ればこの時点で抜管するのが普通である．なお，鎮静薬を使用する場合，できれば神経細胞保護的に働くもの，せん妄を引き起こしにくいものを選択する（p.40 表 1）．

以下，部位別・術式別に管理の要点を述べる．

1．大動脈基部置換術

大動脈弁手術と冠動脈再建手術の同時手術と同様の術後管理を行う．すなわち，心筋虚血の発生を監視し，機械弁を用いたベントール手術では適宜抗凝固を開始する．弁温存手術の場合，弁逆流が残存している可能性があり，その有無と程度を把握し，聴診所見や拡張期血圧などから，その推移を観察する．

2．上行・弓部大動脈置換術

脳合併症を早期に発見することが重要である．覚醒遅延や痙攣（けいれん）がみられたら，脳梗塞の有無を確認するため画像診断を行い，速やかに治療を開始する．

術後せん妄は，挿管中であっても観察により診断可能である．昼夜のリズムを作り，夜間は熟眠できるよう努めるが，中途半端な量のベンゾジアゼピン系睡眠薬はせん妄を増悪させるので注意が必要である．通常，抗精神病薬であるmajor tranquilizer（メジャートランキライザー）で対処する．昼間はご家族などのよく知った顔に触れてもらうとよい．

経口摂取開始に際しては誤嚥に注意する．弓部の手術では左反回神経麻痺（まひ）が発生し得るため，声がかれている場合は経口摂取開始を慎重に行う．高齢者ではもともと嚥下機能が落ちており，軽度の嗄声（させい）でも誤嚥しやすい．さらに，脳機能低下も嚥下機能を悪化させる．誤嚥が見られる場合，積極的に嚥下機能評価を依頼し，リハビリテーションを開始する．水分は誤嚥しやすいため，とろみをつける．

3．下行・胸腹部大動脈置換術

脊髄障害と呼吸器合併症予防が重要である．前者のため留置された脳脊髄液ドレーンは，頭蓋内出血，髄膜炎，チューブ断裂，血腫，髄液瘻などの合併症の可能性があり，適切な管理が必要である（図 1）．特に頭蓋内出血はドレナージ量や速度が大きいと発生しやすいとされ，圧 10mmHg 以上[7]，速度 15mL/h 以下[8]が推奨されており，これを逸脱しないよう，また排液が血性にならないか観察が必要である．さらに脊髄障害発生時には，ドレナージが有効に機能しているかどうか，直ちに確認する．

呼吸器合併症予防には創痛の管理が重要であり，筆者らは肋間神経の持続ブロックを術後早期に行っている（図 2）．十分な喀痰排出ができ，かつ過度の鎮静にならないよう，鎮痛薬を適宜使用しつつ，排痰の補助を行う．

4．ステントグラフト内挿術

特有の合併症に注意する．塞栓症は術中に気付かれない場合も多く，分枝閉塞は術後に発生する場合もある．これらは中枢神経障害に加え，肝・腎・腸管などの腹部臓器障害を来し得るが，特に腸管虚血はしばしば診断困難で致命的であり，患者の自覚症状（腹痛）の把握が早期発見には最も重要である．ステントグラフト治療では分節動脈再建は行われないため，脊髄障害（特に遅発性障害）防止の観点では，脳脊髄液ドレナージなど術後の脊髄灌流圧維持は特に重要である．また，エンドリークにより治療効果が得

〈右点線部分の拡大図〉

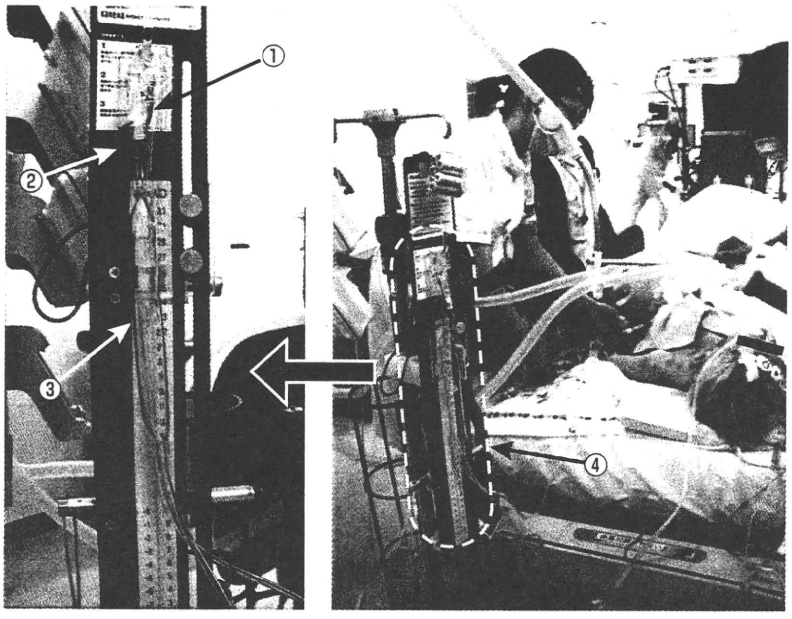

図 1 脳脊髄液ドレナージの管理

①フィルターは濡れていないか，②クランプを外したか，③円盤の高さは設定値か（この図では 13cmH_2O=10mmHg），④基準点は外耳孔の高さか，の４点をチェックする

られていないことがあるため，情報を共有して管理することが重要である．

おわりに

看護師は，患者に発生し得る合併症のサインに最も早く気付くことができる職種である．と同時に，身体的・精神的ケアを通じてさまざまな合併症を予防する第一線の役割を担っている．外科医がカバーしきれない，これらの役割にチームとして期待されるものは大きく，本稿がその一助になれば幸いである．

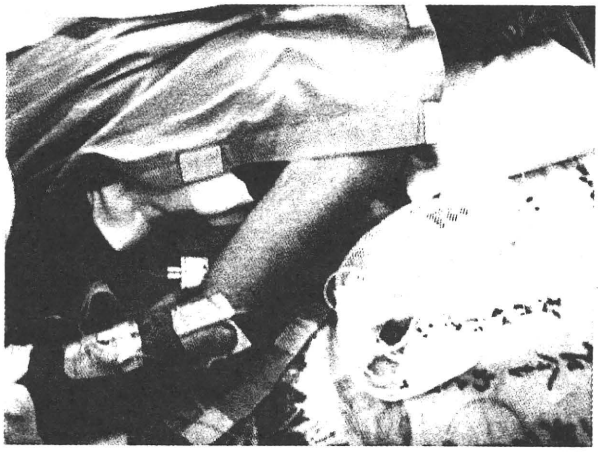

図 2 創痛の管理

胸膜外に留置した肋間神経ブロック用のチューブに局所麻酔薬を持続注入している．大血管手術では抗凝固を行うため，通常硬膜外チューブは留置しない．また，硬膜外は血圧低下の原因となることがあり，脊髄灌流圧低下から遅発性脊髄障害の原因ともなり得るので不利である

★COLUMN

術後ケアこそナースが力を発揮する

私たち外科医は，手術適応を慎重に判断し，知識・経験に基づき適切な術式・補助手段を選択し，その遂行に最善を尽くすが，それでも一定の確率で合併症は発生する．不幸にして合併症が発生した場合，何とか被害を最小限にとどめ，社会復帰できるよう努力するのはもちろんであるが，そのためには早期発見による迅速な対処が必要になる．また，状態の変化に動揺する患者・家族への精神的サポートも必要になる．順調に終了した手術であっても術後に合併症を来すこともあり，良好な結果を得るためには，この防止も大きなウェイトを占めている．外科医は常に患者のベッドサイドにいられるわけではないので，これらはチームとして共に診療に当たっている看護師の皆さんの力に負うところが大きい．

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Long-term results of hybrid endovascular repair for thoraco-abdominal aortic aneurysms☆

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Abstract

Objective: The treatment of thoraco-abdominal aortic aneurysms (TAAAs) is extremely laborious, due to the surgical complexity of this condition. In particular, postoperative spinal paraplegia poses a severe complication that significantly lowers patient's quality of life. In 1997, we devised a hybrid procedure consisting of extended endovascular aortic repair (EVAR) and visceral reconstruction. In this article, we report the long-term results obtained from this procedure. **Methods:** We conducted 1106 endovascular aortic repairs between 1997 and 2008. Among these, we selected 86 cases of TAAA. The mean patient age was 71.6 years. Preoperative complications included 19 cases of stroke, 22 cases of coronary artery disease (CAD) and 16 cases of chronic obstructive pulmonary disease (COPD). Cerebrospinal fluid drainage was initiated during the operation. We performed bypasses from the aortic bifurcation to abdominal visceral arteries, and deployed stent grafts to exclude the entire TAAA. **Results:** Operative time averaged 386 min. We lost two patients and encountered only one case of graft occlusion. Two patients had acute renal failure, but neither required a tracheostomy. Furthermore, no patients exhibited paraplegia or delayed paraplegia. We observed endoleaks in nine cases, and shrunken aneurysms in 73 cases. Long-term results included survival rates of 94.8%, 85.8%, 80.2% and 66.6% at 2, 5, 8 and 10 years, respectively. Only two patients died from aortic events. Rates of freedom from aortic events were 90.7%, 80.6%, 70.8% and 70.8% at 2, 5, 8 and 10 years, respectively. **Conclusions:** The hybrid TAAA-repair protocol yielded satisfactory results. Although thorough follow-up is required for visceral bypass, this procedure could become the standard for TAAAs.

