic arch⁴ and small aortic diameter, it is more difficult to ensure that the proximal landing zone for the stent-graft is sufficiently long. A few techniques for overcoming this problem have been reported, including extension of the proximal landing zone by covering the left subclavian artery (LSA) with the stent-graft^{5,6} and the “stacked” aortic cuff method, which uses commercially manufactured abdominal aortic extension cuffs.⁷ In this study, we present our endovascular procedure for BAI using a fenestrated handmade stent-graft to overcome acutely angulated short proximal landing zone.

METHODS

Use of handmade stent-grafts in TEVAR for BAI was approved by our institutional ethics committee, and written informed consent for the endovascular procedure was obtained from the family of each patient. All patients with BAI with mediastinal hematoma were considered for immediate, emergency treatment with TEVAR. In a case of blunt aortic dissection with mediastinal hematoma, an indication of TEVAR has been determined case by case considering a possible rupture of dissected aorta although a case of blunt aortic dissection was not seen in this series. Excluded from the procedure were young patients with isolated BAI, patients in whom the aortic injury was less than 15 mm from the left common carotid artery (LCCA), and patients in whom the aortic diameter at the prospective proximal or distal aortic landing zone was more than 38 mm. These patients have been considered to be candidates of open repair or combined management, such as debranching techniques.⁸ In cases in which the aortic injury

Submitted for publication September 10, 2008.

Accepted for publication November 19, 2008.

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Supported by Japan Gore-Tex, Tokyo, Japan.

Presented at the 67th Annual Meeting of the American Association for the Surgery of Trauma, September, 24–27, 2008, Maui, Hawaii.

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DOI: 10.1097/TA.0b013e31819adc68

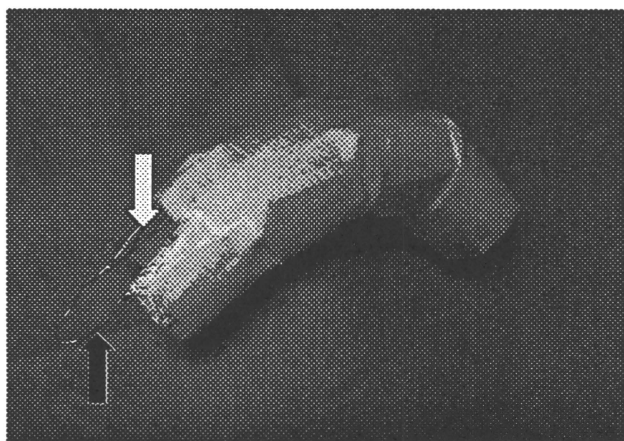


Fig. 1. A handmade stent-graft with a fenestration (white arrow) to allow preservation of blood flow into head vessels and a wire ring (black arrow) to prevent distal migration of the device during deployment.

was less than 20-mm distal of the LSA, the stent-graft was placed from the aortic arch to achieve a sufficiently long proximal landing zone. The brachio-cephalic artery (BCA) and the LCCA were preserved in all cases in which a fenestrated stent-graft was used, and the LSA was preserved in cases in which the aortic injury was more than 15 mm from the LSA.

Stent-Grafting Procedure

Handmade fenestrated (Fig. 1) and nonfenestrated stent-grafts are constructed in the operating room by suturing graft material (Ube, Ube, Japan) to modified Gianturco Z stents (Cook, Bloomington, IN). The Z-stents are attached to each other by soldering together stainless steel wires. Spaces of 8 to 15 mm are left between the stents to allow the stent-grafts to conform to the configuration of the thoracic aorta as depicted on computerized tomography (CT) images, preferably three-dimensional CT (3D-CT) images. It takes 20 to 60 minutes to construct a stent-graft, depending on the complexity of the patient's anatomy.

The TEVAR procedure is performed in an operating room equipped with a radiolucent operating table and with use of mobile digital subtraction angiography (DSA). Patients are placed under general anesthesia with intubation. The stent-graft is manually loaded into the proximal end of a 20 or 22F sheath (Cook). The delivery system is advanced over a guidewire through the femoral artery (or, rarely, the iliac artery) to the target region. The brachial guidewire technique is used to overcome unfavorable anatomic features of the iliac artery and to prevent rerupture of the aortic isthmus pseudoaneurysm. The sheath is withdrawn after the exact target location relative to the head vessels and the injured aortic segment has been confirmed by DSA. During deployment of the stent-graft, distal migration of the device is prevented either by lowering the systolic arterial blood pressure to 80 mm Hg by means of intravenous administration of nicardi-

pine hydrochloride or by inducing cardiac arrest for several seconds by means of rapid intravenous administration of adenosine triphosphate disodium.

Data Analysis

The current series includes all 13 patients who underwent TEVAR for BAI at our institution in 2005 to 2007. Data were collected retrospectively from the patients' electronic medical records and by direct communication with the patients, their families, or their referring physicians. All patients were completely followed up.

Data from individual patients were compiled and expressed as mean (\pm SD) and range values for the series. All statistical calculations were performed by using JMP5.1 statistical software (SAS Institute, Cary, NC).

RESULTS

Characteristics of the 13 patients in the series are shown in Table 1. More than half the patients had a severe brain injury, with two having an abbreviated injury score of 5. For four patients, the PS (probability of survival) was below 50%. Although all TEVAR procedures were performed on the day of admission to our institution, some were done several hours or days after the BAI occurred because of the time required for transportation from referring hospitals.

Figure 2 shows the locations of stent-graft placement. Zone 0 was distal of the ascending aorta; zone 1, distal of the BCA; and zone 2, distal of the LCCA. No concomitant bypass procedures or transpositions of the head vessels were performed in patients in whom a stent-graft was placed in zone 0, 1, or 2. Of the four patients with zone 2 stent-graft placement, two were given a fenestrated device. In three patients, a stent-graft was placed distal of the LSA. Eight of the 13 patients in the series (61.5%) were given a fenestrated stent-graft. In six of these eight patients, the LSA was preserved. In four patients in the series, the LSA was simply covered because of anatomic reasons; in two of the four, a fenestrated stent-graft was placed from zone 0, with preservation of the BCA and the LCCA (Fig. 3).

The BAI treatment was successful in all cases. However, two patients died shortly after TEVAR of brain death due to an associated critical brain injury (abbreviated injury score of 5); thus, the hospital mortality rate was 15.4%. One of the patients, a 77-year-old man who had a PS of 6%, died 23 hours after TEVAR. The other, a 30-year-old woman with a PS of 24%, died 9 days after TEVAR and external decompression for brain edema.

There were no perioperative complications related to placement of a stent-graft or coverage of the LSA. There were no unintentional occlusions of the head vessels by a fenestrated stent-graft. There is no neurologic complication including strokes and spinal cord ischemia. The mean follow-up period was 20.3 months (range, 7 to 36 months). One stent-graft-related complication occurred among the 11 patients discharged from the hospital after TEVAR. The adverse effect

Table 1 Characteristics of Patients With a Blunt Aortic Injury Treated With Stent-Grafting

Case	Age (yr)	Gender	Cause of BAI	Time (h)*	ISS	RTS	PS (%)	Fenestrated SG	LSA Preserved	Proximal Zone	Diameter of Aorta† (mm)	Diameter of SG (mm)
1	49	Male	Fall	60	29 (C4, A2, E3)	6.376	90.8	No	No	Zone 2	24	28
2	73	Female	Traffic accident	66	25 (C4, E3)	6.376	70.6	Yes	Yes	Zone 1	29	32
3	57	Male	Fall	3	29 (H3, C4, E2)	7.841	84.9	Yes	No	Zone 0	29	30
4	77	Male	Traffic accident	3	41 (H5, C4)	3.565	6.1	Yes	Yes	Zone 1	34	36
5	30	Female	Traffic accident	8	66 (H5, C5, E4)	5.967	24.3	Yes	Yes	Zone 2	20	24
6	74	Female	Traffic accident	6	36 (H4, C4, A2)	6.171	44.8	No	NA	Zone Th4	31	34
7	83	Female	Traffic accident	8	36 (H4, C4, E2)	5.439	31.0	No	NA	Zone Th4	29	30
8	51	Male	Fall	3	29 (C4, A2, E3)	7.841	97.0	No	NA	Zone Th7	29	32
9	36	Male	Traffic accident	5	36 (H4, C4, A2)	5.235	68.5	No	No	Zone 2	28	30
10	37	Male	Jet ski accident	26	25 (C4, E3)	6.376	93.2	Yes	Yes	Zone 2	25	28
11	48	Male	Traffic accident	28	25 (H3, C4)	7.108	96.1	Yes	No	Zone 0	29	30
12	41	Male	Fall	3	29 (C4, A2, E3)	7.108	94.7	Yes	Yes	Zone 2	27	30
13	66	Female	Traffic accident	4	29 (F2, C4, E3)	7.108	81.8	Yes	Yes	Zone 1	27	32
Mean	55.5 ± 17.5	8 male (61.5%)		17.2 ± 22.0	33.5 ± 11.0	6.347 ± 1.161	68.0 ± 31.1	8/13 (61.5%)	6/10 (60.0%)		27.8 ± 3.4	30.5 ± 3.0

* Indicates the time from onset to stent-grafting.

