One-stage replacement of the aorta from arch to thoracoabdominal region

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ABSTRACT

Objectives: We present our experience with one-stage replacement of thoracic aneurysm from the ascending aorta to the thoracoabdominal aorta.

Patients and Methods: Fourteen patients (10 male and 4 female; mean age 53.6 ± 12.4 years) with extended thoracic aortic aneurysms underwent graft replacement. The pathology of the diseased aorta was chronic aortic dissection in 13 patients and intraoperative retrograde aortic dissection in 1 patient. Five patients had Marfan syndrome. In a previous operation, 1 patient had undergone the Bentall procedure, 4 had hemiarch replacement for acute type A dissection, and 1 had a Y-graft for abdominal aortic aneurysm. The approach to the aneurysm was posterolateral thoracotomy with rib-cross incision extended to the retroperitoneal abdominal aorta. Arterial inflow for cardiopulmonary bypass consisted of the femoral artery in 13 patients and abdominal aortic aneurysm graft in 2. Venous drainage site was the femoral vein in 7, femoral vein and pulmonary artery in 3, and pulmonary artery in 1. All patients had antegrade cerebral perfusion and visceral perfusion.

Results: Hospital mortality occurred in 1 patient due to acute myocardial infarction. Actuarial survival at 5 years after the operations was $96.5 \pm 9.8\%$. Freedom from the subsequent aortic events was $91.0 \pm 2.9\%$ at 5 years.

Conclusions: Our treatment method for extensive thoracic aneurysm, from the ascending aorta to the thoracoabdominal aorta, achieved satisfactory results via the use of specific strategies and appropriate organ protection according to the aneurysm extension in the selected patients. (J Thorac Cardiovasc Surg 2018;155:498-504)

One-stage replacement from the ascending aorta to the thoracoabdominal aorta.

Central Message

One-stage replacement of extensive thoracic aneurysm, from the ascending aorta to the thoracoabdominal aorta, can be achieved with appropriate organ protection in selected patients.

Perspective

One-stage replacement of thoracic aneurysm, from the ascending aorta to the thoracoabdominal aorta, can be one of the alternative armamentarium in the surgical treatment of extensive thoracic aneurysm.

See Editorial Commentary page 505.

Extensive thoracic aortic aneurysm is not uncommonly encountered, and chronic dissecting aortic aneurysm after replacement of the ascending aorta for acute type A aortic dissection sometimes extends to the infrarenal aorta.¹ The mega aorta syndrome secondary to extensive atherosclerosis may present as similar aortic lesions. Several surgical strategies have been reported to overcome these serious conditions. A 1-stage operation of extensive aortic aneurysm requires a wide exposure of the aneurysm and dissection, secure organ protection, and sound hemostasis.

Preoperative comorbidities may often preclude this aggressive approach. A staged operation is often a preferable choice, with safety as the priority.^{2,3} However, this strategy may result in a greater-than-expected mortality, considering the combined mortality of the first and second operations, as well as death in the interval between operations. Hybrid procedures consisting of open arch repair with additional endovascular stenting or a total endovascular approach have been tried⁴; however, stabilization of the thoracoabdominal aortic area has not been established. In this report, we present our experience with 1-stage surgery from the ascending aorta to the thoracoabdominal aorta.

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Scanning this QR code will take you to a supplemental video for the article.

Abbreviations and Acronyms

- ACP = antegrade cerebral perfusion
- CSF = cerebrospinal fluid
- MEP = motor-evoked potential
- TAAA = thoracoabdominal aortic aneurysm

PATIENTS AND METHODS

This study was approved by the internal review board at Kobe University, and individual consent from patients was waived. This study received no funding.