Keywords: Endovascular aortic repair; Hybrid procedure; Long-term results; Postoperative paraplegia; Thoraco-abdominal aortic aneurysm

1. Introduction

The treatment of thoraco-abdominal aortic aneurysms (TAAAs) is extremely laborious, as these aneurysms are complex and require invasive surgery [1–3]. Data from the Nationwide Inpatient Sample (NIS) database in the United States suggest a mortality rate approaching 22.3% [4]. In addition, devastating complications, postoperative paraplegia in particular, significantly lower postoperative patient quality of life (QOL). Despite refinements in surgical techniques for spinal protection, risk of postoperative neurological deficit remains high [1–4]. Although there is a considerable risk in patients with significant co-morbidity, conventional surgery remains an option because the mortality rate for conservative treatment at 2 years is ~76% [5].

Surgical treatments for thoracic aortic aneurysms have recently shifted to endovascular aortic repair because it is less invasive and improves postoperative QOL. In addition, the incidence of postoperative paraplegia in endovascular aortic repair for thoracic aortic aneurysms has decreased extremely [6–8]. In an attempt to prevent paraplegia, we developed a hybrid TAAA repair in 1997, consisting of abdominal visceral reconstruction and extended endovascular aortic repair. Early favourable outcomes encouraged another group to perform this procedure in patients suitable for this surgery as well [9–11]; however, the long-term results of their study have not been reported.

In the present study, we evaluated the early and long-term results obtained from this procedure in our single-centre experiment.

2. Patients and methods

From January 1993 to July 2009, we performed thoracic endovascular aortic repair (TEVAR) in 1050 of a total of 1458 thoracic and thoraco-abdominal aortic surgeries. Of these 1050 cases of TEVAR, 86 patients with TAAA underwent TEVAR with the reconstruction of abdominal visceral arteries in a

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Table 1
Patient's demographics and aortic characteristics.

Patients	86
Mean age (range)	71.6 years (47–86)
Gender ratio (male/female)	62/24
Mean aneurysmal size (range)	65 cm (55–88)
Aortic pathologies	
Degenerative aortic disease	55
Chronic aortic dissection (Marfan syndrome)	31 (3)
Crawford classification (modified)	
Type I (%)	15 (17.4%)
Type II	8 (9.3%)
Type III	31 (36.0%)
Type IV	11 (12.8%)
Type V	21 (24.4%)

procedure named the hybrid TAAA repair (mean age of patients: 71.6 years; range: 47–86 years; and 62 (72.1%) patients were male). With the exception of infectious TAAAs, we performed this hybrid procedure for almost all patients who were referred to our hospital during this period. Aortic pathologies included 55 degenerative aneurysms and 31 chronic aortic dissections, and three patients had Marfan syndrome. Aneurysms were classified according to the modified Crawford classification: type I ($n = 15$), type II ($n = 8$), type III ($n = 31$), type IV ($n = 11$) and type V ($n = 21$); type III TAAA was the most common (36% of patients). Median TAAA maximum diameter on the short-axis image was 65 mm (range: 55–88 mm; Table 1). Elective operations were performed in 76 cases (88.4%), and urgent operations were performed in eight patients who were symptomatic but had no radiographic evidence of rupture. The remaining two cases had radiographic evidence of rupture. These patients were high-risk cases with preoperative co-morbidity. Cerebrospinal disorders were present in 19 cases (22.1%), coronary artery disease in 22 cases (25.6%), chronic obstructive pulmonary disease (COPD) in 16 cases (18.6%), a histology of thoracotomy in 18 cases (20.9%) and a history of previous cardiovascular surgery in 29 cases (33.7% cardiac surgery, $n = 7$; ascending, $n = 4$; aortic arch, $n = 3$; descending, $n = 8$; thoraco-abdominal, $n = 2$; and abdominal, $n = 5$; Table 2). In all cases, a 64-row multi-slice computed tomography (CT) was performed for planning and sizing.

Anatomical inclusion criteria for this procedure were as follows: length of proximal and distal landing zone longer than 20 mm, aortic neck diameter of 18–42 mm and absence of circumferential thrombus and the possibility of a visceral artery de-branching. Patients were evaluated by post-operative contrast CT scans at 1, 6 and 12 months, and annually thereafter.

Table 2
Preoperative patient profiles.

Coronary artery disease (%)	22 (25.6%)
Cerebrospinal disorder	19 (22.1%)
Chronic obstructive pulmonary disease	16 (18.6%)
History of thracotomy	18 (20.9%)
History of previous cardiovascular disease	29 (33.7%)
Cardiac surgery	7
Vascular surgery	22
Ascending	4
Aortic arch	3
Descending	8
Thoraco-abdominal	2
Abdominal	5

2.1. Operative procedure

Prior to the procedure, we created cross-shaped bypass grafts with a 12-mm woven graft and an 8-mm polytetrafluorpethylene (PTFE) graft. Procedures were performed under general anaesthesia in an operating room. Following laparotomy, a coeliac artery, a superior mesenteric artery, bilateral renal arteries and the inflow site of bypassing were exposed. Bypass grafts were then constructed from the aortic bifurcation or common iliac artery to the superior mesenteric artery and bilateral renal arteries. The choice of the inflow site was based on the extent of TAAA, whether or not prior abdominal aortic repair had been performed and the quality of the walls of the native aorta and iliac arteries.

Next, side-to-end anastomoses were created by suturing the 12-mm woven graft to a superior mesenteric artery from the inflow site, and end-to-end anastomoses were created by suturing bilateral renal arteries with 8-mm PTFE grafts anastomosed to the woven graft. Finally, side-to-end anastomoses were created by connecting a saphenous vein graft to a coeliac artery with ante-pancreatic graft routing. When we confirmed good collateral circulation from the superior mesenteric artery to the coeliac artery, we occluded the coeliac artery. Grafts were covered with retroperitoneal soft tissue at the end of all procedures (Fig. 1).

We then proceeded to the TEVAR procedure. Shin incisions were made in both groins and both femoral arteries were exposed for stent-graft delivery and aortic fluoroscopy. We used a common iliac artery for the retroperitoneal approach when the femoral artery was too small for sheath insertion. The device-deployment procedure was the same for each device system. When the size discrepancy between proximal and distal sites of the landing zone was at least 120%, tapered devices were used (e.g., home-made devices or the Talent Thoracic Tapered Stent Graft). In almost all cases, TEVAR was performed on the day after the bypass procedure.

The absence of endoleaks and good patency of visceral bypasses were assessed by completion aortography after deployment of the stent-grafts in all cases.

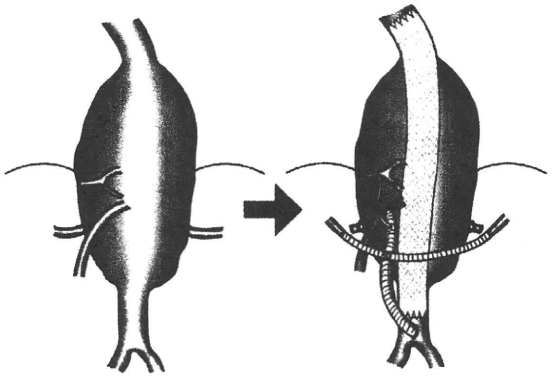

Fig. 1. The procedure of hybrid endovascular aortic repair for thoraco-abdominal aortic aneurysms (see text).