† Indicates the aorta as a proximal landing zone.

ISS, injury severity score; RTS, revised trauma score; PS, probability of survival; SG, stentgraft; NA, not applicable.

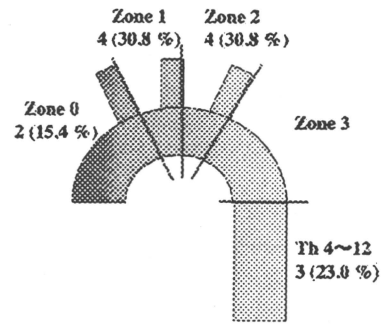


Fig. 2. Distribution of stent-graft placement locations in 13 patients with BAI. See text for a detailed description of the placement zones. Values are numbers (%) of patients. No stent-grafts were placed in zone 3.

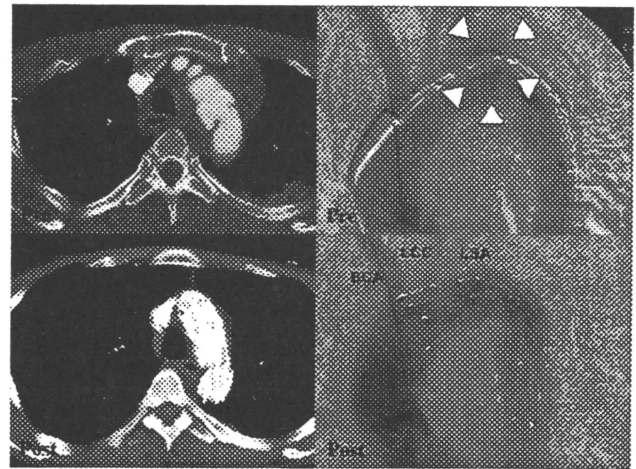


Fig. 3. CT and DSA images obtained from a patient who underwent stent-graft treatment of aortic trauma. Preoperative and postoperative CT images (left) show, respectively, a massive mediastinal hematoma and complete resolution of the hematoma. Preoperative and postoperative DSA images (right) show, respectively, the aortic injury (white arrowheads) and complete exclusion of the pseudoaneurysm resulting from the injury. In this case, the LSA was simply covered with a stent-graft, whereas the brachiocephalic (BCA) and LCCA were well preserved by placement of a fenestrated stent-graft. The LSA was seen by retrograde blood flow.

was development of a type Ia endoleak 7 months postoperatively in a 36-year-old patient in whom a nonfenestrated stent-graft was placed from zone 2 to simply cover the LSA. Complete exclusion of the aortic isthmus pseudoaneurysm was observed on postoperative CT images, but adequate conformation of the stent-graft to the inner curvature of the native aortic arch was not achieved. The patient underwent successful open repair and discharged home. However, the patient died of massive hemoptysis in his home. Exact reason of his sudden death was unclear because autopsy was not allowed. Any other death or events have not been observed during the follow-up periods.

DISCUSSION

An increasing number of cases of BAI are being treated with TEVAR.^{2,9} The early and mid-term results of this procedure are better than those of conventional open repair,³ but its long-term results remain unknown and some problems specifically associated with TEVAR for BAI have been recognized. For example, because most BAIs, reportedly more than 90%,¹⁰ occur at the aortic isthmus, endovascular exclusion of the pseudoaneurysm is highly challenging. This challenge may be further enhanced by the presence of an acutely angulated distal aortic arch,⁴ which is more likely to be present in young patients.

BAI-specific TEVAR issues have generally been addressed in one of two different ways. Previously, some authors reported that the abdominal aortic components of endografts (main-body extension cuffs) are suitable for BAI repairs in patients with an aortic diameter of less than 23 mm or a small distal arch curvature radius.⁷ However, although the use of multiple short extension cuffs may improve conformation to the distal arch curvature, the procedure has some possible risks,¹¹ including component separation and type III endoleaks. According to the 2007 American Association for the Surgery of Trauma report,² the relatively high rate (20%) of repair site complications after TEVAR for BAI may have resulted from use of the abdominal aortic cuff technique in early repairs. Currently, this method is not commonly employed because of the availability of commercially manufactured thoracic aortic endografts.

A more recently developed technique is extension of the proximal landing zone toward the LCCA, without reconstruction of the LSA, by using commercial thoracic aortic endografts.^{5,6} The goal of this procedure is to provide a proximal landing zone that is long enough to prevent type Ia endoleaks. However, simple coverage of the LSA is not always safe because the vertebral artery, as a branch of the LSA, sometimes has a critical role in the circulation to the posterior cerebral lobe, brain stem, cerebellum, and spine.¹² Previously, we found that 2 of 31 patients (6.5%) were adversely affected by an LSA balloon occlusion test.¹³ One patient lost consciousness after several seconds after LSA balloon occlusion, whereas the other had vertigo after several minutes after LSA balloon occlusion. Although a 6.5% rate of adverse effects might be considered negligible in the context of the emergency situation characteristic of BAI, preservation of the LSA is clearly preferable in all patients. Although we have no experience of transcranial Doppler¹⁴ to decide whether or not antegrade blood flow into the LSA is mandatory for the patients whose LSA has to be covered during TEVAR, the evaluation using transcranial Doppler might be helpful.

We think that a long, straight proximal landing zone is the key to successful endovascular exclusion of pseudoaneurysms resulting from BAI (Fig. 4). Moreover, even an acutely angulated distal aortic arch has a relatively straight segment. In the current series, we found that use of a fenestrated stent-graft allowed the aortic arch to be used as the proximal landing

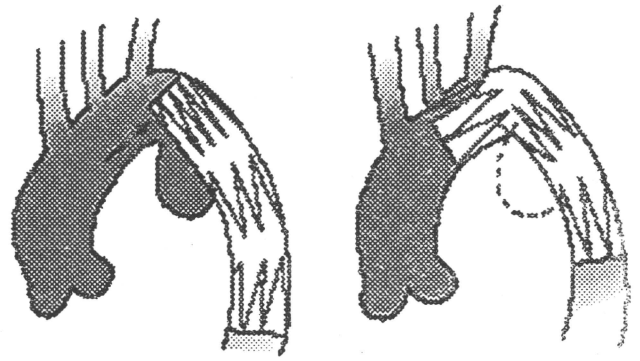


Fig. 4. Two possible placements of a stent-graft for BAI. If the stent-graft is placed just distal of the LSA (left), there is a risk of endoleak and graft collapse because of a lack of conformation to the aortic arch (arrow). If the stent-graft is placed proximal of the LSA (right), complete exclusion of a pseudoaneurysm can be expected. Referred with permission from *Circulation Up-to-Date*. 2008; 377-383.

zone, with preservation of the BCA and the LCCA. Regarding a case of 36-year-old man who required open repair 7 months after TEVAR, an acutely angulated distal aortic arch of the patient was not appropriately assessed due to unavailability of preoperative 3D-CT images. Nonfenestrated stent-grafts (Gore TAG Thoracic Endoprosthesis, WL Gore & Associates, Flagstaff, AZ) were used in the 140-patient series of Bavaria et al.,¹⁶ who observed an endoleak rate of 11% in patients in whom the devices were placed distal of zone 2 even though most subjects of the study consisted of atherosclerotic pathology which is supposed to have less-acutely angulated distal aortic arch. Therefore, a reduction in endoleaks may require extending the proximal landing zone more proximally from the LCCA. In patients with BAI, whose conditions are critical, it may be preferable to accomplish this goal by using a fenestrated stent-graft, without concomitant procedures such as head vessel debranching.

ACKNOWLEDGMENTS

The authors thank Dr. Akihito Konno, Hachinohe City Hospital, Japan, for providing perioperative CT images and Renée J. Robillard, MA, ELS, for editorial assistance.

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DISCUSSION

Dr. Aurelio Rodriguez (Pittsburgh, Pennsylvania): In order to place in perspective my two questions, allow me to in tone with the political times, my initial comments will be on experience, change. And I promise not to talk about the "bridge to nowhere" or lipsticks.

Experience. I have no experience placing an endovascular stent. As a matter of fact, I never have seen one. However, I have been personally involved in the repair of hundreds of traumatic ruptured aortas in my 22 years in Shock Trauma in Baltimore, MD.

I did it, not because I was good, but because the cardiac surgeons in those days were not interested in repairing the aorta. They were doing \$50,000 a day. They weren't interested in an aorta.

I have suffering moments and glory moments, so I can say that a stent is a gift; it came from heaven. It is a gift from heaven, really, the stents.

The endovascular stents at the beginning, as you know, they were placed. Every day they were placed in three cases here, four cases in this hospital and the other hospital.

They were removed because they were not approved. They came back. And, yes, maybe there were occlusions of the subclavian artery. Nobody talked very much about that.

So recently, the developments or the colleague from Japan have demonstrated, that a stent is unique. And I think it will be continually evolving. Hopefully, in the future the stents will replace almost all the repairs of traumatic ruptured aortas.

