Spinal cord injury after endovascular treatment for thoracoabdominal aneurysm or dissection†

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Abstract

OBJECTIVES: Postoperative spinal cord injury (SCI) is a devastating complication of surgical repair for thoracoabdominal aortic aneurysm or dissection (TAAD), despite the complex reconstruction of inter-costal or lumbar arteries involved in the surgery. As an alternative technique, endovascular thoracoabdominal aneurysm repair (EVTAR) with visceral artery reconstruction has been accepted as a treatment option for severe comorbid patients of TAAD, because there is a permissible frequency of SCI after EVTAR in spite of no reconstruction of inter-costal or lumbar arteries. We report the results of EVTAR at our hospital with a focus on spinal cord injury.

METHODS: We analyzed data from 54 consecutive patients with TAAD (mean age, 74 ± 9.6 years; 42 men) who underwent EVTAR at our hospital between February 2007 and February 2014. Three types of EVTAR technique were used: fenestrated and/or branched stent graft implantation in 39 patients, a hybrid technique (bypass grafts to visceral arteries and straight stent graft implantation) in 10 patients, and intentional coverage of the coeliac artery and straight stent graft implantation in 5 patients. In all patients, mean systemic blood pressure was maintained at ≥ 80 mmHg. Opioid use was avoided in the perioperative period.

RESULTS: According to the Crawford classification, the graft coverage extent was 9% (5/54) in type I, 11% (6/54) in type II, 39% (21/54) in type III, 22% (12/54) in type IV and 19% (10/54) in type V. In most patients (74%, 40/54), cerebrospinal fluid drainage was done intraoperatively and 1 day postoperatively. Hospital mortality was 5.6% (3/54). No patient developed SCI in the perioperative period. However, in the follow-up period 2 patients developed paraplegia as a consequence of shock caused by an aortic event.

CONCLUSIONS: With close attention to spinal cord protection, EVTAR may be associated with only a low incidence of SCI in the perioperative period. Therefore, EVTAR is expected to become a promising treatment option for appropriately selected patients with TAAD.

Keywords: Branched stent graft • Endovascular aneurysm repair • Fenestrated stent graft • Spinal cord injury • Thoracoabdominal aortic aneurysm or dissection

INTRODUCTION

The conventional open surgery for patients with thoracoabdominal aneurysm or aortic dissection (TAAD) is highly invasive, and recent studies have shown that it continues to carry a substantial risk of mortality and morbidity [1–4]. The most devastating of the potential complications is spinal cord injury (SCI). The frequency of SCI after open surgery for TAAD is not negligible, despite the use of adjunctive therapies, including cerebrospinal fluid drainage, reconstruction and/or intraoperative perfusion of the inter-costal and lumbar arteries, monitoring of spinal cord function with motor-evoked potentials and cooling of the spinal cord [5, 6].

In recent years, endovascular thoracoabdominal aneurysm repair (EVTAR) has been developed and has gained popularity in some institutes [7–13]. In EVTAR, the visceral arteries are reconstructed by either bypass surgery from downstream branches or the use of a fenestrated and/or branched device. EVTAR has several advantages over open surgery as the following procedures are unnecessary: extracorporeal circulation, thoracotomy, cross-clamp of the aorta and malperfusion of downstream sites. The disadvantages of EVTAR compared with open surgery are that it is unsuitable for emergency cases, the inter-costal and/or lumbar arteries cannot be reconstructed and there is greater coverage of these arteries for the landing area of the endovascular graft. Therefore, controversy continues over whether or not EVTAR offers advantages in terms of SCI. In the present article, we describe the results of a consecutive series of EVTAR procedures. We also discuss 2 cases of SCI that developed during the follow-up.
PATIENTS AND METHODS

Patients

A total of 54 consecutive patients with TAAD were treated with EVTAR at our hospital between February 2007 and February 2014. Most patients (70%, 38/54) had been referred by their vascular/cardiovascular surgeon or by an institute with a vascular surgery/cardiovascular surgery unit. The indications for treatment were maximum aortic diameter ≥55 mm in fusiform aneurysm, ≥50 mm in saccular aneurysm or rapid growth (defined as ≥5 mm in the past 6 months).