For spinal cord protection, cerebrospinal fluid drainage and a dose of naloxone were initiated during the operation and continued for 24 and 72 h after surgery, respectively, in all cases. Cerebrospinal fluid was allowed to drain freely with gravity with a target pressure of 10 mmHg.

2.2. Statistical analysis

All data were analysed retrospectively. Continuous variables were expressed as mean + standard deviation and categorical variables as percentages. Survival and freedom from aortic events were estimated by the Kaplan–Meier method. Data analysis was performed using the Statistical Package of Social Sciences version 11 (SPSS 11.0) for Windows (SPSS Inc. Chicago, IL, USA).

3. Results

3.1. Procedural results

In 11 cases (including two cases of rupture), operations were performed simultaneously, and 75 patients received staged operations. In staged operations, the mean interval between bypass and TEVAR was 1.2 days (range: 1–6 days).

A total of 304 visceral artery bypasses were performed (56 to the coeliac artery, 86 to the superior mesenteric artery and 83 to bilateral renal arteries). Mean number of bypass grafts was 3.6. A total of 49 patients received a quadruple bypass involving all abdominal visceral arteries, 34 received a triple bypass and three received a double bypass. Bypass to the coeliac artery was not performed in 34 cases. The coeliac artery was shown to be occluded in preoperative CT scans in nine cases. In 25 cases, we verified good collateral circulation from the superior mesenteric artery to the coeliac artery, so we occluded the coeliac artery during surgery by ligation ($n = 6$) or by coiling before the operation ($n = 19$) (Table 3).

For the present study, we used home-made devices (thin-walled polyester grafts and stainless-steel Z stents) in 75 cases, TAG thoracic endoprostheses (WL Gore & Associates, Phoenix, AZ, USA) in 10 cases and the Talent Thoracic Stent Graft (Medtronic, Minneapolis, USA) in one case (mean number of devices used: 2.4). In 27 cases, we used tapered devices (home-made devices, $n = 26$: Talent devices, $n = 1$).

Mean operative time was 382 min (reconstruction of visceral arteries: 259 min; TEVAR: 123 min). The access vessels for TEVAR were the common femoral artery ($n = 75$), iliac artery ($n = 9$) and aortic prosthetic grafts ($n = 2$).

Table 3
Visceral artery bypass of the hybrid TAAA repair.

Total amount of visceral bypass grafts	304
Target vessels	
Coeliac artery	56
Superior mesenteric artery	86
Left renal artery	83
Right renal artery	83
Mean number of bypass grafts	3.6
Quadruple bypass (coeliac, SMA, bil. renal)	49
Triple bypass (SMA, bil. renal)	34
Two bypass (coeliac, SMA)	3

TAAA, thoraco-abdominal aortic aneurysm.

Intra-operative type I endoleaks were detected in four cases, so we treated these with Palmatz XL (Cordis Co., New Brunswick, NJ, USA), and endoleaks were eliminated in all cases.

3.2. Early results

Procedural success was achieved in all cases. Two patients (2.3%) died within 30 days of the operations, one due to bowel necrosis by a thrombus and the other due to sepsis from cholecystic necrosis. Shaggy aortae were detected by preoperative CT scan in both cases. No patient deaths occurred prior to discharge from our hospital.

Postoperative complications included minor brain infarction ($n = 1$), acute renal failure without haemodialysis ($n = 2$), prolonged ileus (>7 days, $n = 3$) and one graft to the renal artery was occluded at 2 months following surgery, however, the patient's other kidney remained well preserved with a functioning graft, and no further intervention was pursued. In this study, we observed no incidences of paraplegia and one case of transient paraparesis, and all patients were discharged after achieving independent gait. Median duration of hospital stay was 26 days (range: 14–69 days).

Nine endoleaks (10.5%) were detected by CT scan at the time of discharge. Type II endoleaks were observed in five cases. Back-flow from a superior mesenteric artery to the aneurysm occurred in two of these cases due to loose ligation of a superior mesenteric artery, and intervention with coiling was performed successfully. The other three patients were followed with CT scan. Type I distal endoleaks occurred in two cases; these were successfully treated by additional intervention with Palmaz XL stents. Type III endoleaks were found in two cases; one patient underwent additional TEVAR, and one patient was treated with a balloon at the site of the leak. Both type III endoleaks were eliminated with these interventions (Table 4).

We detected an Adamkiewicz artery in 25 patients within the last several years using a 320-row multi-detector CT; 23 of these were detected prior to surgery. All arteries were shown to be occluded by TEVAR by postoperative CT scan and no incidence of postoperative paraplegia occurred in any of the 23 cases.

3.3. Long-term results

Aneurysmal size was determined by follow-up CT scan (mean follow-up time: 88.5 months; follow-up completion rate: 98.8%). All-cause survival rate was 94.8% at 2 years,

Table 4
Early results of the hybrid TAAA repair.

30 days mortality	2.3% (2/86)
Postoperative complications	
Renal failure (%)	2 (2.3%)
Prolonged ileus	3 (3.5%)
Graft occlusion	1 (1.2%)
Paraplegia	0
Paraparesis (transient)	1 (1.2%)
Endoleak	9 (10.5%)
Migration	0

TAAA, thoraco-abdominal aortic aneurysm.

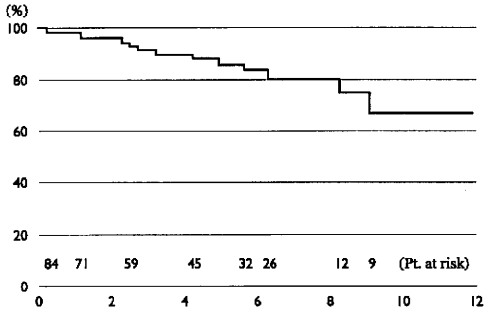

Fig. 2. All-cause survival rate; 94.8% at 2 years, 85.8% at 5 years, 80.2% at 8 years, and 66.6% at 10 years.

85.8% at 5 years, 80.2% at 8 years and 66.6% at 10 years (Fig. 2). Only two patients died due to aortic events; one patient experienced graft occlusion of a superior mesenteric artery resulting in fatal mesenteric necrosis, and the other patient experienced graft infection due to a duodenal fistula. We performed emergency resection of the duodenum and the graft, but this patient died due to multi-organ failure.

Freedom rate from aortic events was 90.7% at 2 years, 80.6% at 5 years, 70.8% at 8 years and 70.8% at 10 years (Fig. 3). Three patients underwent operations for other aneurysms (iliac aneurysm, $n = 2$; annulo-aortic ectasia, $n = 1$). We detected new endoleaks in five patients during follow-up; one patient experienced a type I distal endoleak 3 years after the operation, which was successfully treated by intervention with Palmatz XL stent, and two patients experienced type III endoleaks due to stent-graft migration after 2 years and 3 years. Both patients underwent additional TEVAR and these endoleaks were eliminated. We identified type II endoleaks in two patients during follow-up. Both patients were followed with CT scan because the size of the aneurysms did not change.

In the latest CT findings, short-axis imaging of aneurysms demonstrated shrinkage in 73 cases, no change in 11 cases and enlargement in two cases. As we were unable to detect any type of endoleak in the two cases with enlargement, both cases have been followed intensively with CT scans.

4. Discussion

Surgical treatments have recently shifted to minimally invasive procedures to improve postoperative QOL. As

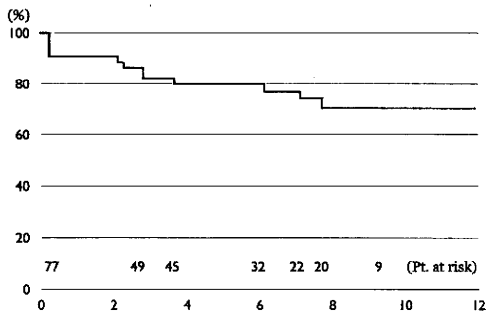

Fig. 3. Freedom rate from aortic events; 90.7% at 2 years, 80.6% at 5 years, 70.8% at 8 years, and 70.8 at 10 years.

pioneers of this procedure, we have achieved solid results in endovascular aortic repair with stent-grafts since 1993 [12]. Postoperative paraplegia after endovascular repair for inferior thoracic aneurysms has been considerably reduced in our experience. We have, therefore, developed a new procedure, which allows for reconstruction of visceral arteries followed by TEVAR to cover the entire aneurysm.