I have two questions. In the United States of America the stents are placed in the majority, it is my understanding by the vascular surgeons. I call it the SSS, the Secret Society of Stent.

Why do I call that? I called my vascular surgeon who puts in the stents in my hospital. He refused to talk to me. I called the hospital surgeon who put in all the stents across the river in the big university – your university.

He yelled at me and he screamed. He didn't want to give me information about it, so there is a lot of secrecy in this stent. They all claim that they publish this in some obscure journal. I never found it. Okay?

So who does the stents in Japan? The vascular surgeons? The trauma surgeons? Like our President, who went to a special course? Certainly, my hospital would not allow me to put in stents, even if I were to take a course. Okay? Who does the stents in your hospital?

And the second question is, in the land of Japan, in the land of gadgets, like Japan is, what percentage of traumatic ruptured aortas are there that do not have open repair? And what percentage are done with the stents?

The study, though, the review by Dr. Demetriades and in only 24 trauma centers, he said that 65 percent of the United States are done these days by stents.

Maybe it's true. I hope it's true. So what happens in Japan? Thank you very much for the privilege. Bail me out.

Dr. L.D. Britt (Norfolk, Virginia): I must submit that I'm violating one of the rules that I have put on myself as Program Chair never to comment during the scientific meeting and to allow the members to comment.

But I would be remiss if I did not highlight this. Is there a cohort of patients that benefit from inter-vascular stent? Yes. Is there a standard of care today? No. I want to sprinkle some caution.

We still cannot really embrace the compliance problem. Once you put in the stent you must follow these patients for life. And it's tough following trauma patients for life, Number 1.

Number 2, no one knows the durability of these grafts. You put it in a young person and they might fray in 10 or 15 years. And should they fray and you have to replace it, it's no sort of "walk in the park" to take these out and replace them.

Number 3, having just presided over the Hallstead Society as President, there was a great paper presented where they're beginning to see paraplegia in the vascular stents.

And then my last comment – and I promise I won't say any more the rest of the meeting – but the vascular surgeons, as my colleague has said, are doing most of these now because they do catheter-based management.

The cardio-vascular surgeons are walking away from even addressing this problem, which I think is a problem of

biblical proportion. And I promise not to say any more so I would love for my colleague to respond to this.

Dr. Yoshihko Kurimoto (Sapporo, Japan): Thank you for questions. In Japan, aortic endovascular stent-grafting is generally performed by a vascular surgeon.

I have a history, a ten-year history of vascular surgery and now I'm working in the emergency department. So I take care of aortic emergency stent grafting in our hospital.

In Japan, unfortunately we have no commercially-available stent graft device, so probably I think that less than 10 percent with blunt aortic injury are treated by endovascular therapy.

But I think Japanese physicians also follow the United States' experience. And I definitely agree that long-term follow-up will be necessary for patients who underwent endovascular therapy. Considering a long follow-up period and unknown late complications, we have not performed stent-grafting for young patients, except for in an extraordinary situation.

Saving lives is our priority. And not only to save the life, but also, we want to provide a better quality of life for patients with blunt aortic injuries. So I believe this less-invasive treatment is preferable for trauma patient with blunt aortic injury.

And regarding paraplegia according to the many records of endovascular therapy, paraplegia rate is much less in endovascular therapy group so open repair is less useful in terms of postoperative paraplegia. Thank you.

EDITORIAL COMMENT

Endovascular management (TEVAR) of traumatic rupture of the descending thoracic aorta (TRA) seems to have greater and greater acceptance compared with open repair, in some instances as a temporizing measure.¹ Part of the reason is that there is a perception that TEVAR is associated with a reduction in mortality (particularly in more critically injured patients) and neurologic injury.²

Apart from the concerns regarding lack of significant follow-up data, the issues regarding risks of TEVAR are based on the vagaries of a 2–4 cm stretch of aorta, from the origin of the left common carotid to just distal to the origin of the left subclavian artery. Issues regarding diameter, degree of angulation, ability to get apposition against the inner curve, "anomalous" origin of the vertebral artery from the arch, and risk of posterior stroke occasioned by subclavian occlusion interfering with vertebral flow all have an impact on when to use TEVAR, what type of device to use, and where to land it.³ Added to this are differences at the extremes of age, with hyperdynamic but fragile aortas in younger patients as opposed to stiffer, but more atheromatous, vessels in older patients. The risk of stroke with TEVAR is related to the degree to which posterior cerebral circulation is dependant on left vertebral perfusion and the risk of emboli or injury occasioned by wire or device manipulation in the arch of the aorta. Late stroke may occur because of embolism, particularly in settings when the origin of a great vessel is partially crossed, but this is a theoretical risk because the incidence of this has yet to be properly documented. In the majority of younger patients, the risk of stroke is <1% and so if con-

fronted with an immediate need to use TEVAR, and if the origin of the left subclavian must be covered then this should be done.² If it is felt that left subclavian perfusion must be maintained (because of a patent mammary graft or risk of stroke), then options include carotid-subclavian bypass or transposition, or "kissing" stents placed via a brachial access.

A dreaded complication of TEVAR, particularly in younger patients with trauma, is acute or delayed endograft collapse and/or intimal tear leading to type A dissection or free perforation.⁴ The risks of these occurring are linked to a combination of factors and include relative over sizing of the device, vigorous ballooning, and/or lack of apposition along the inner curvature. A number of approaches have been used to reduce the risk of these complications, including using smaller diameter and shorter "stacked" abdominal components, developing curved devices, and/or using proximal bare extensions to improve inner curve apposition. Using bare metal proximal components in younger patients does raise the concern of creating injury, although it has been used to treat stent collapse.

This preamble is necessary when considering the article by Kurimoto and colleagues. The authors use anatomic-specific, precurved, and shaped devices that they can prepare in a relatively quick time frame. A requirement is that the patient be completely stable. Their goal is to show that a device can be made that can take into account the vagaries of the distal arch and proximal descending aorta. They do use some bare extensions to help the device conform to the aortic curvature. In addition, they describe a clinical test to determine the relative risk of interfering with left vertebral perfusion. Thus, assuming one agrees that in this subset of patients a TEVAR approach is better than open repair, the authors have expanded the horizon of device-specific changes that may increase the utility of TEVAR by addressing the anatomic-specific concerns previously discussed. Finally, this group seems to have achieved a full team, in which open and endovascular skill sets are combined not only in the performance of the procedure, but in the most critical aspect, the decision and planning stages.

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Institutional report - Vascular thoracic Less-invasive management of left subclavian artery in stent-grafting for distal aortic arch disease[☆]

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Received 2 September 2008; received in revised form 26 January 2009; accepted 27 January 2009

Abstract

Simple coverage of the left subclavian artery (LSA) in thoracic endovascular aortic repair (TEVAR) is still a controversial procedure. We present our modified strategy dealing with LSA in TEVAR. Hand-made stent grafts were placed more proximal beyond the LSA for 104 patients. In elective 76, preoperative LSA occlusion test was performed on 31 patients, and preoperative computed tomographic angiography (CTA) of the vertebro-basilar artery was performed on the remaining 45. Head vessels were planned to be kept patent using fenestrated stent grafts, if possible. Stent grafts were placed from zone 0 in 23, zone 1 in 39, and zone 2 in 42. The LSA occlusion tests revealed harmful effects, such as loss of consciousness and vertigo in two out of 31 patients (6.5%). Vertebro-basilar arterial CTA revealed possible risks, if LSA covered, in three out of 45 patients (6.7%). Fenestrated stent grafts could successfully preserve 131 head vessels, except for one unintentional occlusion of the left carotid artery (0.75%). There was no LSA-related complication in any of the cases. A combination of preoperative vertebro-basilar arterial CTA and fenestrated stent grafts is useful to avoid possible LSA-related complications in TEVAR.
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Keywords: Stent graft; Left subclavian artery; Vertebral artery; CT angiography; Thoracic aorta

1. Introduction

One of the major limitations to expand the indication of thoracic endovascular aortic repair (TEVAR) is an inadequate length of proximal landing zones because of clinically important head vessels branched from the aortic arch. Because of the unavailability of a commercial device with a fenestration or a branch to keep the head vessels patent after TEVAR, proximal extension of a proximal landing zone has been achieved by a simple coverage of the left subclavian artery (LSA) or revascularization of LSA using LSA bypass-grafting or transposition.

A recent review of TEVAR in which a stent graft was placed from zone 2 reported that revascularization of LSA should be recommended [1]. Although it is well recognized that possible risks following a simple coverage of LSA in TEVAR can be largely prevented by concomitant LSA revascularization [2], we still need to seek an even less-invasive treatment.

2. Material and methods

We began TEVAR by using a hand-made stent graft placed more proximal beyond the LSA (zone 2 [3]) from October

2001. By March 2008, 104 patients underwent TEVAR for distal aortic arch pathology. In elective cases, preoperative assessments were performed to evaluate an influence of possible coverage of LSA. In emergency cases, preoperative evaluation regarding possible LSA coverage was not carried out even if LSA was covered or could be preserved by a fenestrated stent graft.