Fourteen patients (10 male and 4 female) with extended thoracic aortic aneurysms underwent graft replacement from the ascending aorta to the thoracoabdominal aorta from September 2006 to January 2017. The age at operation was 53.6 ± 12.4 years, ranging from 27 to 75 years. Five patients had Marfan syndrome, and 8 had hypertension. The indications for open surgery were that the maximum diameter of the thoracic aorta exceeded 55 mm and that the patients weren't frail. The extent of the replacement of the aorta was defined at the aortic diameter of 40 mm. During the same period, we performed total arch replacement in 818 patients and replacement of the thoracoabdominal aorta type II Crawford extension in 85 patients. The pathology of the diseased aorta was chronic aortic dissection in 13 and acute intraoperative aortic dissection in 1 patient. This patient had retrograde dissection from the distal arch to the ascending aorta during repair of the thoracoabdominal aorta. Two patients had dissecting type B aortic aneurysm with dilatation of the aortic arch, and 2 had dissecting type B aortic aneurysm with involvement of the arch. In a previous operation, 1 patient had undergone the Bentall procedure, 9 had hemiarch replacement for acute type A dissection, and 1 had a Y-graft for abdominal aortic aneurysm. Profiles of the patients are shown in Table 1.

Surgical Procedure

Endotracheal intubation is performed with a double-lumen endotracheal tube or a selective left main bronchus blocker, enabling collapse of the left lung. Drainage from the cerebrospinal fluid (CSF) drainage catheter, installed the day before, and intraoperative transcranial motor-evoked potentials (MEPs) were recorded in all patients. CSF pressure was assessed with an intrathecal catheter, and the CSF was allowed to drain spontaneously if pressure increased greater than 10 mm Hg. CSF drainage was continued for 72 hours postoperatively. Transcranial electrical stimulation was performed to monitor MEPs. These strategies include selective reattachment of intercostal and lumbar arteries as well as blood pressure management to maintain spinal cord blood supply.

Both groins were exposed and were accessible as Stoney's position to allow access to the right femoral vein and the femoral artery with the patient in the supine position. Then, the patient was set to the right semirecumbent position. Usually, a straight 50-cm-long incision in the skin was made from the left subscapular region to the left pararectal line. Approaches to the aneurysm were made through the fourth or fifth intercostal spaces with transection of the several ribs (rib-cross thoracotomy⁵). The retroperitoneal space was entered after transecting the costal arch (Figure 1). The pericardium was opened anterior to the phrenic nerve and the arch was approached over the pulmonary artery, subsequently entering the inner curvature of the arch. The aorta was completely freed from the esophagus after transection of the ductus arteriosus. In all cases, no sternum transection was necessary, and the left internal thoracic artery was preserved.

Arterial inflow for cardiopulmonary bypass consisted of the femoral artery in 13 patients and abdominal aortic aneurysm graft in 2 (1 patient had double arterial inflow). The venous drainage site was from the femoral vein

TABLE 1. Patient profiles

Variables	No %
No. of patients	14
Age, y	53.6 $\pm$ 12.4 (27-75)
Male sex	10
Aortic pathology	
Acute type A dissection	1
Chronic dissection	13
Marfan syndrome	5
Emergent/urgent	1
Comorbidities	
Hypertension	12
Hyperlipidemia	5
Diabetes	2
Old stroke	2
Mild aortic regurgitation	2
Chronic kidney disease (eGFR < 40 mL/min/m ²)	2
Congestive heart failure	1
LVEF	61.7 $\pm$ 23.5% (51%-74%)
FEV _{1.0} %	84.8 $\pm$ 24.5% (35%-118%)
%VC	83.0 $\pm$ 31.2% (34%-128%)
Carotid artery stenosis	0
EuroSCORE II	3.6 $\pm$ 2.1 (1.19-6.9)
Japan score	4.9 $\pm$ 2.4 (0.9-9.5)
Previous operation	
Ascending aorta replacement	9
AAA graft	1
Bentall	1

Variables are presented as mean and standard deviation (range). *eGFR*, Estimated glomerular filtration ratio; *LVEF*, left ventricular ejection fraction; *FEV_{1.0}%*, forced expiratory volume in 1 second, %; %VC, percent vital capacity; AAA, abdominal aortic aneurysm.

in 10, femoral vein and pulmonary artery in 3, and pulmonary artery in 1. All patients had selective antegrade cerebral perfusion (ACP) and visceral perfusion. Patients were cooled down to $25.0 \pm 2.7^\circ\text{C}$ (range 18.6 - 28.5°C), measured by a tympanic thermometer, and $26.4 \pm 3.3^\circ\text{C}$ (range 20.2°C - 33.6°C), measured by a rectal temperature (Table 2).