The present study obtained excellent early and long-term results. All-cause survival rate was 80.2% at 8 years, and 66.6% at 10 years, which is significantly higher than rates observed following conventional surgical procedures. One reason for our good results was our follow-up system. For long-term follow-up, all patients received CT scans once every year to prevent serious issues such as aortic rupture due to stent-migration or endoleaks. Freedom from aortic-related events was 70.8% both at 8 and 10 years, due to migrations and endoleaks that are specific complications of endovascular repair. We identified five new endoleaks, three of which required critical attention. These patients could have died had we not detected the endoleaks by CT scan.

Graft patency is the most important factor for obtaining good long-term results from this procedure. In the long-term, only two patients died due to graft problems. We achieved excellent graft patency of bypassing to visceral arteries, which represented good long-term results Encouraging patency rates of 90–95% at 3 years have been reported in some series of bypass grafting for chronic mesenteric ischaemia and treatment of renal artery stenosis [13,14]. However, the safety and durability of retrograde bypass grafting have remained controversial. Kansal et al. [15] reported no difference in patency between antegrade and retrograde grafts in this later series.

Attainment of satisfactory patency for bypassing as well as excellent long-term results depends on the management of graft bypassing. The following three key points are recommended as ways to obtain good bypass patency.

(1) Bypass-graft shape

We created a cross-shaped graft for visceral bypassing, as described in Fig. 1. The bypass technique with this was simple and required a short operative time due to the few sites for anastomoses. In addition, graft lengths were short, especially in renal arteries.

(2) Selection of bypass-inflow sites

The appropriate choice of inflow sites is very important for excellent long-term graft patency. Prosthetic grafts are thought to be the best inflow sites for the visceral bypass to avoid sutures on the atherosclerotic native arterial wall and emboli from shaggy aortas [16]. We, therefore, performed graft replacement of abdominal aortas in 32 cases even when aneurysms were small. When the common iliac artery was used for the graft inflow, we also performed graft replacement to attain the ideal inflow.

(3) Bypass-graft route

Bypass-graft routes must also be selected carefully; we had a patient with a duodenal fistula. After experiencing this complication, we have tried to maintain separation of the grafts from the gastrointestinal tract by covering grafts with retroperitoneal soft tissue [16]. Visceral grafts require close monitoring to

reduce the risk of late enteric erosion or fistula in their extra-anatomic route.

The most significant advantage of this procedure is the extremely low incidence of postoperative paraplegia. We had only one patient with transient paraparesis on the day following surgery from hypotension due to paroxysmal atrial fibrillation; by maintaining increased blood pressure, this patient recovered completely. According to a report from Griepp and Griepp [17], the spinal cord has high collateral circulation and a collateral network. Therefore, if we occlude several intercostal arteries, spinal cord ischaemia may not occur immediately. In addition, some believe that reconstruction of the Adamkiewicz artery may be important to prevent postoperative paraplegia. However, Adamkiewicz arteries were detected by preoperative CT in 22 cases occluded by TEVAR in the present study, and there was no incidence of postoperative paraplegia in these cases. Thus, the necessity for reconstruction of intercostal arteries for TAAA repair should be reconsidered.

Some studies have reported a 'steal phenomenon', which describes back-flow from intercostal arteries in the aorta where the aorta was dissected between the aortic clamping for the graft replacement of an aortic aneurysm [17–19]. Some studies reported that postoperative paraplegia was not common when conventional surgery for thoracic descending aneurysm was performed after ligation of the intercostal arteries in the operative lesion [19,20]; this procedure may prevent the steal phenomenon in cases where conventional TAAA surgery surgeries are performed. Thus, it is not difficult to understand how the rate of postoperative paraplegia is reduced due to the absence of the steal phenomenon in TEVAR.

The choice of simultaneous or staged procedures is an issue in hybrid TAAA repair and is made according to the specific clinical situation of each case. The staged strategy reduces operative invasiveness and postoperative complications, but as the interval between the bypass operation and TEVAR is extended. The risk of rupture may increase. In our treatment strategy, we use a staged operation, and TEVAR is performed on the day after re-vascularisation of visceral arteries.

Although we have achieved satisfactory early and long-term results for the hybrid TAAA repair, this procedure is not appropriate for all TAAAs. Additional long-term results are needed prior to use of this surgery in young patients. A branched device is strongly desired in the endovascular field [21,22]; if a branched device is approved for TAAAs, surgery to treat TAAAs will shift to simple TEVAR with branched devices. In the meantime, this hybrid procedure with TEVAR may become one of the standard procedures.

5. Conclusion

We have obtained satisfactory early results for hybrid TAAA repair; in particular, the complete lack of postoperative paraplegia strongly encourages us to use this procedure without hesitation. In the long term, the rate of aortic event-related death was extremely low. There were more than a few aortic events, especially specific complications related to endovascular repair, such as migrations and endoleaks; these patients required follow-up CT scans at regular intervals.

Based on our early and long-term results, we conclude that the hybrid TAAA repair may become one of the standard surgeries for TAAAs in high-risk patients although sufficient follow-up is needed for visceral bypass.

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Appendix A. Conference discussion

Dr M. Grimm *(Vienna, Austria)*: The results are very impressive and in contrast to the currently available literature reporting these small results in this combined approach. As a consequence, I feel that it is important to work out factors that are perhaps responsible for this difference to the current literature with your results.

In the current literature, most of the reports are dealing with Caucasian people suffering from obesity, they are suffering from COPD, so surgical exposure during the initial procedure seems to be more problematic than in people from Asia, as we know that these people are smaller. Do you think, this is my first question, that the smaller body surface area or body mass index of Japanese people maybe makes it technically simpler as compared to Caucasian patients?

The second question is: These are truly very excellent results. Nevertheless when comparing it with results of the surgical repair of a thoracoabdominal replacement of the aorta, don't you think that the higher need of repeated investigations by CT scans may be problematic for the patient and also more costly?

And the third question is: Could you be so kind as to give us a definition. What is a high-risk patient in your cohort and what is a low-risk patient? And do low-risk patients go into conventional surgery?

Dr Kuratani: All of the Japanese patients are, as you say, very small and the Asian people are the same. But usually it is better to expose the artery or the anastomosis. The Japanese people and the Asian people have a very low rate of diabetes or hypertension, so the aorta and also the artery are good. It is better in such a small surface patient, it is better to use this operation.

And as to cost, there are many cities in Japan, and there is a difference in the insurance compared to Europe and the USA. But I think that the cost is higher than the conventional operation, because there are many CT scans and checking is a need in the difficult patient. So maybe the cost is higher. And so we selected only the high-risk patients. For the low-risk patients, it is better to do the conventional operation. Maybe the risk is maybe the same.

Dr Grimm: Could you just briefly give us an impression, what is high risk? What are risk factors that turn people into high-risk or low-risk groups in your series?

Dr Kuratani: The high-risk series, high risk is okay.

Dr G. Wheatley *(Phoenix, Arizona, USA)*: Why did you choose a saphenous vein graft to the coeliac artery versus PTFE?

Dr Kuratani: Before we used a PTFE graft. In one case we had intestine and also a gastric fistula occurring with this PTFE graft, so that we changed it to the saphenous vein graft. After the changing, we have no problem with this graft.

Dr J. Bachet *(Abu Dhabi, United Arab Emirates)*: I'm very impressed by the number of patients that you find in your experience, 86 patients of this kind is an important number. I have no experience in this matter, so my question should be irrelevant. But, as I observe, it is heavy surgery. So to repeat what the previous discussant said, how did you define what are high-risk patients and not high-risk patients?

And a subsidiary question: is the use of your method a systematic policy in your department or it applied only to a few selected patients?

Dr Kuratani: That's a very difficult question. This operation is not so risk invasive, I think. So this operation, I avoid thoracotomy and the postoperative paraplegia rate is very low. This point is very good for this operation. The hybrid operation with this TEVAR operation, I think in the future, if the branched stent-graft is approved, maybe we can use this stent-graft. But now we cannot use this stent-graft, so as such avoids postoperative paraplegia, maybe this operation is an advantage for such a patient.

Dr Bachet: Yes. But I'm somewhat surprised that you focus only on paraplegia. There are other complications in this kind of surgery, like death, for instance. Having done a few cases of vascular surgery in my life, I know, as everybody here, that from time to time those Dacron prostheses get occluded. For instance, when you put the two renal arteries in the same mustache on an iliac deviation as I've seen on one of your slides, in how many patients will this occlude in the future? You don't know. And we know that surgery is not always perfect. I mean, the grafts might be too long and kink, they can be too short and be stretched, et cetera. So don't you think that you may be trading a risk for another higher risk?