The study was done in accordance with the Declaration of Helsinki (1975, as revised in 2008) and the regulations of the Japanese Ministry of Health, Labour and Welfare. The study protocol was approved by the ethics committee of Morinomiya Hospital. All patients provided written informed consent.

Baseline patient characteristics and preoperative conditions are given in Table 1. The median age of patients was 74 ± 9.6 years (range, 38–88 years). Most were men (78%, 42/54). Median maximal aortic diameter on the short-axis image was 62.3 ± 9.0 mm (range, 50–90 mm). Degenerative aneurysm (72%, 39/54) was more common than dissecting aneurysm (28%, 15/54). In accordance with the relevant reporting standards, we anatomically classified the aneurysms in this series using the modified Crawford classification [14]: 4 were type I, 8 type II, 12 type III, 15 type IV and 15 type V. Of the 54 patients, 26 (48%) had a history of aortic surgery; the aortic surgery was thoracic (22%, 12/54), abdominal (13%, 7/54) or both (13%, 7/54), and it was done once (22%, 12/54), twice (20%, 11/54) or thrice (6%, 3/54). All patients were unsuitable for open surgery, except for 2 younger patients with aortic dissection; both were physicians with a strong preference for endovascular treatment.

Preoperative assessment

All patients underwent 64-row multislice computerized tomography (CT) for planning and sizing. Preoperative assessment also included brain magnetic resonance imaging, duplex ultrasonography of the carotid arteries and heart, pulmonary function testing, routine blood tests and physical examination.

Spinal cord protection

We established and strictly adhered to the following principles to prevent SCI in patients undergoing treatment for TAAD:

(i) During planning, the aim is to minimize the extent of the inter-costal and lumbar arteries covered with the endovascular graft.

(ii) Cerebrospinal fluid drainage is established the day before the procedure for patients with the following required conditions.

(iii) The region covers ≥4 segments of the inter-costal and/or lumbar artery between thoracic vertebra (T) 8 and lumbar vertebra (L) 1.

(iv) The region covers three segments of the inter-costal and/or lumbar artery between T8 and L1 and the patient has had previous aortic surgery and/or malperfusion in the subclavian artery or internal iliac artery.

(v) Preoperative or intraoperative reconstruction of the internal iliac artery and/or subclavian artery is to be performed, if possible, for any potential stenosis.

(vi) A statin is administered preoperatively for ≥1 week (from 2011).

(vii) Opioid use is avoided on the day of the EVTAR and in the early postoperative period.

(viii) Mean systemic blood pressure in the intraoperative and immediate postoperative period is strictly maintained at ≥80 mmHg.

(ix) The time required for intraoperative malperfusion of the iliac, femoral and subclavian arteries, particularly that for the internal iliac arteries, is minimized.

(x) Bypass surgery and EVTAR as well as each EVTAR are done separately, as much as possible.

Devices and implantation

We used three EVTAR techniques, which are explained separately below. Fenestrated/branched EVTAR was used for patients who were able to afford the device. Other patients underwent hybrid EVTAR or, if their anatomy was suitable, coeliac coverage EVTAR.

Fenestrated and/or branched endovascular aneurysm repair. All fenestrated and/or branched devices were manufactured by Cook Medical (Bloomington, IN, USA). Cross-sectional axial

<table>
<thead>
<tr>
<th>Table 1: Baseline characteristics of 54 consecutive patients with thoracoabdominal aneurysm or dissection</th>
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<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Maximal aortic diameter (mm)</td>
</tr>
<tr>
<td>Comorbid conditions</td>
</tr>
<tr>
<td>Hypertension</td>
</tr>
<tr>
<td>Dyslipidaemia</td>
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<tr>
<td>Diabetes mellitus</td>
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<tr>
<td>Smoking former/current</td>
</tr>
<tr>
<td>Previous cerebral infarction or bleeding</td>
</tr>
<tr>
<td>Coronary artery disease</td>
</tr>
<tr>
<td>Angina/CABG/PCI stenting</td>
</tr>
<tr>
<td>Left ventricular ejection fraction &lt;40%*</td>
</tr>
<tr>
<td>Severe chronic pulmonary disease</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
</tr>
<tr>
<td>Chronic kidney disease</td>
</tr>
<tr>
<td>30-eGFR ≤ 60/eGFR &lt; 30/HD</td>
</tr>
<tr>
<td>History of aortic surgery</td>
</tr>
<tr>
<td>Abdominal/thoracic/both</td>
</tr>
<tr>
<td>Once/twice/thrice</td>
</tr>
<tr>
<td>Preoperative medication</td>
</tr>
<tr>
<td>Antiplatelet drug(s)</td>
</tr>
<tr>
<td>Warfarin</td>
</tr>
<tr>
<td>Statin(s)</td>
</tr>
<tr>
<td>ASA physical status</td>
</tr>
<tr>
<td>2/3/4</td>
</tr>
<tr>
<td>EuroSCORE II</td>
</tr>
</tbody>
</table>