An aortic crossclamping was performed on the mid-part of the descending aorta, maintaining lower body perfusion. The aorta was opened from the proximal descending aorta to the ascending aorta mainly up to the previous prosthetic graft for the ascending aortic replacement. Cardioplegic solution was administered from the inside of ascending aorta with a balloon-tipped catheter (14 Fr, 40 mL Pruitt; LeMaitre Vascular, Inc, Burlington, Mass). The selective ACP was initiated. A 15-Fr balloon-tipped cannula was inserted from inside the aorta into the brachiocephalic artery, and 12-Fr cannulae were positioned in the left common carotid and left subclavian arteries. We have routinely used self-inflating serrated balloon-tipped cannulae (Sumitomo Bakelite Akita, Tokyo, Japan). Snaring the neck vessels was not necessary. The antegrade selective cerebral perfusion flow was maintained at 10 to 12 mL/kg/min using an independent roller pump, the balloon tip pressure was maintained between 30 and 40 mm Hg, and bilateral regional oxygen saturation on the forehead was closely monitored. A 4-branch Dacron graft (Vasktek [Terumo, Tokyo, Japan] and J Graft [Japan Life Line, Tokyo, Japan]) was first anastomosed to the previous graft or the ascending aorta with 4-0 polypropylene suture

FIGURE 1. A 63-year-old man with chronic type A 3-channelled dissection who had undergone replacement of the ascending aorta 3 years before. He had replacement of the aorta from the abdominal aorta to the aortic arch with reconstruction of the visceral arteries, intercostal arteries, and arch vessels. A, Preoperative CT. B, Illustration (①, ②, ③) of staged clamping. C, Preoperative illustration. D, Postoperative CT.

(Monofulene 22-mm needle; Alfresa Pharma Corporation, Osaka, Japan), and arch vessel reconstruction to the 8- and 10-mm graft branch was done with a 5-0 polypropylene suture (Nesplene 16 mm needle; Alfresa). In 4 patients, arch vessels were reconstructed as an aortic cuff. Perfusion of the heart and brain was re-established after the reconstruction of the brachiocephalic artery through the side branch of the prosthetic graft. Systemic rewarming to 30°C at the rectal temperature was initiated after the reconstruction of the brachiocephalic artery. The heart was defibrillated, and ventilating the right lung was started at the rectal temperature of 34°C.

Reconstruction of the segmental arteries from Th 7 to L2 was performed as necessary in all patients. The target segmental arteries were identified by preoperative computed tomography scans in all patients. They were reconstructed with aortic cuff in 6 patients and with branched grafts in 8 patients. Anastomosis of the intercostal arteries was achieved via the inclusion technique with a 4-0 polypropylene suture (Nesplene; Alfresa). The number of reconstructed intercostal arteries was 3.3 ± 1.6 (1-5) pairs. Segmental-staged aortic clamping was liberally used. Each aortic segment, which contained fewer than 3 pairs of the intercostal arteries, was clamped and opened tandem. We tried to clamp the intercostal arteries externally before the aortic opening or insert balloon-tipped catheters (3 Fr; Pruitt; LeMaitre Vascular, Inc) into the orifice of the intercostal arteries after aortic opening to prevent “blood steal-phenomenon” from the spinal cord. The graft clamp was transposed to perfuse this intercostal artery.

The infrarenal portion of the abdominal aorta was clamped and opened. The button of each visceral artery was created. Both renal arteries were perfused with a 10-Fr balloon-tipped catheter, and the celiac and the superior mesenteric artery were perfused with 12-Fr catheters (Sumitomo Bakelite). Each arterial flow was 150 to 200 mL/min. First, the right renal artery was reconstructed by 5-0 polypropylene sutures to the graft branch, and distal anastomosis was performed using 4-0 polypropylene (Monofulene 22 mm needle; Alfresa) with a Teflon felt reinforcement to have earlier pulsatile reperfusion to the lower body. The superior mesenteric artery and the celiac artery were anastomosed in the same manner. Finally, the left renal artery was anastomosed higher on the main thoracic graft using an 8-mm

graft to prevent kinking the artery. Cardiopulmonary bypass was weaned, and hemostasis was achieved after protamine reversal.