Until April 2005, preoperative LSA balloon occlusion tests were conducted in cases in which there was a possibility that LSA was covered by a stent graft in elective TEVAR. Since May 2005, preoperative computed tomographic angiography (CTA) of the vertebro-basilar artery has been chosen as an initial screening to predict possible complications if LSA is simply covered. Therefore, a preoperative LSA occlusion test has been considered only for the cases in which preoperative CTA of the vertebro-basilar artery suggests possible complications if LSA is simply covered. The indication of TEVAR for distal aortic arch pathology is that a proximal end of the diseased aortic segment is >15 mm away from the left common carotid artery (LCC) and that a diameter of a proximal landing zone, the aortic arch, is <37 mm (Fig. 1).

The stent graft was custom-made and reconstructed by suturing graft material (Ube Corp, Ube, Japan) to an endoskeleton of Gianturco Z stents (Cook Inc, Bloomington, IN). Z-stents were attached to each other using stainless steel wires with solder, leaving spaces of 8–15 mm between stents so as to fit the configuration of the distal aortic arch

[☆] Presented at the 22nd Annual Meeting of the European Association for Cardio-thoracic Surgery, Lisbon, Portugal, September 14–17, 2008.

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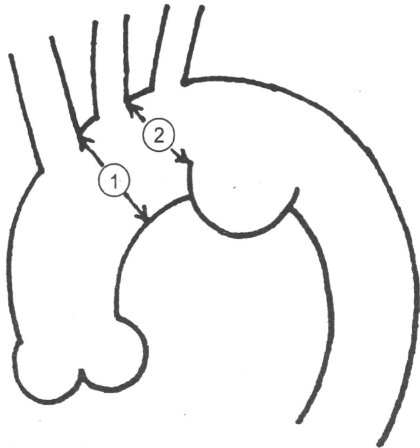


Fig. 1. Schema of distal aortic arch aneurysm. The indication of thoracic endovascular aortic repair is that a diameter of a proximal landing zone is <37 mm ① and that a proximal end of the diseased aortic segment is >15 mm away from the left common carotid artery ②.

based on CTA images. A procedure of TEVAR in our institute was previously reported [13]. In cases in which LSA was located >15 mm away from the diseased aortic segment, LSA was kept patent using a fenestrated stent graft (Fig. 2). In cases in which the proximal edge of the diseased aortic segment or primary entry was located fewer than 15 mm away from LSA or in which LSA was involved in the aortic aneurysm, LSA was covered by a stent graft. LSA revascularization was considered if preoperative evaluation suggested a possible risk of neurological complications following a LSA simple coverage. When type II endoleak from LSA was preoperatively expected or seen in digital subtracted angiography (DSA) following stent-graft deployment, LSA was occluded using coil or a stent graft with one end stitched up before or after aortic stent-graft deployment.



Fig. 2. A hand-made fenestrated stent graft. A proximal roof of a stent graft is fenestrated (white arrow) to preserve head vessels. A wire ring (black arrow) prevents distal migration of the device during stent-graft deployment. In a case of aortic dissection, a stent graft is often tapered to fit a size of a true lumen. A stent graft is custom-made to fit the distal aortic arch.

A procedure of LSA occlusion test was previously reported [13]. Briefly, during balloon occlusion of LSA for 20 min, neurological tests, including a finger-to-nose test were repeatedly performed to reveal possible adverse effects, such as cerebellar, brain stem, spinal cord or left arm ischemia.

A case in which the right or left vertebral artery (VA) measured above the posterior inferior cerebellar artery (PICA) was hypoplastic (Fig. 3), or in which the right VA was terminated (Fig. 4) or stenotic (Fig. 5), was considered to have the possibility of neurological complications if LSA is simply covered. In such a case, preoperative LSA balloon occlusion test or LSA revascularization was planned on the same day of TEVAR.

3. Results

In 76 elective cases out of 104 subjects, preoperative LSA occlusion tests were conducted on 31 and preoperative CTA of the vertebro-basilar artery was performed on 45. In 28 emergency cases (26.9%), preoperative evaluations regarding an influence of LSA coverage were not carried out regardless if LSA was covered or could be preserved by a fenestrated stent graft. The patients, aged 17–94 years (mean 70.2), consisted of 84 males (80.8%) and 20 females.

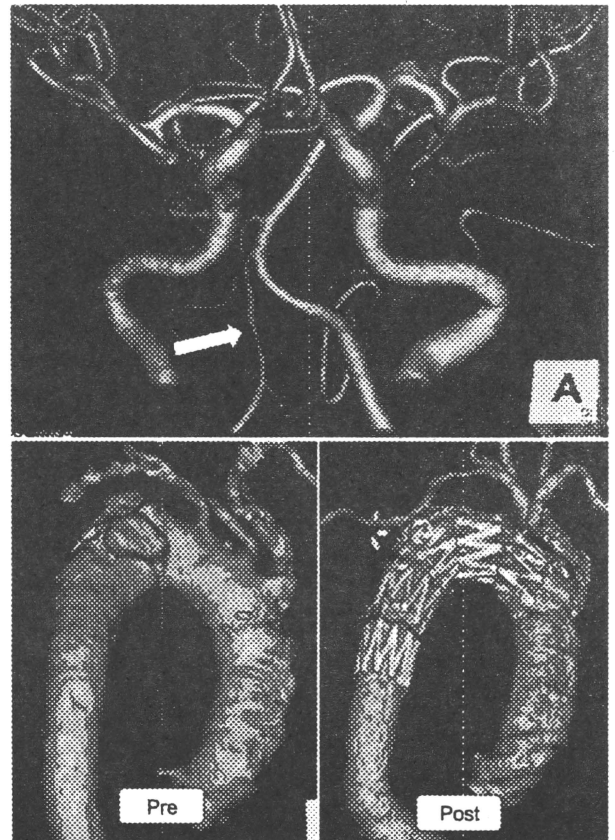


Fig. 3. Computed tomographic angiography (CTA) images. CTA of the vertebro-basilar artery revealed hypoplastic right vertebral artery (white arrow) (upper). A fenestrated stent graft well preserved antegrade blood flow into the left subclavian artery as well as the left common carotid artery (lower).

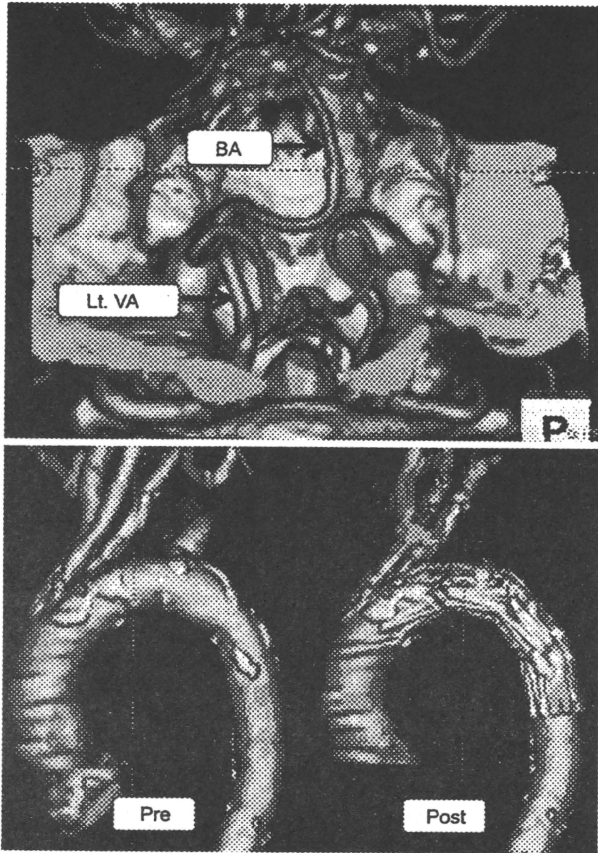


Fig. 4. CTA images. CTA of the vertebro-basilar artery suggested terminated right VA (upper). A fenestrated stent graft well preserved antegrade blood flow into LSA as well as LCC (lower). Lt. VA, left vertebral artery; BA, basilar artery.

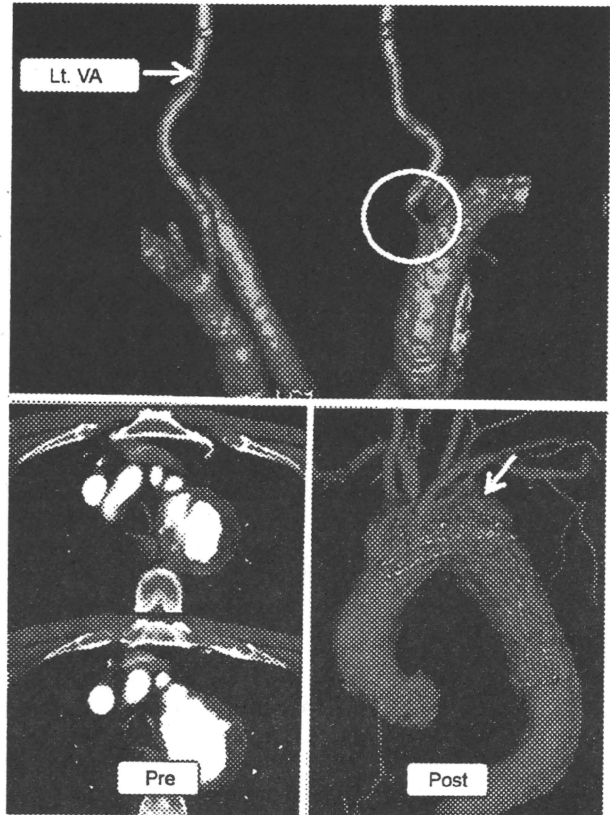


Fig. 5. CTA and CT images. CTA of the vertebral artery revealed stenotic orifice (white circle) of right VA (upper). A fenestrated stent graft well preserved antegrade blood flow into LSA as well as LCC (lower). Postoperative CTA shows complete thrombo-occlusion of distal aortic arch aneurysm (lower, white arrow). Lt. VA, left vertebral artery.