CABG: coronary artery bypass graft; PCI: percutaneous coronary intervention; eGFR: estimated glomerular filtration rate; ASA: American Society of Anesthesiologists; EuroSCORE II: European System for Cardiac Operative Risk Evaluation II.

*Measured echocardiographically.

*With forced expiratory volume in 1 ≤ 70% of predicted value.
images of the aorta showing flow reconstruction were used to calculate the length of the device and the position of the visceral vessel. Devices required a proximal landing site length of ≥20 mm in the aorta, and a distal landing site length of ≥15 mm in the aorta or ≥10 mm in the iliac artery (Fig. 1A). Fenestrations or branches for the coeliac and superior mesenteric arteries were all 8 mm in diameter, renal arteries were all 6 mm in diameter. The choice of fenestration or branching to reconstruct the visceral arteries was determined according to the diameter of the device and the aortic diameter at the branch point of each visceral artery.

If the aortic diameter was greater than the main device diameter, branching was chosen. If the aortic diameter was less than the main device diameter, fenestration was chosen.

Open access to both common femoral arteries was required. On the one side, the main device (fenestrated and/or branched) was inserted through a purse-string suture on the femoral artery. The main graft was then deployed, facilitated by the gold markers on the device for alignment of visceral target vessels.

On the contralateral side, one to four open punctures were made and a 6- or 7-Fr sheath was inserted. Small-calibre stent grafts (Advanta, Atrium Medical Corp., Hudson, NH, USA) were inserted through fenestrations to each branch. The sheath of the main device was then removed as soon as possible before the branched bridging endografts were completed. The visceral bridging stents (Advanta) were expanded so that 4–5 mm of each protruded into the aortic lumen. Finally, a 12-mm balloon was used to over-dilate these protruding segments and thus create a seal between the fenestrations of the device and the aorta. An 80-cm 10-Fr sheath was advanced through the axillary artery into the main device, then each branch and its corresponding artery were catheterized, wired and stented with a self-expanding (Advanta) or balloon-expandable covered bridging stent (Fluency, CR Bard, Inc., Murray Hill, NJ, USA). After the fenestrated and/or branched device and covered bridging stent were deployed, the distal and/or proximal body were extended in the usual way.

**Hybrid endovascular aneurysm repair.** In the hybrid technique, patients underwent graft replacement of the infrarenal abdominal aorta and simultaneous bypass grafts to visceral arteries, if the proximal anastomosis of the infrarenal aorta was gourd-shaped and its diameter ≤40 mm. In cases in which there was no neck for the proximal anastomosis in the infrarenal aorta, two bypass grafts to visceral arteries were connected to the region between the native bilateral common iliac arteries and external iliac arteries. Several days after the bypass surgery, EVTAR was conducted in the usual way (Fig. 1B).

**Endovascular aneurysm repair with intentional coeliac artery coverage.** In patients with a Crawford type I or type V aneurysm and a landing site length ≥15 mm just above the superior mesenteric artery, simple EVTAR was done with intentional coverage of the coeliac artery orifice (Fig. 1C). Collateral vessels to the coeliac artery from the superior mesenteric artery were examined before the procedure.

**Postoperative management and follow-up**

Patients spent ≥12 h in the intensive care unit for active physiological monitoring. We maintained a mean systemic blood pressure of ≥80 mmHg to improve spinal cord perfusion in the first 72 h postoperatively. In patients without neurological symptoms, cerebrospinal fluid pressure was maintained at 10 cm H₂O for the first 24 h; the catheter was clamped for the next 24 h before removal at 48 h.