In chronic aortic dissection, in which the true lumen is compressed, or in patients with extensive atherosclerotic “shaggy” aorta or extensive thrombi around the aortoiliac regions, we prefer to reverse the surgical direction because of the unpredictable changes in organ perfusion with retrograde flow through the dissected iliac arteries and aorta (3 patients). At first, an aorto-bi-iliac or aortic tube graft is anastomosed distally, crossclamped, and cannulated as arterial inflow site. After starting extracorporeal circulation, aortic reconstruction is commenced with the abdominal phase, followed by reconstruction of the visceral arteries, segmental arteries, descending aorta, and aortic arch.

The level of the proximal anastomosis was the sinotubular junction in 1, the ascending aorta in 2 patients, a previously inserted ascending prosthesis in 10, and between the innominate and left carotid artery in 1 patient. The distal anastomosis was performed at the infrarenal portion of the abdominal aorta in 3 patients, at the aortic bifurcation in 9 patients, and on bilateral iliac bifurcation in 2 patients. Cardiopulmonary bypass time was 284 ± 36 (232-338) minutes, myocardial ischemic time was 60.4 ± 20.7 (26-107) minutes, and ACP time was 73.6 ± 21.5 (47-123) minutes (Video 1).

Statistical Analysis

Data are shown as mean $\pm$ SD. Actuarial survival was assessed by the Kaplan–Meier method with the SPSS package for Windows (SPSS Inc, Chicago, Ill).

RESULTS

One patient died because of acute myocardial infarction and stroke. The postoperative profiles of the patient groups are shown in Table 3. Average duration of ventilation support was 78.5 ± 175 hours (range 6-576 hours), and

TABLE 2. Cardiopulmonary bypass

Variables	No %
Arterial cannulation	
Abdominal aorta (AAA graft)	2
Femoral artery	13
Venous drainage	
Femoral vein	10
Femoral vein + right atrium/pulmonary artery	3
Pulmonary artery + right atrium	1
Duration	
Cardiopulmonary bypass, min	284 ± 36 (232-338)
Cardiac ischemia, min	60.4 ± 40.3 (26-107)
ACP, min	73.6 ± 21.5 (47-123)
Arch reconstruction	
Individual graft	11
Aortic cuff	3
Segmental arteries attached	3.3 ± 1.3 (1-5)
Proximal anastomosis	
ST junction	1
Ascending aorta	2
Ascending aorta graft	10
Arch (between BCA and CCA)	1
Distal anastomosis	
Abdominal aorta	3
Aortic bifurcation	9
Bilateral common iliac arteries	2
Tympanic temperature, °C	25.0 ± 2.7 (18.6-28.5)
Rectal temperature, °C	26.4 ± 3.3 (20.2-33.6)

Variables are presented as mean and standard deviation (range). AAA, Abdominal aortic aneurysm; ACP, antegrade cerebral perfusion; ST, sinotubular; BCA, brachiocephalic artery; CCA, common carotid artery.

respiratory failure, defined as the need for more than 48 hours of support with mechanical ventilation, was observed in 4 patients. Intractable endobronchial bleeding was seen in 1. The length of stay in the intensive care unit was 5.7 ± 6.2 (2-24) days.

Follow-up

Follow-up was 100% completed. Average follow-up was 5.6 ± 7.6 years (range 0.3–131 months). Thirteen patients were alive and back to their normal life. Actuarial survival at 5 years after the operations was $96.5 \pm 9.8\%$. Freedom from the subsequent aortic events was $91.0 \pm 2.9\%$ at 5 years. One patient with Marfan syndrome underwent repair of the aneurysm of the aortic cuff where the intercostal arteries were attached to the graft.