Distal aortic arch pathology consisted of degenerative thoracic aortic aneurysm in 55 (52.9%), type B aortic dissection in 20 (19.2%), thoracic aortic pseudoaneurysm in 28 (26.9%) and inflammatory thoracic aortic aneurysm in one (Table 1).

Stent grafts were placed from zone 0 in 23 patients (22.1%), zone 1 in 39 (37.5%), and zone 2 in 42 (40.4%) (Fig. 6). LSA was preserved by a fenestrated stent graft in 53 patients (51.0%) and revascularized by axillo-axillary bypass-grafting in 8 (7.7%) due to LSA occlusion tests being positive in two, patent left internal thoracic artery (LITA) graft in two and patient's discretion in four. LSA was simply covered by a stent graft in the remaining 43 patients (41.3%). Fenestrated stent grafts could successfully preserve 131 head vessels, except for one unintentional occlusion of LCC (0.75%). Fortunately, no neurological complication was observed in this 75-year-old man who additionally underwent LCC bypass-grafting following unintentional coverage of LCC.

LSA occlusion tests revealed harmful effects in two out of 31 patients (6.5%). A 71-year-old man lost consciousness several seconds after LSA occlusion. As soon as the occlusion balloon was deflated, his consciousness returned. A 76-

year-old woman complained of vertigo a few minutes after LSA occlusion. LSA could not be preserved by a fenestrated stent graft due to a lack of distance between LSA and the diseased aortic segment in both cases. TEVAR was performed on these patients following concomitant axillo-axillary bypass-grafting.

CTA of the vertebro-basilar artery revealed possible risks, if LSA covered, in three out of 45 patients (6.7%). A 76-year-old woman with a hypoplastic right VA underwent TEVAR from zone 1 using a fenestrated stent graft (Fig. 3).

Table 1
Patient characteristics (n=104)

Age (years)	70.2 ± 13.6 (17-94)
Male	84 (80.8%)
Pathology	
Degenerative aortic aneurysm	55 (52.9%)
Aortic dissection-related	20 (19.2%)
Pseudoaneurysm	28 (26.9%)
Blunt aortic injury	12
Ruptured degenerative	7
Ruptured aortic dissection	3
Anastomotic	6
Inflammatory	1 (1.0%)
Emergency	28 (26.9%)

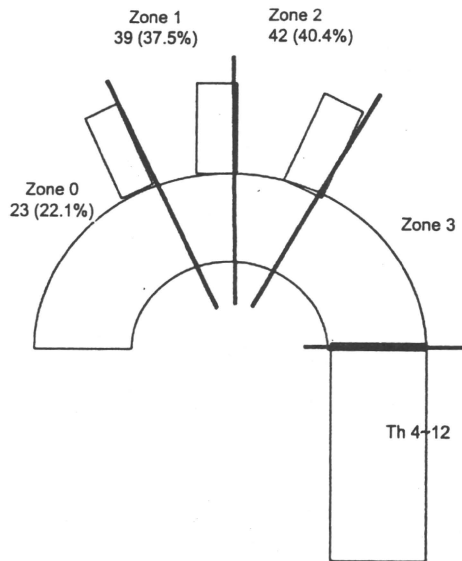


Fig. 6. Zone classification of a stent graft deployed from the aortic arch [3].

A 75-year-old woman with a terminated right VA underwent TEVAR using a fenestrated stent graft to preserve LSA although a preoperative LSA occlusion test was negative (Fig. 4). Finally, a 74-year-old man with a stenotic orifice of right VA underwent TEVAR using a fenestrated stent graft to preserve LSA without a preoperative LSA occlusion test (Fig. 5).

There was no LSA-related complication in any of the cases. Postoperative neurological complications included strokes in five patients (4.9%) and spinal cord ischemia in three (2.9%). Among five patients who suffered from strokes as an operative complication, two were treated using a fenestrated stent graft from zone 2 and 0 preserving LSA. The remaining stroke-complicated three patients were treated using a fenestrated stent graft preserving the brachio-cephalic artery (BCA) and LCC, but covering LSA. One of these patients suffered a stroke in the left VA region, but this was due to an embolism, not by LSA coverage. Delayed paraplegia was observed in two emergency rupture cases in which LSA could not be preserved due to the location of the aneurysm, and in one elective case which LSA was preoperatively occluded.

Two patients died due to an aortic aneurysm rupture or acute myocardial infarction in 76 elective cases (early mortality rate, 2.6%) and six patients in 28 emergency cases (21.4%). Excluding these early-death patients, 92 patients (95.8%) could be interviewed about post-TEVAR course, at least six months after operation by telephone or at out-patient clinic. We could not follow one patient until six months after TEVAR due to an unknown reason. Two patients underwent removal of stent grafts and open repair of thoracic aortic diseases three months and four months after TEVAR. One patient died due to cerebral hemorrhage five months after TEVAR. None of the patients, including 43 patients whose LSA was simply covered by a stent graft,

have undergone any intervention to restore the blood flow into LSA in the follow-up periods.

4. Discussion

Previously, intentional occlusion of LSA was widely accepted in cases in which a proximal landing zone was too short to exclude distal aortic arch aneurysm in TEVAR [4,5]. However, it is obvious that LSA is anatomically important for some patients. A super-dominant or single left VA or VA that ends in PICA could be considered important anatomy, as could contralateral subclavian arterial disease. This anatomy would be particularly important in the presence of a circle of Willis that is incomplete, reportedly as high as 42.4% [6]. In another example, LSA is also very important for patients with previous coronary artery bypass-grafting with use of LITA. Although left arm ischemia immediately after LSA occlusion is very rare [7] and revascularization of intentionally occluded LSA was reported mainly in the follow-up periods [5], brain stem ischemia and paraplegia as complications following TEVAR [5,8] are different stories, which means these are too late to be treated at the time of diagnosis. According to a report [9] in which the anatomy of the cerebral arteries in 92 forensic medicine autopsies was assessed, the right VA measured above PICA was hypoplastic in 8.7% and the left VA in 7.6%. The right VA terminated to PICA in 3.3%. In 56.5%, either the left or right posterior communicating artery (PCoMA) was hypoplastic (or absent) and in 7.6%, both PCoMAs were absent. The authors concluded that there was a substantial risk of neurological complication following a simple coverage of LSA in TEVAR in 5.4% of the cases. This study indicates not only that there is a 5.4% risk following a simple coverage of LSA, but also that >90% of patients do not need LSA revascularization as an additional procedure in TEVAR.

As recent reports recommended [1,2], LSA revascularization is the easiest way to prevent LSA-coverage-related complications. However, LSA revascularization itself also has potential complications, such as vocal cord palsy, spinal cord ischemia, and a chance of infection [10]. Even LSA revascularization alone has a mortality rate of 2.6% [11]. Therefore, we believe that LSA revascularization should also be performed by endovascular techniques, such as a branched [12] or a fenestrated stent graft [13], if possible. Although a fenestrated stent graft cannot allow LSA revascularization for distal aortic arch aneurysm involving LSA, zone 2 cases can be treated using a fenestrated stent graft preserving LSA.

Although the report dealing with the subjects distal from zone 3 showed stroke rates of 2.2% [14], the report dealing with only zone 2 cases showed a rate as high as 8.6% [15], which was reported not to be related to LSA coverage. It seems obvious that more proximal stent-graft placement is related to a high incident rate of stroke. In our experience of 270 TEVAR by March 2008, there was only one patient (0.6%) who showed stroke symptoms following TEVAR in the group of zone 3 or more distal ($n=166$). However, the stroke incident rate was 4.8% as presented in this study. The prevention of strokes must be one of the important points to extend the indication of TEVAR for distal aortic

arch pathology. Spinal cord ischemia also happened in our subjects much like other reports, for example, often in emergency cases. We agree that unprotected LSA coverage increases an incident rate of spinal cord ischemia in TEVAR [2]. Despite two emergency rupture cases, an incident rate of spinal cord ischemia in 76 elective cases was 1.3%, which might mean that spinal cord ischemia does not happen frequently compared to strokes in TEVAR for distal aortic arch pathology.