Patients underwent 64-slice CT angiography before discharge. The follow-up clinical assessment, laboratory testing, CT angiography, abdominal duplex ultrasonography to assess aneurysm exclusion and graft patency, and to detect endoleaks, and plain chest and abdominal radiography were done at 1, 6, 12, 18 and 24 months and yearly thereafter. The exception was patients with renal dysfunction, who underwent plain CT, as well as transoesophageal and/or abdominal duplex ultrasonography.

**Statistical analysis**

Statistical analysis was done with the SPSS 17.0 software (SPSS, Inc., Chicago, IL, USA). Actuarial survival analysis and postoperative aortic event-free analysis were done using Kaplan–Meier life tables.

**RESULTS**

**Preoperative preparation**

In most patients (74%, 40/54), cerebrospinal fluid drainage tubes were inserted on the day before surgery. In 2 patients, insertion of the drainage tube was not possible. A quarter of the patients (25%, 10/40) had post-spinal puncture headache after removal of the cerebrospinal fluid drainage tube. Preoperative severe stenosis or occlusion was present in 4 patients (3 internal iliac, 1 subclavian artery). We reconstructed these arteries by using preoperative percutaneous transluminal angioplasty in 2 patients, subclavian artery bypass in 1 patient and intraoperative internal iliac artery bypass in 1 patient. Preoperatively, 32 patients were receiving statin therapy, including 15 who did not have dyslipidaemia but did have degenerative aneurysm.

**Anaesthesia**

In all patients, rapid sequence induction was used for general anaesthesia, which was maintained with sevoflurane, ketamine and propofol. No opioids were used. In all patients, mean systemic
blood pressure was maintained at ≥80 mmHg both intraoperatively and postoperatively, using the following vasopressor agents: dopamine hydrochloride in 52 patients and noradrenaline (norepinephrine) in 43 patients. Conversely, depressors were used to maintain systemic blood pressure at ≤160 mmHg: alprostadil alfadex (prostaglandin E1) was used in 52 patients, human atrial natriuretic peptide in 17 patients and nicardipine hydrochloride in 25 patients.

### Devices and implantation

**Fenestrated and/or branched endovascular thoracoabdominal aneurysm repair.** A total of 39 patients underwent EVTAR using 39 custom-made fenestrated and/or branched endovascular devices. There were 109 fenestrations in total, and 31 branches in total. All bridging stent grafts were successfully implanted except for three dissections in the visceral arteries of 2 cases. Number and graft patency are summarized in Table 2.

After implantation of the custom-made device and the bridging stent grafts, 31 proximal thoracic endovascular aneurysm repair (TEVAR) grafts and 20 distal EVAR grafts were employed to exclude the aneurysm. In 1 patient, intraoperative rupture of the abdominal aorta occurred with balloon touch-up, but the rupture was rectified by implantation of additional bifurcated stent grafts. Median operative time, media volume and fluoroscopy dose were 425 min (range, 251–815 min), 165 ml (range, 10–196 ml) and 4.86 Gy (range, 1.55–15.5 Gy), respectively.

**Hybrid endovascular thoracoabdominal aneurysm repair.** Ten patients underwent hybrid EVTAR (debranching of visceral arteries and either standard endovascular graft implantation or fenestrated/branched EVTAR). A total of 28 visceral artery bypasses were performed (8 to the coeliac artery, 9 to the superior mesenteric artery and 11 to the renal artery). EVTARs were done, 0–106 days later (mean 30 days), with 20 TEVAR grafts and/or 4 EVAR grafts and two fenestrated/branched devices (one device had a branch for the coeliac artery and a branch for the right renal artery; the other device had a branch for the coeliac artery, a fenestration for the superior mesenteric artery and a fenestration for the right renal arteries). All reconstructed grafts were patent in postoperative CT and duplex scan (Table 2). Median operative time, media volume and fluoroscopy dose were 301 min (range, 136–590 min), 73.4 ml (range, 0–145 ml) and 2.14 Gy (range, 0.75–5.15 Gy), respectively.

**Endovascular thoracoabdominal aneurysm repair with intentional coeliac artery coverage.** Five patients underwent straight stent graft implantation with intentional coverage of the coeliac artery, and 11 TEVAR devices were implanted just above the superior mesenteric artery. Before the procedure, 3 patients underwent coeliac balloon occlusion and selective superior mesenteric artery arteriography to confirm good collateral circulation to the hepatic and splenic arteries. In the other 2 patients, CT angiography confirmed good collateral circulation between the coeliac artery and the superior mesenteric artery. Median operative time, media volume and fluoroscopy dose were 200 min (range, 182–242 min), 73 ml (range, 0–155 ml) and 2.48 Gy (range, 1.83–3.33 Gy), respectively.