VIDEO 1. The patient was a 75-year-old woman who had an acute type B aortic dissection 13 years ago. The size of the aorta was enlarged to 52 mm at the distal arch, 45 mm in the diaphragmatic portion, and she was scheduled for the replacement of the thoracoabdominal aorta electively. The patient's position was right semirecumbent, and a left posterolateral thoracotomy and spiral incision were made. Preoperatively, a cerebrospinal fluid drainage catheter was inserted and motor-evoked potential monitoring was done. A femorofemoral partial cardiopulmonary bypass was used, and a replacement of the aorta from the left subclavian to the celiac artery level using a 20-mm Dacron graft with multiple branches was performed. Reconstruction of the intercostal arteries of the left Th 9 and 10 was done under moderate hypothermia at a rectal temperature of 32°C. The aortic arch between the left common carotid and left subclavian artery was clamped and then segmental transitional aortic clamps were liberally used. After the distal anastomosis was complete, a sudden atrial fibrillation occurred, and transesophageal echography showed a new aortic dissection in the aortic arch. A severe aortic regurgitation and ST-segmental elevation on the electrocardiogram were noticed. A full core-cooling to 25°C at the tympanic temperature with an additional venous cannula in the pulmonary artery and a left ventricular venting catheter from the left atrial appendage was done. With the patient in a deep Trendelenburg position, the descending aorta was clamped. While maintaining the perfusion from the femoral artery, the aortic arch was opened. The balloon-tipped catheters were inserted into the each brachiocephalic, left common carotid, and left subclavian arteries and the antegrade cerebral perfusion as started. A cardioplegic solution was given by an aortic occlusive balloon catheter. The intimal tear was originated from the proximal suture line of the descending aorta. Total arch replacement was done with a 22-mm Dacron graft and resuspension of each commissure. Total cardiopulmonary bypass time was 287 minutes, duration of the antegrade cerebral perfusion was 87 minutes, and cardiac ischemia time was 68 minutes. The postoperative course was complicated. The patient required a tracheostomy with enteral tube feeding; however, her hemodynamics were stable, and no new neurologic deficit was recognized. Video available at: [http://www.jtcvsonline.org/article/S0022-5223\(17\)31966-9/fulltext](http://www.jtcvsonline.org/article/S0022-5223(17)31966-9/fulltext).

DISCUSSION

Combined aneurysmal disease of the aortic arch and descending thoracic and thoracoabdominal aorta is rather common, especially in patients with Marfan syndrome. Patients who have undergone ascending aorta or hemiarch replacement for acute type A dissection sometimes have extensive thoracic aortic aneurysms due to residual patent false lumen in the distal false lumen. Also, patients with

TABLE 3. Operative procedure and outcome

Variables	No %
Results	
Hospital mortality	1
Late mortality	0
Postoperative complications	
Brain complications	
Stroke	1
Transient neurologic disorder	0
SCI	
Paraplegia	1
Paraparesis	1
Heart failure (inotropic ≥ 3 d)	0
Prolonged ventilation (≥ 48 h)	4
Tracheostomy	2
Renal failure (required dialysis)	1
Pancreatitis	1
Spleen injury	1
Bleeding	1
ICU stay, d	5.7 $\pm$ 6.2 (2-24)

Variables are presented as mean and standard deviation (range). *SCI*, Spinal cord ischemia; *ICU*, intensive care unit.

chronic type B aortic dissection extending to the arch require replacement of this segment.

This study demonstrates that simultaneous surgical repair of thoracoabdominal aortic aneurysms (TAAAs) and aortic arch aneurysms is feasible through the left-sided extended thoraco-retroabdominal approach. These extensive surgical procedures were performed with acceptable morbidity and mortality. Wide surgical exposure is mandatory, and it is of primary importance to achieve a secure anastomosis. Massimo and colleagues⁶ and Hu and colleagues⁷ reported the efficacy of multiple independent incisions for the exposure of thoracic and thoracoabdominal aneurysms. In most patients in the current series, we could approach the ascending aorta, aortic arch, and the entire descending aorta through the left posterolateral rib-cross thoracotomy, but the aortic root was not accessible with this approach. The posterolateral incision was extended to the left retroperitoneal space, and reconstruction of the visceral arteries or reattachment of the intercostal arteries is technically feasible.⁵

Several strategies have been described that address these extensive aortic lesions. Patients often have multiple, staged operations with elephant trunk installation in the descending aorta for the extensive aortic lesions. Initially, the aortic arch, and if required the ascending aorta, is repaired through a median sternotomy. During the second stage, the descending thoracic aortic aneurysm or TAAA is repaired via a left thoracotomy or thoraco-retroabdominal approach. Accordingly, there may be significant mortality in each staged operation. Furthermore, many patients do not return for the second operation.⁸⁻¹¹ They might die due to rupture of the residual aortic lesions while awaiting second

procedures or comorbidities preclude another procedure through a lateral thoracotomy.¹² In contrast, the risk of spinal cord complications may be reduced by staged operations. Etz and colleagues¹³ have demonstrated experimentally in pigs that development of the collateral arterial supply to the spinal cord was completed after 1 week after severing blood supply to the spinal cord.