In conclusion, a combination of preoperative vertebro-basilar arterial computed tomographic angiography and fenestrated stent grafts is useful to avoid possible LSA-related complications in thoracic endovascular aortic repair.

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Conference discussion

Dr. B. Zipfel (Berlin, Germany): I wish to congratulate Dr. Kurimoto and his colleagues on their contribution to the problem how to manage the left subclavian artery when it has to be occluded by the stent graft. This remarkable series has good results of stent grafting in distal aortic arch disease.

Dr. Kurimoto and his colleagues were able to preserve the LSA in many cases, and in many cases, also more proximal head vessels by using handmade stent grafts with a scallop fenestration at the proximal end.

In elective cases the authors used an LSA balloon occlusion test to evaluate the cerebral perfusion dependent on patency of the LSA. This procedure was obviously abandoned after computer tomography angiography provided exact anatomical information on the vertebrobasilar artery. Only in cases of known anomalies or stenosis they performed additionally the occlusion test.

Using this policy, in 51% of the patients, the LSA perfusion was preserved by the scallop fenestration and an additional 7.7% with an axio-axillary bypass. In 43% of the patients, the LSA was simply covered with the stent graft. Eight neurological events, five strokes and three spinal cord ischemias are reported. Remarkably six of these events occurred in patients after simple coverage of the LSA.

This is basically the same experience we made. We use a little bit different approach because we are not so confident in fenestrated stent grafts. We use straight stent grafts, and in doubt we perform more general surgical revascularization using extrathoracic left carotid-subclavian bypass.

Now, this is my first question. After simple coverage of the LSA, 6 of 43 patients developed neurological complications that may be related to the LSA occlusion despite sophisticated preoperative workup of the vertebral circulation. How reliable is the balloon occlusion test of the LSA at rest in the cath lab, even if it is restricted to patients with identified abnormalities in the vertebral circulation? Don't you think that transcranial Doppler sonography might provide additional information?

Dr. Kurimoto: You are talking about the two cases of positive by occlusion test?

Dr. Zipfel: My question is whether this test is really reliable to identify potential problems from the LSA circulation, whether you should use additional information like a Doppler sonography.

Dr. Kurimoto: Yes. I really believe the occlusion test is reliable to predict the serious neurological complication. But occlusion test cannot predict possible delayed spinal cord ischemia or delayed claudication of the left arm.

But, yes, really critical neurological complications I think is very important to predict preoperatively.

Dr. Zipfel: You used stent grafts with a proximal scallop fenestration in a significant part of your distal aortic arch implantations. What is your experience in sealing of these grafts at the proximal end? How many Type I endoleaks did you experience?

Dr. Kurimoto: Endoleak?

Dr. Zipfel: Yes.

Dr. Kurimoto: It is one of the major concerns, but we experienced probably 15% of Type I endoleak. But only less than 5 patients underwent open conversion. Just we observed the size of aneurysm. If aneurysm size is increasing, we suggest the patient undergo open conversion.

Dr. E. Saadi (Porto Alegre, Brazil): When you cover the left subclavian artery, you may have Type II endoleak by retrograde flow. Did you have any in your experience, and if yes, how did you treat it?

Dr. Kurimoto: If the left subclavian artery is branched from aneurysm, it is definitely necessary to embolize using the coil or something else.

But if the left subclavian artery is branched from normal arch wall, it isn't necessary to coil-embolize because the stent graft completely seals the left subclavian artery root.

So we don't see any Type II endoleak if the left subclavian artery branched from normal wall.

Adamkiewicz動脈のCTAとMRA

吉岡 邦浩 田中 良一

要 旨：最近のCTAとMRAの進歩はAdamkiewicz動脈の非侵襲的画像診断を可能とした。これらの方法を用いて診断を行う場合には、Adamkiewicz動脈と前根髄質静脈を正確に区別することが特に重要である。CTAは三次元表示や側副血行路の描出に適しており、MRAは解離性大動脈瘤においてAdamkiewicz動脈を分岐する肋間動脈が偽腔から起始する場合の描出に優れている。

(J Jpn Coll Angiol, 2009, 49: 517-521)

Key words: Adamkiewicz artery, CT, MRI, angiography

はじめに

近年のCT、MRIはハード、ソフト両面ともに進歩がめざましい。特にマルチスライスCTを用いたCT血管造影(CT angiography: CTA)とMRIの技術を用いたMR血管造影(MR angiography: MRA)は、心臓血管領域では侵襲的な血管造影法に匹敵する診断精度を持つまでに発展している。一方、胸(腹)部大動脈瘤の症例において、術後対麻痺の回避を目的としてCTAやMRAを用いて、Adamkiewicz動脈を手術前に同定する試みが広まりつつある。本稿では、これらの非侵襲的な診断法を用いてAdamkiewicz動脈の診断を行う場合の注意点、その診断精度、将来展望について解説する。

Adamkiewicz動脈の解剖

Adamkiewicz動脈は、脊髄の尾側1/3を栄養する太さ1mm前後の細い動脈で、大前根髄質動脈(great anterior radiculomedullary artery)の別名であり、これを最初に報告したポーランド生まれの病理学者であるAlbert Wojciech Adamkiewicz(1850~1921)にちなんでいる。解剖学的にAdamkiewicz動脈を分岐する肋間あるいは腰動脈の位置は個体差が大きいことが知られており、本邦の剖検例での検討では第8肋間動脈から第1腰動脈の間で分岐するものが91%で、左側から分岐する確率が72%

と報告されている¹⁾。その走行経路は概ね次のようである。下行大動脈から分岐した肋間(腰)動脈は椎体の外側で前枝と後枝に分かれる。前者は肋骨に沿って走行するのに対し、後者は脊柱管内へと向かう。その後枝は根髄質動脈、筋枝、椎体枝に分かれ、根髄質動脈はさらに前根髄質動脈と後根髄質動脈に分かれる。前根髄質動脈は脊髄の前根に沿って脊柱管内に入り、脊髄の前面を頭側に向かって斜走した後に前脊髄動脈と合流する。この前根髄質動脈は複数存在するが、その中で最も太いものが大前根髄質動脈、即ちAdamkiewicz動脈である。Adamkiewicz動脈が前脊髄動脈と合流する際には特徴的な“ヘアピンターン(ヘアピンカーブ)”を描く。この特徴的な形態がCTAやMRAでAdamkiewicz動脈を診断する際の重要な目印となる。

侵襲的画像診断法(血管造影)

CTAやMRAが登場する以前は、血管造影がAdamkiewicz動脈を診断する唯一の方法であり、カテーテルを用いて左右の肋間(腰)動脈を1本ずつ選択して造影する必要があった。しかし、手術適応を有するような大きな大動脈瘤や大動脈解離を持つ症例では、手技的に施行が困難であるばかりでなく、破裂や血栓症等のリスクを伴うためにわが国で行われることはほとんどなかった。しかし、ヨーロッパからは血管造影によるAdamkiewicz動脈

診断の報告が散見される。ところが、480例という多数の症例を対象とした最近の検討でも、Adamkiewicz動脈の診断率は86%と高かったものの、瘤破裂による死亡が2例、対麻痺を含む重大な合併症も1.2%に発生したことが報告されている²。

このような背景から、非侵襲的画像診断法であるCTAやMRAによるAdamkiewicz動脈の診断に期待が寄せられていた。

非侵襲的診断法(CTAとMRA)

(1)注意点:動静脈の区別

CTAやMRAでAdamkiewicz動脈の診断を行う際に最も留意しなければならないのは、動脈(Adamkiewicz動脈)と静脈(前根髄質静脈)を厳密に区別することである。CTAでもMRAでも、描出された血管(この場合はAdamkiewicz動脈)が、必ずしも正確に動脈相で撮影されているとは限らず、動静脈が混在して描出されるタイミングで撮影されていたり、場合によっては静脈だけが描出されていたりする場合もあり得る。そのうえ、形態的にAdamkiewicz動脈と前根髄質静脈は非常に類似しており、両者の区別は容易ではない。解剖学的には、Adamkiewicz動脈は前脊髄動脈と合流する際に急峻な角度で“ヘアピンターン”を描くのに対し、前根髄質静脈と前脊髄静脈が形成する角度は動脈より鈍角で“コートフック”状と形容されている。しかし、実際の臨床では典型例はむしろ少なく、このような形態のみを根拠として診断を行うことは非常に困難である³。繰り返すが、“ヘアピンターン”という形態だけで診断を行った場合には、常に前根髄質静脈を誤ってAdamkiewicz動脈と判定している危険性を孕んでいることに留意しなければならない。

今のところ、形態以外の情報で動静脈の区別を行う方法として、次に述べる2つの工夫がある。一つは、画像処理の技術を用いて大動脈から肋間動脈を経て、Adamkiewicz動脈、そして前脊髄動脈へと至る経路の連続性を証明する方法である。もう一つは、同じ場所を経時的に複数回撮影する、いわゆるダイナミック撮影(多相撮影)を行って動静脈を区別する方法である。それぞれの方法の詳細は次のCTAとMRAの項目の中で述べる。