Dr Kuratani: You say that maybe we use a long bypass, so there is some trouble in the future. But we have a long-term result in the 10 years. We have two cases with a left occlusion. One case in the renal artery occlusion, and one case the supramesenteric artery bypass occlusion, and there is no kinking. This is a technical problem. We changed the operation and change it, change it, change it. And before we used a long bypass on each visceral bypasses. And now we use this bypass system. After changing to this bypass system, we have no occluded and also no kinking and no problem about the graft problem.

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CURRENT TOPICS REVIEW ARTICLE

Current strategy of endovascular aortic repair for thoracic aortic aneurysms

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Abstract Thoracic aortic aneurysms are extremely burdensome to treat owing to their surgical complexity. In particular, major postoperative complications lower significantly patients' quality of life. Surgical treatment has recently shifted to thoracic endovascular aortic repair (TEVAR) to respect the patients' needs and improve postoperative quality of life. This procedure is radical and innovated for thoracic aortic pathology, but the devices and the delivery systems are immature because only a little over a decade and a half has passed since starting to use them. Ready-made stent-grafts were originally indicated only for degenerated aortic aneurysms, but aortic dissection and traumatic aortic transection will become the next targets for TEVAR. This review addresses the history and changes in TEVAR as well as the current TEVAR strategy. Finally, we describe a new trial of TEVAR for aortic dissections, traumatic aortic transections, and aortic arch aneurysms.

Key words Endovascular aortic repair · Thoracic aortic aneurysm · Aortic dissection · Stent-graft · Hybrid procedure

This review was submitted at the invitation of the editorial committee.

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Introduction

Thoracic endovascular aortic repair (TEVAR) for aortic pathology is a young procedure as it has only been a little over a decade and a half from the first clinical procedure.[1–4] The procedure is radical and innovative, but technology has not kept up with medical advancements. It is expected that this procedure will have a successful future.

However, we should not forget that the good results of TEVAR rest on the achievement of graft replacements for aortic aneurysms, and the operative methods should be chosen only after evaluating the risks and benefits.[5] Hence, we should not hesitate to perform conventional surgery when a case is beyond the reach of TEVAR.

To clarify the issues surrounding TEVAR, we first explain the functions of TEVAR and then outline the treatment strategy for each pathology seen in the thoracic descending aorta and the aortic arch. Finally, the future possibilities of TEVAR are described.

TEVAR devices

In Japan, we started performing endovascular aortic repair for type B dissections with homemade devices in 1993.[6] These stent-grafts were made of thin-walled polyester grafts and stainless Z stents.

In Europe, 12 kinds of ready-made stent-grafts for thoracic aortic aneurysms were approved; and in the United States, Gore thoracic aortic graft (Gore TAG; Gore, Newark, DE, USA) , TX2 (Cook, Spencer, IN, USA), and Talent graft (Medtronic, Grand Rapids, MI, USA) were approved by the U.S. Food and Drug

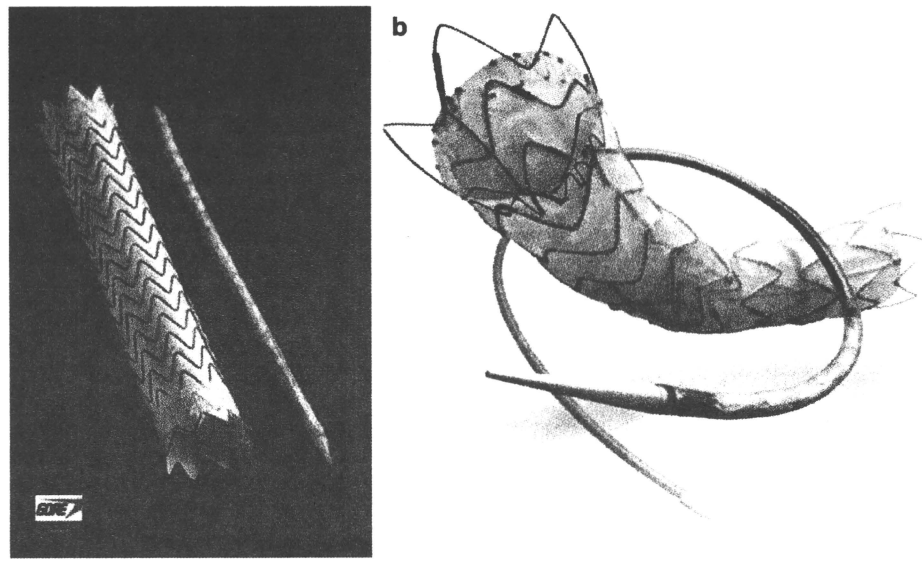

Fig. 1 Ready-made stent-grafts. **a** Gore thoracic aortic graft (TAG). **b** Talent (Medtronic)

Administration (FDA). In Japan, only TAG and Talent have been approved up to now (Fig. 1). TAG has wonderful flexibility and an unique deployment system, so this device may be applicable for almost all lesions of the aorta.[7] The new TAG devices are tapered with diameters >40 mm and may be developed within the next few years. Talent has a tapered type and has a diameter >40 mm. However, the flexibility of Talent is poor, so this device should be used only for straight lesions of the aorta.

Several new devices of endovascular aortic repair will be approved during the next few years, and TEVAR's success rate will improve with the new devices.

Thoracic descending aortic aneurysms

Degenerative aortic aneurysms

The pathological indication for using ready-made stent-grafts was originally only degenerated (true) aortic aneurysms. Therefore, we first described TEVAR for degenerated thoracic aneurysms. Almost all true aneurysms end in aortic rupture even if the best medical treatment is performed. Furthermore, the mortality rate associated with aortic rupture is >90% even if subsequent surgery is performed.[8] Unfortunately, conventional surgical treatment for thoracic aortic aneurysms is highly invasive, and the results are unfavorable for the elderly and high-risk patients.[9] As a result, less-invasive surgical techniques are necessary, and we believe that thoracic endovascular aortic repair serves such a purpose.

In Japan, we used only home-made stent grafts from 1993 to 2008.[10,11] However, so many doctors were not able to venture into the endovascular aortic repair field, the ready-made stent-graft called TAG was approved in 2008. Thus, treatment of true thoracic aortic aneurysms may be shifted from conventional surgery to TEVAR in the near future.

The thoracic aortic graft achieved excellent early and midterm results in some studies. A Phase II multicenter trial of TAG in the United States achieved excellent results: Brain infarctions were down to 4%, postoperative paraplegia was reduced to 3%, and the freedom rate of aortic-related death was 97% during the first 2 years.[12] In comparison to conventional surgery, the incidences of brain infarctions, paraplegia, mortality, and intensive care unit (ICU) stays after TEVAR were significantly lower. TEVAR also achieved better midterm results than did conventional operations.[7]

However, the access route for TEVAR was more troublesome than that of conventional surgery. The diameter of TAG's sheath is too large for Japanese people (and other Asian people). According to our data, the iliac artery or aortic approach was used in 45 of 112 cases (38%) treated with TAG. For our homemade devices, we usually use 20F (inside diameter) sheaths, so the iliac artery approach with homemade devices was used in <5% of patients. Rupture of an iliac artery is a serious problem, so when we have to use large sheaths we should select the iliac artery approach to prevent rupture of an iliac artery.

The incidence of endoleak by TAG was 5.6%–29.0% in the early results.[7,12,13] We advocate performing reintervention for type I endoleak; however, how to treat

type II endoleak is controversial. As we had one aortic rupture with a type II endoleak, we have since aggressively performed interventions with the coiling method. Long-term results with type II endoleak are seriously needed.

Aortic dissection

Treatment strategy for acute aortic dissection may be similar worldwide. For type A dissection, almost all surgeons perform an emergency operation to close an intimal tear. For type B dissection, medical therapy is commonly selected, although complicated cases may require emergency operations. The results of type B aortic dissection after best medical treatment are not satisfactory.[14] Aneurysms expand in both transverse and longitudinal directions, and aneurysms involving visceral arteries have serious consequences for the patients. Finally, the true lumen becomes narrower. Hence, we need to operate during the chronic phase. In such a situation, however, the thoracoabdominal aorta might need to be addressed surgically. We think a less invasive operation at an earlier phase of aortic dissection is the best procedure.