Recent endovascular innovations allow alternative approaches for complex aortic arch pathology. Several groups used endografts for the descending thoracic aorta as the second-stage procedure in patients who underwent an elephant trunk repair of the arch; however, these hybrid procedures are only feasible in patients who meet certain anatomic criteria. In elderly patients with multiple comorbidities, staged endovascular procedures may be beneficial, including a branched or debranching technique for the aortic arch or for the thoracoabdominal aorta. Endovascular repairs have been applied selectively, replacing the second-stage procedure. Such repairs potentially avoid the second complex open surgery; however, these procedures are currently limited to patients who meet certain anatomic criteria. The recent development of the branched stent graft might implement total endovascular repair for the thoracoabdominal aorta; however, the current procedure requires a long fluoroscopy time and is associated with a greater incidence of endoleak.

Eagleton and colleagues¹⁴ reported their clinical experience with 354 high-risk patients undergoing fenestrated or branch thoracic endovascular aortic repair for Crawford extension II and III aneurysms of the thoracoabdominal aorta. They found that perioperative mortality was greater in extension II repairs (7.0% vs 3.5%; $P < .001$), permanent spinal cord ischemia occurred in 4%, and renal failure requiring hemodialysis occurred in 2.8% of patients. Twenty-seven branches (7.6%) required reintervention for stenosis or occlusion, and 80 endoleak repairs were performed in 67 patients. At 36 months, freedom from aneurysm-related death was 91%, and freedom from all-cause mortality was 57%. The treatment of type II TAAA, age, and chronic obstructive pulmonary disease negatively affected survival.

Oderich and colleagues¹⁵ investigated clinical data of 185 consecutive patients (age 75 ± 7 years) treated for TAAAs using fenestrated and branched stent grafts. Seventy-three patients were treated for extent I to III TAAAs. Thirty-day mortality was 8.2%, and early major adverse events occurred in 26 patients (36%), including spinal cord injury in 4 patients. Mean follow-up was 21 ± 20 months. Patient survival was 59%, and freedom from any reintervention was 53% at 5 years. Hu and colleagues¹⁶ screened 370 articles in which multibranched stent grafts were used. However, only 4 articles encompassing 185 patients (mean age 71.1 years) were aligned with the inclusion criteria. There were 23 TAAAs, and the

Crawford classification was extension I in 10 patients, II in 47, III in 37, IV in 58, and V in 9. The 30-day mortality was 9% (95% confidence interval, 3%-19%), for all-cause mortality 27%, endoleaks 10%, spinal cord ischemia 17%, renal insufficiency 15%, and reintervention rate 21%.

Several meta-analyses of hybrid repair of the thoracoabdominal aortic repair have been reported. Canaud and colleagues¹⁷ reported a meta-analysis of hybrid repair of TAAAs reported in which 19 studies of 660 patients were included. Perioperative mortality ranged from 0% to 44.4%, and spinal cord ischemia ranged from 0% to 15.3%. After a mean follow-up of 26 months (range 6-88.5 months), the overall mortality was 20.8%. They concluded that hybrid repair of TAAAs may reduce early morbidity and mortality even in a group considered high risk for open surgery but still carries the risk of perioperative complications.

Moulakakis and colleagues⁴ investigated 14 studies of hybrid treatment of the TAAA with a total of 528 patients (68.0% male, mean age 70.5 years). The mean follow-up period was 34.2 months. The pooled estimate for primary technical success and visceral graft patency was 95.4% and 96.5%, respectively. An endoleak developed in 106 (21.1%) patients, and symptomatic spinal cord ischemia occurred in 7.0%, with irreversible paraplegia developing in 4.4%. The pooled proportion for permanent renal failure was 7.0% and for mesenteric ischemia was 4.5%. Prolonged respiratory support and cardiac complications were observed in a pooled rate of 7.8% and 4.6%, respectively. The meta-analysis for 30-day/in-hospital mortality revealed a pooled rate of 14.3%. They concluded that although the hybrid technique for thoracoabdominal aortic pathology provides a less-invasive approach, the technique is still associated with considerable rates of morbidity and mortality.