(2)CTA

マルチスライスCTを用いて造影CTを行うが、非常に

細い血管が検査の対象となるので、できるだけ薄いスライス厚で撮影することが望ましい。また、造影剤も通常の大動脈瘤や大動脈解離の診断のときとは異なり、高濃度の非イオン性のヨード造影剤を通常量より多く使用する必要がある。われわれの施設では、370mgI/mlの高濃度造影剤を秒間3.5mlの注入速度で、注入量2.0ml/kgのプロトコルを用いている⁴。一方、Utsunomiyaらは中濃度と高濃度の造影剤を比較した検討を行い、350mgI/mlの造影剤を秒間5.0mlで100mlを注入した場合がAdamkiewicz動脈の描出率が最も高かったと報告している⁵。

CTAでAdamkiewicz動脈を診断する手順は以下のようである。まず、MPR(multiplanar reformation)画像を用いて脊髄の前面でヘアピンターンを描く血管を探索する(Fig. 1A)。それが見つかったら、上流方向(大動脈方向)へ連続性に注意しながら追跡する。最終的にはCPR(curved planar reformation)画像を用いて、前脊髄動脈—Adamkiewicz動脈—根髄質動脈—肋間動脈の後枝—肋間動脈—大動脈を「一筆書き」のように描出し連続性を証明する(Fig. 1C)。この方法では解剖学的位置関係が失われるが、これを補うにはVR(volume rendering)法を用いた三次元画像(Fig. E)を追加することも有用である⁶。

大動脈瘤や大動脈解離等の大動脈疾患を有する症例を対象とした研究でのCTAによるAdamkiewicz動脈の診断能をTable 1に示す。

(3)MRA

MRAでのAdamkiewicz動脈の診断方法には2つの方法がある⁸。一つは空間分解能を重視したhigh spatial resolution MRAで、造影剤を0.2ml/秒程度で緩徐に持続注入しながら撮像することからslow infusion法とも呼ばれる。この方法では高い空間分解能を生かして、CTAと同様に大動脈からの連続性を証明することで動静脈の識別を行う(Fig. 1B, D)^{3,4}。

もう一つは、時間分解能を重視するtime-resolved MRAと呼ばれる方法で、造影剤を秒間3~4mlのスピードで急速注入しながら1回あたり20~60秒程度の高速撮像法を用いて、同じ場所を多時相(ダイナミック)撮像する方法である⁸⁻¹⁰。この方法では造影剤の動態を経時的に観察できるので動脈相と静脈相を区別することができる。

MRAは放射線被ばくがなく、使用する造影剤の安全性が高い、骨構造の影響を受けない等の利点があるが、CTAと比較して撮像に技術と熟練を要するのが大きな問題

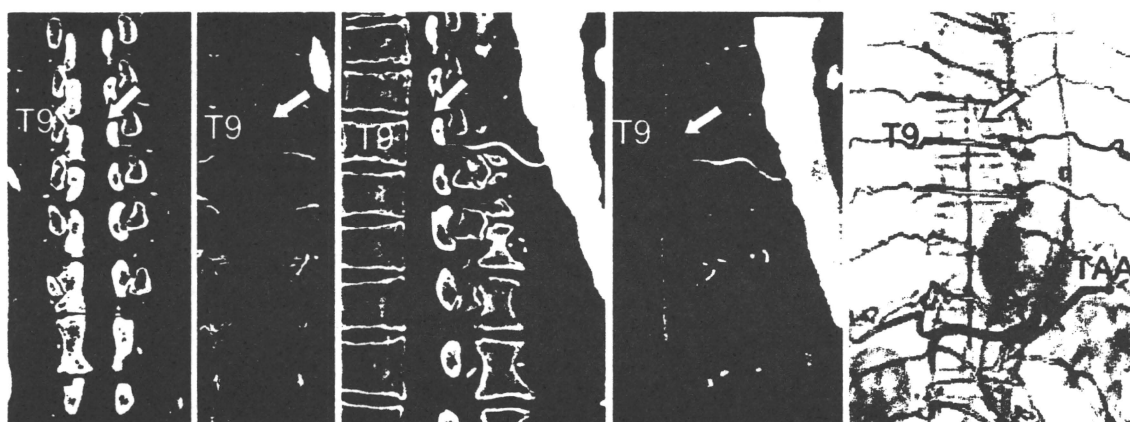


Figure 1 Identification of the artery of Adamkiewicz in a patient with thoracic aortic aneurysm.
 A: Oblique coronal multiplanar reformation (MPR) image from CTA shows the artery of Adamkiewicz (arrow). This artery has a characteristic hairpin turn connection with the anterior spinal artery.
 B: Oblique coronal MPR image from MRA shows the artery of Adamkiewicz (arrow).
 C: Curved planar reformation (CPR) image from CTA shows continuity of the aorta, left 9th intercostal artery, radiculomedullary artery, the artery of Adamkiewicz (arrow), and anterior spinal artery.
 D: CPR image from MRA shows the entire sequence from the aorta to the artery of Adamkiewicz (arrow) and anterior spinal artery.
 E: Three-dimensional volume-rendered (VR) image from CTA, displayed with a semitransparent skeletal system and aorta. Arrow indicates the artery of Adamkiewicz.
 T9: 9th thoracic vertebra, TAA: thoracic aortic aneurysm

A | B | C | D | E

Table 1 Detection rates for the artery of Adamkiewicz by CTA

	No. of patients	No. of detector rows	Slice thickness (mm)	Detection rate (%) by hairpin turn	Detection rate (%) by continuity
Takase K et al, 2002 ⁷⁾	70	4	2	90	29
Yoshioka K et al, 2003 ⁴⁾	30	4	1	80	50
Yoshioka K et al, 2006 ³⁾	30	16	0.5	83	60
Utsunomiya D et al, 2008 ⁵⁾	20	64	0.5	80	50

Table 2 Detection rates for the artery of Adamkiewicz by MRA

	No. of patients	Method	Detection Rate (%) by multiphase imaging	Detection Rate (%) by continuity
Yamada N et al, 2000 ⁹⁾	26	Time-resolved MRA	69	—
Hyodoh H et al, 2005 ¹⁰⁾	50	Time-resolved MRA	84	—
Yoshioka K et al, 2003 ⁴⁾	30	High Spatial Resolution MRA	—	57
Yoshioka K et al, 2006 ³⁾	30	High Spatial Resolution MRA	—	80

点である。Table 2 に大動脈疾患を有する症例を対象とした報告でのMRAによるAdamkiewicz動脈の診断能を示す。

(4)CTA vs. MRA

CTAとMRAはそれぞれに利点と欠点を有している

が、大動脈瘤の手術を前提としてAdamkiewicz動脈を診断する場合を想定すると、われわれは次に掲げる事項が重要と考えている。

1)側副血行路の描出(CTA > MRA)

高度の動脈硬化等によってAdamkiewicz動脈を分岐す

Table 3 Comparison of CTA and MRA

	CTA	MRA high spatial resolution method	MRA time resolved method
Proof method	Continuity	Continuity	Multiphase imaging
Technique	Easy	Hard	Moderate
Interruption by osseus structure	Yes	No	No
Demonstraion of the collateral circulation	Good	Partial	Partial
Aortic dissection (False lumen origin)	Poor	Good	Good
3D demonstration	Good	Fair	—

る肋間(腰)動脈が閉塞し、側副血行路が形成されていることがある。閉塞部位は、そのほとんどが大動脈からの起始部である。このような症例は決して稀ではなく、われわれの施設の検討では23%の頻度で認められた¹。さまざまな経路の側副血行路が形成されるが、肋間(腰)動脈の筋枝を介するものが多い。このような側副血行路はCTAでもMRAでも描出が可能である。しかし、MRAは撮像範囲が脊柱管の周囲に制限されるために、この範囲を超えて形成される側副血行路は描出できない弱点がある。例えば、肋間動脈の前枝の末梢部を架橋するルートや内胸動脈を経由するようなルートはMRAでは描出が不可能な部分が生じる。しかし、視野に制限のないCTAではそのルートの全容を描出することができる^{3,11}。

2) 偽腔開存型大動脈解離への対応(CTA < MRA)

偽腔開存型大動脈解離では、肋間(腰)動脈は真腔からも偽腔からも起始し得る。Adamkiewicz動脈を分岐する肋間(腰)動脈においても同様である。もし、Adamkiewicz動脈を分岐する肋間(腰)動脈が偽腔から起始している場合には、CTAでのAdamkiewicz動脈の描出は非常に困難な場合が多い。それは、偽腔内の血流は遅延しており造影タイミングの最適化が困難なことで、手術適応を有するような解離性瘤では偽腔の拡大が著しいために、偽腔内の造影剤が希釈されてしまうためである。われわれの施設の検討でも、解離性大動脈瘤におけるAdamkiewicz動脈の描出率は、連続性の証明を診断根拠とした場合に、MRAでは92%であったのに対してCTAではわずか58%であった³。

3) 三次元表示(CTA > MRA)

Volume rendering(VR)法を用いた三次元表示は大動脈瘤や大動脈解離の病変の広がりや周囲組織との解剖学的な位置関係の把握に有用である。同様に、Adamkiewicz動脈を分岐する肋間(腰)動脈の位置の把握