**Adjunct endovascular graft implantation.** Planned separate endovascular aneurysm repair was performed in 1 thoracic and 3 abdominal aneurysms.

### Extent of the aorta covered by the stent graft

Aortic coverage in this series is summarized in Table 3 and Fig. 2. Stent grafts extended across a total of 465 pairs of inter-costal arteries (ICAs) and lumbar arteries (mean, 8.6 pairs of ICAs/patient) in the 15 vertebrae between T3 and L5 (Fig. 2, white bar). In the critical area of the six ICAs between T8 and L1, where the artery of Adamkiewicz branches off, stent grafts extended across 264 pairs of ICAs aortic (mean, 4.9 pairs of ICAs/patient). According to the Crawford classification, aortic coverage extent of this series was 9% (5/54) in type I, 11% (6/54) type II, 39% (21/54) type III, 22% (12/54) type IV and 19% (10/54) type V (Table 3).

Combining the aortic coverage data from this series with those of previous procedures, grafts extended across 566 pairs of ICAs in total (mean, 10.5 pairs of ICAs/patient) in the 15 vertebrae between T3 and L5 (Fig. 2, hatched bar). In the critical area between T8 and L1, grafts extended across 276 pairs of ICAs (mean, 5.1 pairs of ICAs/patient). Aortic coverage in this series and in previous procedures, according to the modified Crawford classification was 7% (4/54) type I, 39% (21/54) type II, 22% (12/54) type III, 19% (10/54) type IV and 13% (7/54) type V (Table 3).

### Mortality and complications in acute phase

Endoleaks were detected in 17 patients: 2 were type I endoleaks, 12 were type II endoleaks and 3 were type III endoleaks. Two type I and 2 of the 3 type III endoleaks were treated with additional endovascular treatments. All type II endoleaks were monitored, without treatment, in the perioperative period.

Postoperative mortality and complications are summarized in Table 4. In-hospital mortality was 6% (3/54). The causes of death were broad area cerebral infarction (postoperative day (POD 10)), rupture of targeted TAAD from type III endoleak (POD 56) and pulmonary embolism (POD 39). These 3 deaths occurred in fenestrated/branched EVTAR cases.

No patients developed SCI (paraplegia and paraparesis) in the perioperative period. Median intensive care unit and hospital

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**Table 2:** Number of visceral artery reconstructions and results for 49 of 54 consecutive patients with thoracoabdominal aneurysm or dissection treated with endovascular aneurysm repair

<table>
<thead>
<tr>
<th>Variable</th>
<th>Endovascular aneurysm repair technique</th>
<th>Fenestrated and/or branched</th>
<th>Hybrid</th>
<th>Coeliac artery coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artery</td>
<td></td>
<td>34/39</td>
<td>10/10</td>
<td>0</td>
</tr>
<tr>
<td>Coeliac</td>
<td></td>
<td>38/39</td>
<td>10/10</td>
<td>0</td>
</tr>
<tr>
<td>Superior mesenteric</td>
<td></td>
<td>34/39</td>
<td>6/10</td>
<td>0</td>
</tr>
<tr>
<td>Right renal</td>
<td></td>
<td>34/39</td>
<td>7/10</td>
<td>0</td>
</tr>
<tr>
<td>Mean number of arteries</td>
<td></td>
<td>3.56</td>
<td>3.3</td>
<td>0</td>
</tr>
<tr>
<td>reconstructed/patient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perioperative period</td>
<td></td>
<td>138/140</td>
<td>33/33</td>
<td>–</td>
</tr>
<tr>
<td>Follow-up period</td>
<td></td>
<td>139/140</td>
<td>33/33</td>
<td>–</td>
</tr>
</tbody>
</table>
Follow-up

No patients were lost to the follow-up. The median follow-up period was 20.7 months (range, 1–45 months). All cause mortality free survival is shown in Fig. 3. During the follow-up, 11 patients died; 1 patient died because of an aortic event caused by a disease unrelated to the targeted aneurysm (saddle embolism). Another 3 patients died from pneumonia, 1 from myocardial infarction, 1 from heart failure and 1 from lung cancer.