Very few reports have been published regarding 1-stage replacement from the aortic arch to thoracoabdominal aorta.^{11,18,19} Svensson and colleagues²⁰ reported a successful case in a 68-year-old patient who underwent replacement of the entire aorta from the aortic valve to the aortic bifurcation via deep hypothermia with circulatory arrest and retrograde perfusion of the brain. Massimo and colleagues⁶ reported that 7 patients underwent replacement of the aorta from aortic valve to bifurcation. Operations were performed with circulatory arrest under profound hypothermia, and no permanent spinal neurologic deficits occurred. Sun and colleagues²¹ reported 21 patients who had total or subtotal aortic replacement using a separate skin incision of midsternotomy and thoracoabdominal approach. The mean age of their series was very young (39.4 years), and all had ACP under profound hypothermia. They reconstructed intercostal arteries as a branched patch and also visceral arteries as a separated patch. There was 1

early death, and 20 patients were all alive during the follow-up period, ranging from 18 to 84 months postoperatively.

Corvera and Fehrenbacher²² reported 27 patients who had total arch replacement from the left thoracotomy using hypothermic circulatory arrest and selective ACP. Among them, 5 patients had replacement of the thoracoabdominal aorta. There were no early deaths or stroke, and only 1 had paraparesis. Mommertz and colleagues²³ investigated the clinical data of 32 patients who had extensive aortic replacement through left thoracotomy. The mean age of the patients was 50.9 years (range 18-75 years). There was 4 Crawford extension I replacement, and 6 had extension II replacement. Total arch replacement was done in 12 patients, and 20 had distal hemiarch replacement. All patients were operated on according to the protocol with CSF drainage, distal aortic and selective organ perfusion, as well as antegrade brain perfusion. Neuromonitoring was performed by means of MEPs, transcranial Doppler, and electroencephalography. All patients survived, and only 1 died 47 days postoperatively.

During the wide-range reconstruction of the thoracic aorta, protection of multiple organs, such as the myocardium, brain, spinal cord, and visceral organs, was a crucial determinant of a successful outcome in our study. Extracorporeal circulation was basically established with femoral artery return and right atrial drainage through the right femoral vein. In the right decubitus position, femoral vein cannulation usually sufficed by applying negative pressure. Rarely, additional main pulmonary artery drainage was necessary to obtain good venous drainage. Myocardial protection was reliably obtained by a cardioplegic solution delivered through a balloon-tipped catheter placed in the ascending aorta. Maintaining the circulation of the lower body by clamping the descending aorta and by perfusion from the femoral artery can alleviate the need for profound hypothermia. The efficacy of ACP was proven by the absence of permanent neurologic deficits with exception of only 1 patient.²⁴

A major concern with the left posterolateral thoracotomy was intraoperative endobronchial hemorrhage under fully heparinized conditions. In the majority of cases, mild endobronchial hemorrhage was observed but resolved without respiratory failure occurring. The duration of intubation was a mean of 19.4 ± 17.0 hours, and prolonged respiratory assistance longer than 48 hours was required in 1 patient. Pulmonary complications were observed in 6 patients (37.5%), but none were lethal. We believe that this is an acceptable rate of pulmonary complications. Redo left thoracotomy in the staged approach may have a greater risk of pulmonary complications because of possible adhesion of the lung to the aneurysm or to the graft.²⁵

Our study has several limitations. First, a retrospective, noncomparative study of single-stage operation does not strongly confirm advantages over staged surgery for

extensive aortic lesions. Second, we believe that our beneficial outcome is determined mainly by the fact that our patients were significantly younger (mean 53.6 years) as compared with the standard TAAA population. Mean EuroSCORE II or Japan score was 3.6% or 4.9%, respectively. Third, the postoperative follow-up was not long enough to determine long-term results in this patient cohort.

CONCLUSIONS

In conclusion, the single-stage repair of TAAAs with concomitant aortic arch disease via left-sided thoracotomy is feasible and provides promising short- and mid-term outcomes in selected patients. Appropriate organ protection and a multidisciplinary approach according to the aneurysm extension are prerequisites for better patient outcomes.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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