にも有用である。Adamkiewicz動脈の高さの診断のみならず、それを分岐する肋間(腰)動脈と大動脈(瘤)との位置関係、主要な分枝(例えば腹腔動脈)との位置関係を立体的に知るうえで三次元画像は役に立つ。この画像は、手術を実際に行う外科医と情報を共有し、手術方法や術式を検討するうえで特に有用である。このような画像を得るには空間分解能に優れ、骨組織や石灰化の情報も得られるCTAの方が適している。

Table 3 にCTAとMRAの利点と欠点の要点を示す。このように一長一短のあるCTAとMRAではあるが、もし同一症例に対して両方の検査を行うことができれば、Adamkiewicz動脈の診断能は、連続性の証明を診断根拠とした場合でも、90%と非常に良好な成績が報告されている³。この診断能は侵襲的な血管造影法に匹敵する。

将来展望

CTでは、320列という超多列のマルチスライスCTや、現在よりも高い空間分解能を有する新型の装置が既に稼働している。これらがAdamkiewicz動脈の診断に用いられれば、前者ではワイドな検出器を生かしたダイナミック(多相)撮影による動態診断が可能となるであろうし、後者の高空間分解能は細いAdamkiewicz動脈の診断には打って付けて、例えば連続性の証明が容易になることから診断能の向上が期待される。

MRIでは、高磁場(3 テスラ)装置が普及しつつあるが、この装置では、信号・ノイズ比や空間分解能の向上が可能である。一方、現在の1.5テスラ装置でも非造影MRAが急速に進歩しており、これをAdamkiewicz動脈の診断に応用する試みも始まっている。

これらの方法が実現されれば、現在よりも診断能が向上するであろうし、より容易に診断ができるようになるものと思われる。

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CT Angiography and MR Angiography of the Artery of Adamkiewicz

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Key words: Adamkiewicz artery, CT, MRI, angiography

New developments in CT angiography (CTA) and MR angiography (MRA) enable non-invasive diagnosis of the artery of Adamkiewicz. It is very important to differentiate the artery of Adamkiewicz from the anterior radiculomedullary vein in both CTA and MRA.

CTA is suitable for three-dimensional demonstration and visualization of the collateral circulation to the artery of Adamkiewicz.

MRA is superior for depiction of the artery of Adamkiewicz when it arises from false lumen of a dissecting aortic aneurysm. (*J Jpn Coll Angiol*, 2009, **49**: 517-521)

Images in cardio-thoracic surgery

Three-dimensional demonstration of the collateral circulation to the artery of Adamkiewicz via the thoracodorsal artery with multi-slice computed tomography angiography

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Received 17 August 2009; accepted 18 November 2009; Available online 24 December 2009

Keywords: Thoracodorsal artery; The artery of Adamkiewicz; Aneurysm; Computed tomography; Spinal cord

A 59-year-old woman with a thoraco-abdominal aortic aneurysm was hospitalised and scheduled to undergo endovascular aneurysm repair. Computed tomography (CT)

angiography using 64-row multi-slice CT clearly demonstrated the artery of Adamkiewicz and its collateral circulation via the left thoracodorsal artery (Figs. 1 and 2).

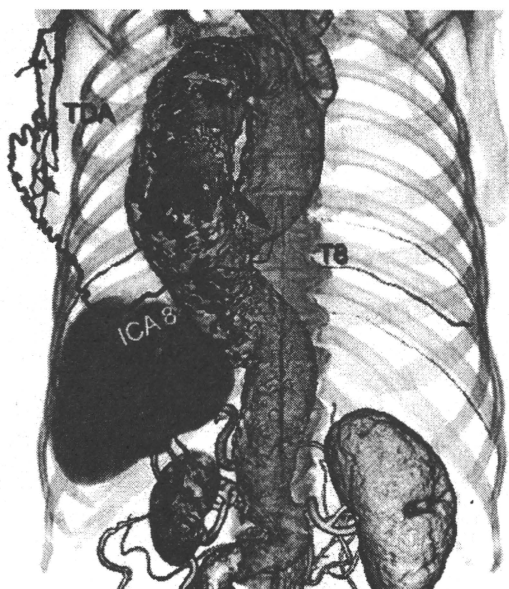


Fig. 1. The posterior view of volume-rendering image with semitransparent skeletal system shows that the left 8th intercostal artery (ICA 8), which is the origin of the artery of Adamkiewicz (arrow), is occluded proximally at the aorta. This image also shows collateral circulation from the left thoracodorsal artery (TDA) to ICA 8. T8: 8th thoracic vertebra.

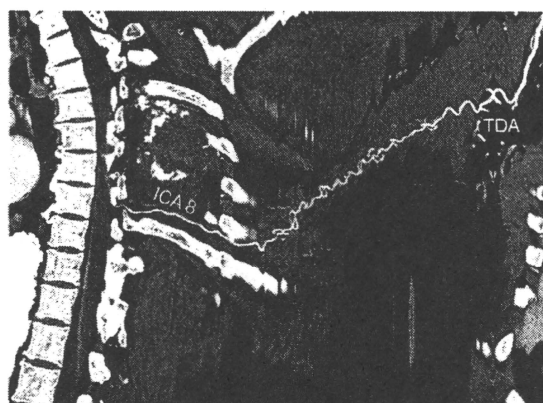


Fig. 2. A curved planar reformatted image shows full continuity from the TDA to the artery of Adamkiewicz artery (arrow) via ICA 8.

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Images in cardio-thoracic surgery

Three-dimensional demonstration of the collateral circulation to the artery of Adamkiewicz via the thoracodorsal and inferior phrenic arteries

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Received 8 February 2010; received in revised form 24 March 2010; accepted 1 April 2010; Available online 18 May 2010

Keywords: Thoracodorsal artery; Inferior phrenic artery; The artery of Adamkiewicz; Computed tomography; Thoracic endovascular aneurysm repair

A 75-year-old woman with a thoracic aortic aneurysm (Fig. 1) was admitted for thoracic endovascular aneurysm repair (TEVAR). TEVAR was performed successfully without

spinal cord ischaemia. Postoperative computed tomography demonstrated collateral blood flow to the artery of Adamkiewicz via the bilateral thoracodorsal arteries and left inferior phrenic artery (Fig. 2).

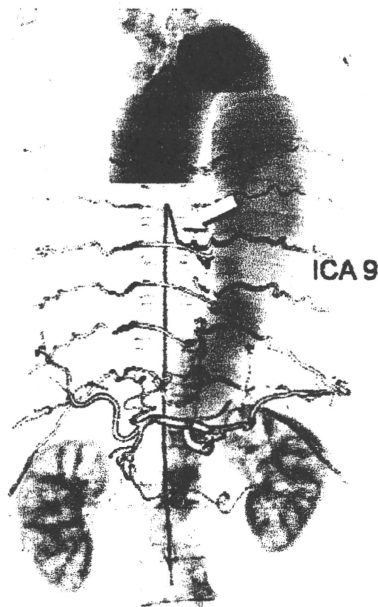


Fig. 1. Preoperative evaluation of the thoracic aortic aneurysm and the artery of Adamkiewicz using a 64-slice computed tomography. The anterior view of volume-rendered image with semitransparent aorta and skeletal system shows the artery of Adamkiewicz (arrow) originating from the left 9th intercostal artery (ICA 9). The heart and ascending aorta are electronically removed to show the artery of Adamkiewicz.

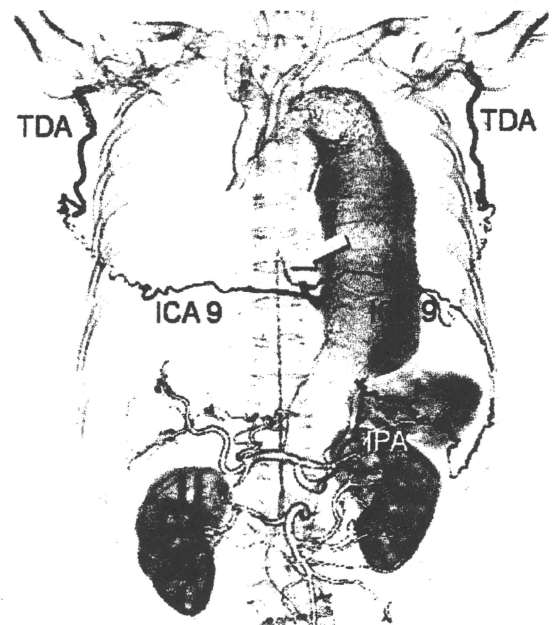


Fig. 2. Postoperative evaluation using the same computed tomography unit. The anterior view of volume-rendered image with semitransparent aorta and skeletal system shows the artery of Adamkiewicz (arrow) and occluded left 9th intercostal artery at the ostium, which is covered by the stent-graft. The image also shows collateral blood flow to the artery of Adamkiewicz from the bilateral 9th intercostal arteries (ICA 9) via the bilateral thoracodorsal arteries (TDA) and left inferior phrenic artery (IPA).

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