We started to use TEVAR for type B aortic dissection with a homemade stent-graft in 1993 (Fig. 2). The device and technique have been improved since then, so we have been able to achieve excellent early and long-term results. For acute type B aortic dissection, based on our data, the pseudolumen might be expected to diminish when an intimal tear is closed by TEVAR. A Stanford University study during the 1990s reported similar long-term results after applying TEVAR for acute type B dissection.[15]

To achieve good results for TEVAR, strict measurement of the circumference is important. The proximal diameter of stent grafts was oversized 10%–20% of the native aorta, and the distal diameter was oversized 5%–10% so as not to create a new intimal tear; bare stents were never used. When there was a discrepancy of >120% between the proximal and distal diameters at the deployment area, we decided to use a tapered stent-graft.

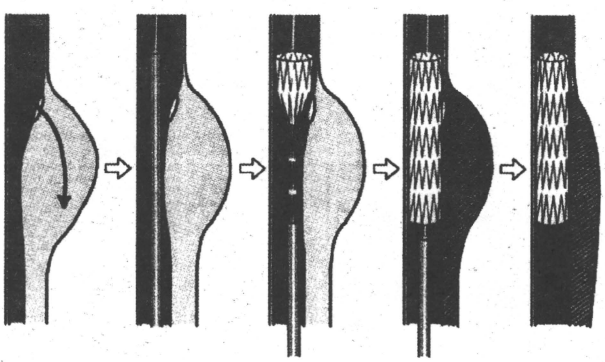

Fig. 2 Thoracic endovascular aortic repair (TEVAR) for type B aortic dissection with a homemade device

As for the treatment strategy for type B dissection, we usually select medical treatment for uncomplicated cases and surgery for those that are more complicated. However, the results of the surgery have never been satisfactory. In contrast, a recent compendium summarized the results of 39 published studies of TEVAR in 609 cases with type B dissections.[16–27] Procedural success was achieved in 96%, with only 2.3% of patients requiring in-hospital surgical conversion. The prevalence of neurological complications was remarkably low: brain infarction 1.2% and postoperative paraplegia 0.5%.

On the other hand, the treatment strategy for uncomplicated cases was controversial. Nienaber et al. conducted the INSTEAD trial for uncomplicated aortic dissections in Europe.[18] The study did not achieve favorable results owing to problems with the devices and trial institutions. Among our preliminary data of 12 acute uncomplicated cases, there were no operative deaths or postoperative major complications. The rate of freedom from aortic events was 100% for 3 years.

Currently, ready-made devices for aortic dissections, such as the Gore TAG, have diameters ranging from 26 mm to 40 mm, so it may be difficult to use them on aortic dissections. Talent has a large variety of diameters of stent-grafts, but Talent does not have enough flexibility for aortic dissections. Our treatment strategy of TEVAR for acute type B aortic dissection requires that we use short stent-grafts only when needed to cover intimal tears. hence, we have recently used the Gore aortic extender for aortic dissection because it comes in diameters of 23.0, 26.0, and 28.5 mm; and the length is only 3.3 cm. We used it in only a few cases, but the results were excellent.

TEVAR for type B aortic dissection is acceptable. Therefore, once companies develop next-generation devices for aortic dissection, TEVAR might be become the next major surgical treatment in this field.

Traumatic aortic aneurysms

The operative mortality rate for traumatic aortic transection is extremely high because these patients have multiorgan injuries and excess bleeding that might occur because of heparinization for cardiopulmonary bypass (CPB). However, the aorta must first be addressed surgically because other operations cannot be

performed until the high risk of aortic rupture is averted. We are expecting TEVAR to perform well in this situation.

In a multicenter study,[28] 30 traumatic aortic transections were performed using TEVAR. All of the cases were successful, and only two ended in late death. One patient had a brain infarction, and the other experienced collapse of the device.

The main area of concern with traumatic aortic transection is the distal arch. Usually, these patients are young and have normal aortas that have smaller diameter than that of elderly patients. Therefore, bird's beak deformities at the lesser curve of the aorta are often seen, and an endoleak might occur. Finally, in the worst scenario, collapse of the stent-graft would lead to malperfusion of the spinal cord, visceral arteries, and legs in such patients.

We strongly recommend that new devices be developed that have excellent flexibility and smaller diameters. If these devices can be created, most traumatic aortic transections can be repaired with TEVAR.

Aortic arch aneurysms

It is difficult when TEVAR is used to address aortic arch aneurysms to achieve a landing zone large enough to prevent endoleaks and migration because there are three cervical arteries. We recommend that the landing zone of TEVAR be at least 2 cm. When a device is not flexible, however, it cannot adjust for aortic angulation. For example, the proximal 4 cm of TAG is not flexible, so the proximal end of TAG is not suitable for a tortuous aorta. Bird-beak deformities occur even if the landing zone is >2 cm. Therefore, we have to use the area in which cervical arteries are branched for the landing zone. In recent years, the reconstruction of cervical arteries for bypassing them with prosthetic grafts (debranching) may be the most useful technique.[10,29–31]

In our university hospital, we performed debranched TEVAR for elderly patients and patients who cannot undergo CPB because of some severe complications. Debranched TEVAR is the revascularization of cervical arteries with TEVAR to cover the entire aneurysm (Fig. 3).

We performed 87 debranched TEVAR operations from 1995 to 2008. The main procedure, performed in 43 cases, is to bypass from the right subclavian artery to the left subclavian artery and the left carotid artery. When the brachiocephalic artery has stenosis, we perform media sternotomy, and bypass from the ascending aorta to the left carotid artery and left subclavian artery or to three cervical arteries. The landing zone, zone 0, was used in 45 cases; and zone 1 was used in 26 cases. Thus, the incidence of the ascending aorta and proximal arch landing is >70%. The operative mortality was 1.5%, and there was no incidence of paraplegia or conversion to the conventional operation. We had two cases of brain infarction with the fenestrated devices.

When patients with aortic arch aneurysms have no proximal landing zone and can undergo CPB, we have performed the branched open stent grafting technique[32] (Fig. 4). The endoprosthesis is composed of the main body and cervical branches. Grafts are thin-walled woven polyester grafts, and the main body's stented portion is composed of a self-expandable Giantruco Z-stent. The cervical branches are composed of a balloon expandable Palmaz stent with a percutaneous transluminal angioplasty catheter, and they can be opened by inflating the balloon (Fig. 5). With the bladder temperature at 20°C and under CPB, deep-hypothermic circulatory arrest is introduced. The proximal aortic arch is

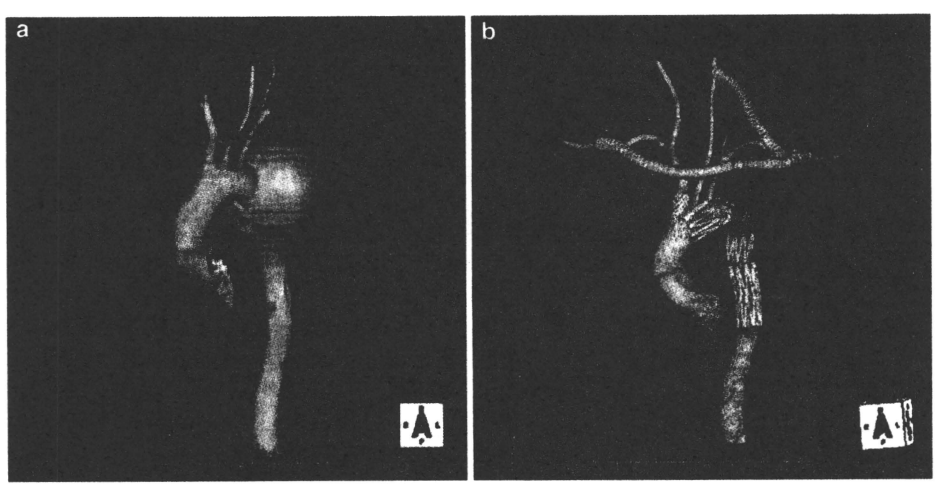

Fig. 3 Debranched TEVAR. **a** Large distal arch aortic aneurysm. **b** We performed the bypass (debranching) from the right subclavian artery to the left subclavian artery and left carotid artery and deployed a stent-graft from just below the brachiocephalic artery