There were 4 sudden deaths and the cause was not isolated; 3 of the 4 patients had an arch aneurysm with maximum diameter ≥55 mm and TAADs of these patients were shrinking without endoleak. The other case of sudden death was a 77-year old female; she received EVTAR for her enlarged type B aortic dissection that had an onset at 55 years of age. Her TAAD also had no endoleak after the EVTAR.

In the follow-up period, 2 patients developed SCI. The first was a woman who underwent the hybrid procedure 5 months previously and whose endovascular graft extended across T3–L3, covering the inter-costal and lumbar arteries. Saddle embolism resulted in bilateral internal iliac malperfusion, which caused paraplegia. We were able to restore internal iliac artery reperfusion within 4 h. However, the patient consequently developed first intestinal necrosis, then multiple organ failure. She died 42 days after the onset of the saddle embolism. The second patient who developed SCI during the follow-up was another woman who underwent the hybrid procedure; her stent graft extended across T7–L5, covering the inter-costal and lumbar arteries. Two years after the original EVTAR, she required repeated TEVARs for acute type B dissection of impending rupture. TEVAR for proximal descending aortic dissection seemed the best course of action without SCI; however, she suddenly developed shock 2 days postoperatively. Emergent CT showed extension of the dissection from the BCA to the descending aorta and rupture of the left thorax with tension haemothorax. The patient’s life was saved with a massive blood transfusion, drainage of the haemothorax and closure of the BCA.
orifice with a covered stent; however, her prolonged shock progressed to paraplegia.

Late endoleaks were detected in 8 patients. One was a distal type I endoleak between the covered bridging stent and the coeliac artery; an additional covered stent was implanted. Another seven endoleaks were type II continuing from the acute phase. In 2 patients whose aneurysm was ≥5 mm dilated compared with its preoperative size, the feeding artery was embolized. Freedom from aneurysm-related events is shown in Fig. 4. Five aortic events occurred during the follow-up. One required graft replacement of the ascending to arch aortae for acute type A aortic dissection.

**DISCUSSION**

In 2010, Kuratani et al. [7] reported the long-term results of 86 cases of hybrid EVTARs. In that series, we were able to achieve a remarkably low incidence of SCI in the perioperative period, with no cases of paraplegia and only one of paraparesis.

With continuous advances in endovascular treatment, total fenestrated/branched EVTAR is expected to replace hybrid EVTAR. However, the recently reported accumulated results for the perioperative period of fenestrated/branched EVTAR have been disappointing regarding the incidence of SCI; 5–23% [11–13]. Against this background, we decided to report our most recent treatment results for patients with TAAD, most of whom underwent fenestrated/branched EVTAR.

In our series, the perioperative results of EVTAR have been excellent. No cases of SCI occurred in this period. This may have been because the spinal cord was protected in three ways.

First, we used cerebrospinal fluid drainage procedures shown to prevent SCI in open surgery for TAAD [15–17]. The use of cerebrospinal fluid drainage was restricted for patients at extremely high risk of SCI (74%) because of the considerable risks associated with insertion of a spinal drainage tube [18]. Furthermore, the onset of SCI is usually postoperative in patients undergoing EVAR and/or TEVAR, while the patient is in the intensive care unit. Prompt insertion of a spinal drainage tube at that time makes full recovery from SCI highly likely.

Secondly, EVTAR has particular advantages over open surgery, for example in terms of blood pressure maintenance, there is no necessity for the use of opioids [18, 19], and the separation of each endovascular graft implantation and/or adjunct other procedures. These protection procedures are all for the maintenance of collateral circulation to the inter-costal and/or lumbar arteries.

Thirdly, we avoided a pitfall associated with EVTAR, namely a wider graft covering area and inadequate circulation of the internal iliac and subclavian arteries. Endovascular aneurysm repair requires attachment areas proximal and distal to the aneurysm. It is a great disadvantage to have graft covering areas wider than the open surgery, as well as impossible for reconstruction of intercostal and lumbar arteries. Thus, it is important to work towards minimizing the area covered by the endovascular graft. If branched grafts would be used for TAAD, the coverage of the aorta would be greater than that in our series. In order to minimize the graft covering area, it is better to use fenestrated devices for reconstruction of the visceral arteries, hence the high frequency use of fenestration for reconstruction of visceral arteries in our series (77% of all reconstructions in fenestrated/branched EVAR).

It is also essential to avoid malperfusion of the internal iliac and subclavian arteries for spinal cord protection. In our series, when there was any likelihood of intentional coverage of the subclavian and/or internal iliac artery, which is often necessary in EVTAR, these arteries were, without exception, reconstructed, because they are the only arteries left to supply the spinal cord circulation in patients with broad coverage of the inter-costal and/or lumbar arteries. Also important is prompt reperfusion of the internal iliac, external iliac and deep femoral arteries, which are obstructed by the large diameter sheath. In this series, the main device sheath was not only withdrawn as soon as possible but also no large diameter sheath was ever employed for the opposite side of the main device that was used for bridging stent implantations for visceral arteries.

An important point to note from the present series is in regard to spinal cord protection in the follow-up period after EVTAR. Unfortunately, 2 patients developed paraplegia caused by an aortic event as a result of impaired collateral circulation to the spinal cord. These major complications in the present series were not encountered in our former series, nor have they been described in other reports of EVTAR. The development of paraplegia in the patients during the follow-up period provides a lesson to all physicians concerned with endovascular treatment for TAAD, by emphasizing the importance of preserving collateral circulation to the spinal cord in the follow-up period as well as in the perioperative period in patients whose procedure requires...
exclusion of a broad area of the inter-costal and lumbar arteries from the systemic circulation.

One more important cautionary point of EVTAR in the follow-up is to provide protection from fatal aortic events. There were 4 sudden deaths in this series and all were suspected to have derived from aortic rupture or dissection. Although 3 of the 4 patients were found to have an arch aneurysm of high treatment indication, aneurysm repair was not undertaken due to severe co-morbidities in their preoperative condition. Less invasive treatment applied at the optimum timing might have saved their life and achieved better EVTAR values.

CONCLUSIONS

The results of this series, in which most patients underwent the fenestrated/branched procedure, are encouraging: they suggest a low risk of SCI when EVTAR is undertaken with careful attention to spinal cord protection. However, it is necessary to continue the monitoring of the spinal cord collateral circulation in the follow-up period. Since EVTAR is a minimally invasive treatment associated with a low incidence of SCI, we expect that it will become a promising option for patients with TAAD.

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Conflict of interest: Masaaki Kato has received grants from Medtronic Inc. and Japan Lifeline Co., Ltd, and personal fees from Japan Gore, Inc., Junken Medical Co., Ltd. and Cook Japan, Inc., for work outside the submitted work.

REFERENCES


APPENDIX. CONFERENCE DISCUSSION

Dr T. Resch (Malmö, Sweden): I think that most agree that the extent of aortic coverage is an important indicator for the incidence of spinal cord ischaemia, and in your manuscript you didn’t delineate between anatomical classification and the actual covered portion of the aorta with the endograft, but I saw that you added that now to your presentation.

As endovascular repair requires sealing zones proximal and distal to the extent of the aneurysm, more aortic coverage is required during EVAR repair than during open repair for the same anatomical aneurysm extent. So which of these classifications did you actually use in calculating your outcome values and which do you find is more appropriate when reporting results for spinal cord ischaemia?

Dr Kato: I did the count after your question, and in our anatomical classification, Crawford I is four and Crawford II is eight. III is 12, IV and V are 15. The majority of the anatomical classification underwent extent IV and V. But in endovascular treatment, graft covering extent is wider, and the majority of the covering extent is Crawford type III, 21 patients. I think endovascular treatment has the demerit for covering extent of the graft, but close attention to spinal cord protection will offset this demerit.

Dr Resch: My second question refers to the staging. Obviously you are a very strong advocate of staging. Almost 50% of patients were what I call naturally staged, having extensive previous aortic surgeries, and, in addition to that, you then staged the actual operation. So what do you think is the optimal interval of staging and do you use spinal drainage for all these stages or simply for the one when you actually close off the circulation?

Dr Kato: For the second question the answer is ‘I don’t know about the optimal interval about a separate operation’. But in coronary artery occlusion, collateral circulation develops within 24 h, and in middle cerebral artery occlusion, collateral circulation raises seven days after occlusion maximally. And so I think a one-week separation is optimal timing of a second endovascular treatment.