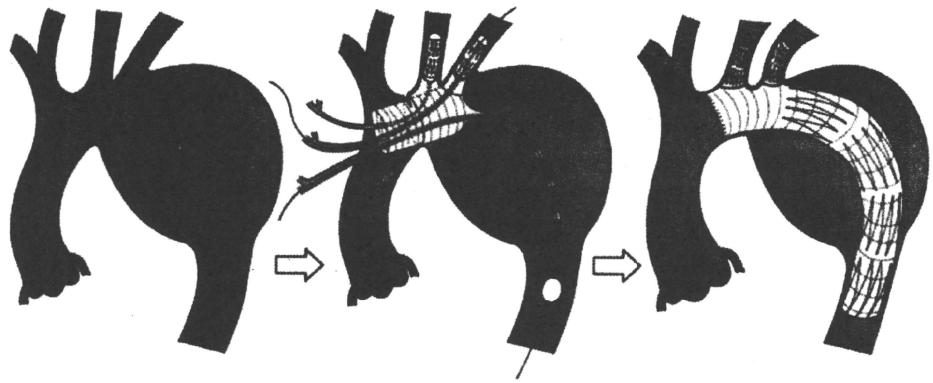

Fig. 4 Branched open stent grafting technique (BOS)

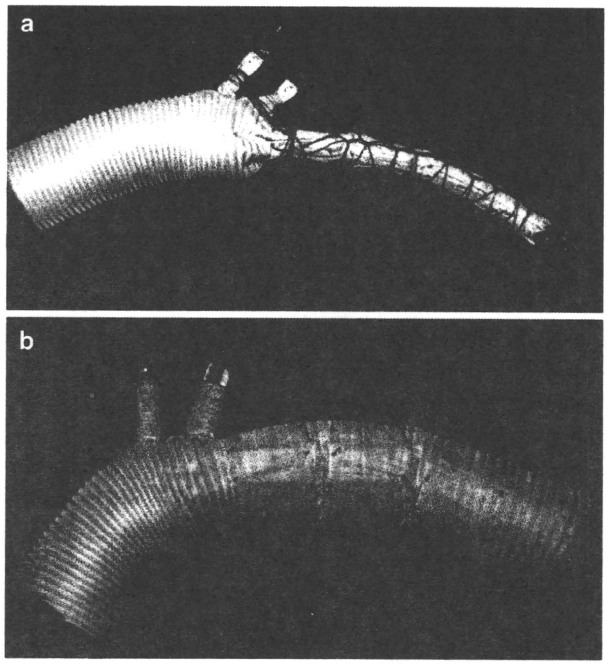

Fig. 5 Homemade device for BOS. **a** Before deployment. **b** After deployment

opened between the brachiocephalic artery and left carotid artery, and the stent graft is inserted through this incision. The main body, the left subclavian artery branch, is guided over the guiding wire. The stent-graft is deployed, and the suturing portion of the stent-graft is anastomosed to the aortic wall or the graft of an ascending aortic replacement by the inclusion technique. The operative mortality was 2.5%, and the incidence of paraplegia was 1.6%. The survival rate is 88% at 3 years. This procedure achieved good results, so we would like to use this procedure with these criteria until branched stent grafts are approved.

Recently, a new stent-graft named Najuta is being used in a clinical trial. This new stent-graft is a fenestrated device for aortic arch aneurysms. It is completely custom-made and has two or three holes to maintain blood flow to cervical arteries. Because it takes several weeks to make them owing to the need for precise adjustment for the holes, this device is not suitable for emergency operations. However, its use might someday replace conventional total arch replacement.

Conclusions

The efficacy of TEVAR for aortic pathology has been presented. Currently, TEVAR for the descending aortic aneurysm is the first line of treatment. In the future, TEVAR will be the first treatment strategy for aortic arch aneurysms. Furthermore, based on some reviews, TEVAR might be performed for aortic dissections because it is a less invasive treatment. We expect to see the development of next-generation devices in the future. Many companies will be competing for fenestrated or branched devices, new delivery systems, and new devices with adjunct treatment, such as a drug-eluting stent graft. We can look forward to the new developments over the next decade.

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弓部大動脈瘤に対する
ハイブリッドステントグラフト治療の現状と将来

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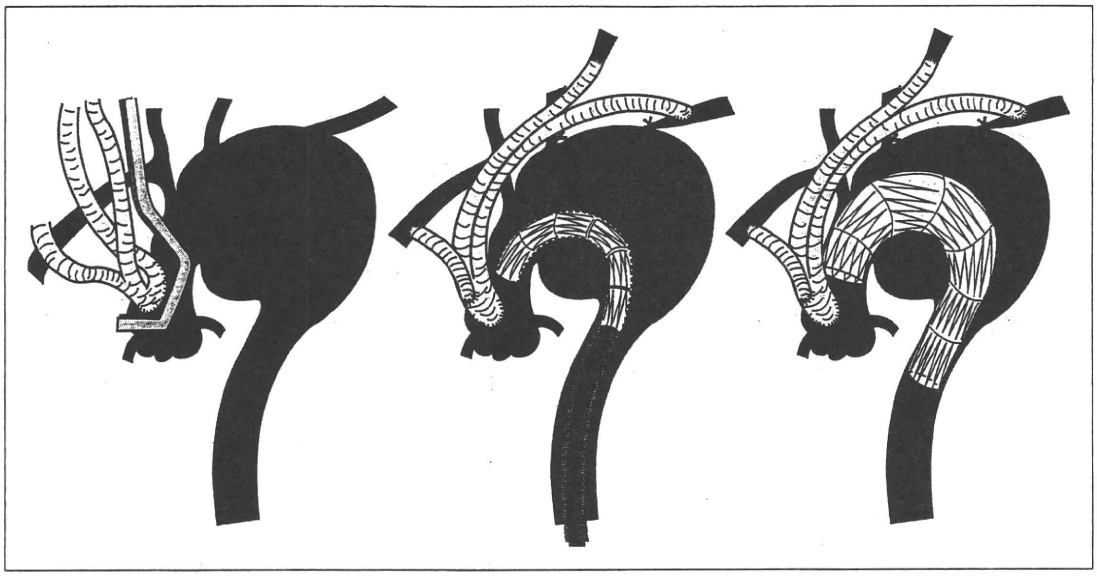

図3　上行大動脈–頸部3分枝バイパス＋TEVAR

flowとして頸部3分枝にバイパスを行う．inflowの吻合場所は，次のTEVARのlanding zoneを上行大動脈に十分得るために，できるだけ上行大動脈基部側に吻合を行っている．またわれわれは，少しでも脳塞栓症を予防するために，左右鎖骨下動脈に端側吻合にてバイパスを行い，左総頸動脈に端々吻合にてバイパスを行っている．このバイパス法を用いると，体外循環非使用下にて弓部全置換と同様のステントグラフト治療が行える．

弓部大動脈瘤の場合，上行大動脈も拡大傾向を示すことが多い．TAGでも最大径が40 mmで，対応サイズとしては最大径が37 mmである．Talentは46 mmまでのdeviceがあるが，シースおよびdeviceのflexibilityから大動脈弓部には適応しがたいステントグラフトと思われる．そのためこのような瘤において，上行大動脈から弓部がlanding zoneに使えないことが多い．このような症例に対しては後述のopen stent-graft法を用いているが，体外循環が用いられない症例に対しては治療法がなくなってしまう．径の大きい症例にいかにステントグラフト治療を行うかが，今後の課題である．また，弓部および上行大動脈がlanding zoneになるため塞栓症による脳梗塞がもっとも危惧される合併症であり，今後脳血管のprotection deviceを開発し，臨床導入されるのが望まれる．

Open stent graft technique

われわれは，中枢側にlanding zoneが十分でない弓部大動脈瘤症例で，体外循環が併用できる患者に対しては，open stent法を積極的に用いている．open stent法は，体外循環下に大動脈末梢吻合をステントグラフトで代用する術式であり，1994年より加藤らが臨床導入を行い[5]，われわれは126例に対してこの術式を弓部大動脈疾患に対して施行した．成績としては，術後30日以内の死亡率は3.2%，術後脳合併症が5.6%，paraplegia 2.4%，paraparesis 4.0%であり，生存率は5年で63.3%，8年で53.7%であった．やはり脊髄障害が多く，脳合併症としても通常手術と同等の値であった．

そこでわれわれは，2004年よりこの術式をさらに改良したbranched open stent grafting（BOS）を臨床導入した[6]．second generationであるBOS法は，通常のopen stent-graftに頸部分枝用の側

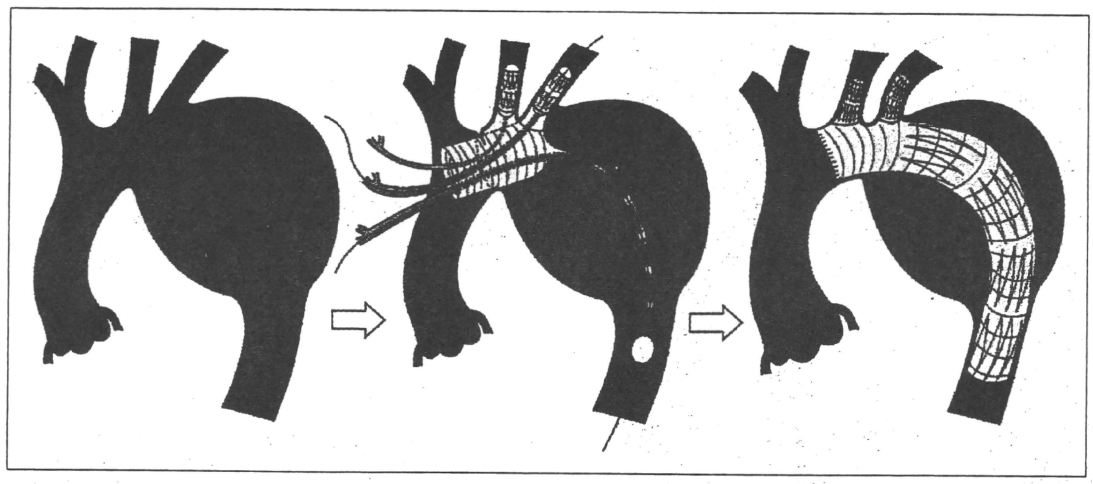

図4　branched open stent 法（BOS）

枝を作成し，体外循環下循環停止下にて大動脈弓部を横切開して，切開部より先に頸部2分枝（左総頸動脈および左鎖骨下動脈）に側枝ステントグラフトを挿入して，さらに大動脈末梢用ステントグラフト本幹を挿入する．これによって分枝付きステントグラフトが大動脈内に挿入できた訳で，最後に中枢側切開部をステントグラフト中枢側をinclusionするように吻合する（図4）．

上行大動脈も人工血管置換が必要な場合は，ステントグラフト中枢側と人工血管を大動脈壁をラッピングするように端々吻合すればよい．このように，頸部分枝および大動脈末梢吻合がステントグラフトで代用できる．手術成功率は98.3%，30日以内の死亡率は3.4%，術後脳梗塞5.0%，脊髄障害3.3%であった．3年での生存率は88.8%と良好な成績を得ることができた．

今後，open stent graft techniqueの分野においても，ライフライン社（旧宇部循研）のready-made deviceが治験中である．今後数年で臨床導入される可能性が高い．

新しい術式
——chimney grafts technique

debranched TEVARにおいて，どうしても胸骨正中切開および上行大動脈のpartial clampが必要となる．これは侵襲が増大するとともに，遮断による塞栓症も危惧される．当然branched deviceが期待されるが，まだ研究段階である．そこで考案されたのがchimney grafts technique である[7]．これは大口径と小口径のステントグラフトを用いる．つまり腕頭動脈から小口径のステントグラフトを上行大動脈にまで挿入し，中枢側が揃うようにして，大口径のステントグラフトを小口径ステントグラフトと同時に留置する方法である（図5）．

この方法では煙突が上行大動脈から腕頭動脈に入ったような形となり，腕頭動脈への血流が確保できる．さらに腕頭動脈から上記のように左鎖骨下動脈と左総頸動脈にバイパスを行うことにより，頸部への血流が確保することができる．この方法により，開胸することなしに上行大動脈を十分なlanding zoneとして用いることができ，かつtotal arch TEVARを完成することが可能となった．まだ長期成績は得られておらず，明確になっていない部分は多いが，branched deviceが用いられるまで一つのオプションとして，症例を選んで使用可能ではないかと思われる．

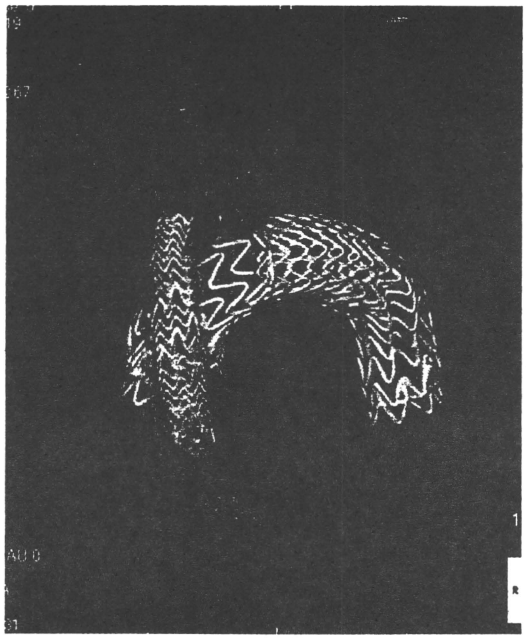

図5　chimney grafts technique
（当院での手術症例）

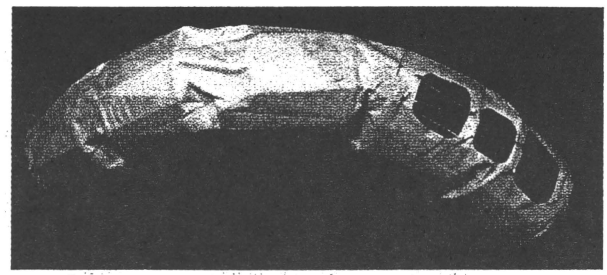

図6　fenestrated device（Najuta）

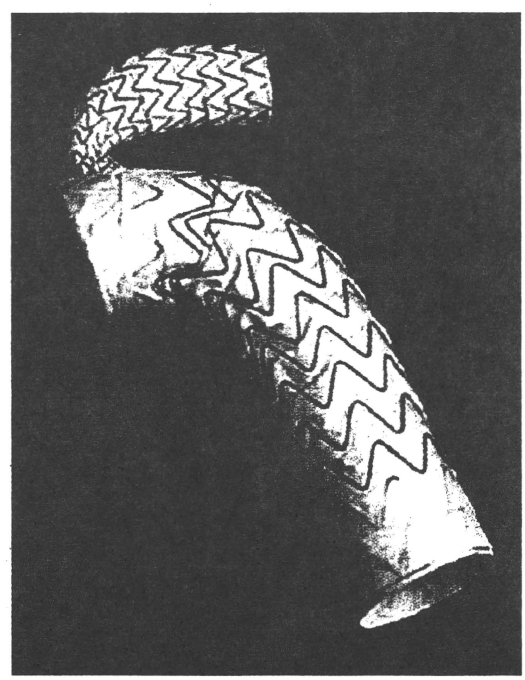

図7　branched device（Gore社）

新しいステントグラフト——fenestrated device と branched device

今後，弓部大動脈疾患に必ず必要となる fenestrated device や branched device は，現在数社で実験もしくは臨床研究中である．Cook 社はこれまで腹部，胸腹部に対して，custom made にて fenestrated device を作成，臨床導入してきたが，弓部大動脈瘤に対してもこの経験を生かして fenestrated device を作成し臨床において使用している．ただ，まだ症例数は少なく，満足できる成績とはいえない．現在日本で治験が開始されている Najuta（川澄化学，**図6**）は，大動脈弓部用の fenestrated stent-graft としては完成度が非常に高い．custom-made type であり，綿密な計測によりストレスなくステントグラフトを留置できる．ただ，このステントグラフトは作成にある程度の期間が必要で，ready-made とは一線を画しているものである．

現在，いくつかの会社が ready-made type の branched stent-graft の完成を目指している．千差万別の頸部分枝と瘤の位置関係から，ready-made が完成するまでにはまだまだ時間を要するのではないかと思われる．ただ Gore 社は single-branch type の弓部大動脈瘤用 device をほぼ完成しているが（**図7**），前述した debranching を併用した術式を導入すれば，single branch のみで十分に弓部大動脈瘤に対応できると考えられる．この device は ready-made device として考案されており，この先5年間で非常に期待できるステントグラフトと思われる．

おわりに

今後ステントグラフト治療は，さらなる進歩が

見込めると思う．今後，device 自体の開発（fenestrated や branched など），挿入システムの改良，device への補助機能の追加（薬剤塗布など）など開発競争がなされるであろう．その中で大動脈血管内治療がどのように改善，進歩していくか次世代に期待するところであるが，10年後の大動脈治療が非常に楽しみである．

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