Open surgery for descending thoracic aorta in an endovascular era

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ABSTRACT

Background: Thoracic endovascular aortic repair has become the preferred treatment for a variety of descending thoracic aortic pathologies. However, there are unresolved issues such as morphologic appearance of chronic dissection, persistent false lumen perfusion, and adequacy of landing zone. Enthusiasm for improving the technique of open aortic repair and perioperative management is fading. In this study, we would like to demonstrate how we improve our surgical outcomes by establishing a dedicated aortic multidisciplinary team at the Kawasaki Aortic Center.

Method: We performed a single-center retrospective study from January 2015 to December 2016. All patients with open descending thoracic aortic replacement were recruited. Preoperative patient demographic data, bypass strategies, operative details, and postoperative outcomes were reviewed.

Result: From January 2015 to December 2016, we treated 168 cases of descending thoracic aortic repair using a left thoracotomy. Median age was 69.0 ± 21.8 years old, and 63.1% were aortic dissection (acute, 4.8%; chronic, 58.3%); 81.3% patients underwent elective operations. Left heart bypass, deep hypothermic circulatory arrest, and partial cardiopulmonary bypass were performed in 88.6%, 9.0%, and 2.4% of patients, respectively. Mean operative time was 312 ± 94 minutes. In-hospital mortality in total was 0.6%. The rate of transient spinal cord injury was 4.7%.

Conclusions: Under a dedicated aortic multidisciplinary team, we demonstrated that open descending thoracic aorta replacement can be performed with excellent early outcomes with low reintervention rates, regardless of the nature of the aortic pathologies. (J Thorac Cardiovasc Surg 2019;157:2168-74)

Open surgery is the gold standard for most of the descending thoracic aortic pathologies.

Central Message

In a highly specialized center with a multidisciplinary team, we can achieve excellent results for patients requiring open descending thoracic aortic surgery regardless of pathology.

Perspective

In the modern era, TEVAR is an increasingly popular treatment for descending thoracic aortic pathology, and interest in refining open surgery to improve outcome has faded. However, there are still various limitations of TEVAR in the treatment of descending aortic diseases. We would like to demonstrate the versatility of open surgery, its safety, and midterm outcome in a high-volume aortic center.

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Thoracic endovascular aortic repair (TEVAR) has emerged as the treatment of choice for descending thoracic aortic pathologies. Enthusiasm for improving techniques of open aortic repair and perioperative management is fading, partly because of high mortality and morbidity in reported series of open surgery for descending thoracic aorta; in addition,

30-day mortality was 0 to 33% in previous reports.¹⁻⁹ Although TEVAR is less invasive and has lower mortality compared with conventional open surgery, especially in the early phase, there are still unresolved issues in the treatment of descending thoracic aorta, such as inadequate landing zone, angulation of the aortic arch, tortuosity of the descending aorta, and chronic dissection. These factors lead to various types of endoleak and repeated reintervention. The reported incidence of endoleak of contemporary series was 3.9% to 8.9% and reintervention for endoleak has

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Abbreviations and Acronyms

CSFD	= cerebrospinal fluid drainage
DHCA	= deep hypothermic circulatory arrest
DSR	= descending thoracic aortic replacement
KAC	= Kawasaki Aortic Center
LHB	= left heart bypass
MDT	= multidisciplinary team
TAR	= total arch replacement
TEVAR	= thoracic endovascular aortic repair

been a lingering issue for endovascular procedure in chronic dissection, and long-term results are still unsatisfactory.^{10,11} Open conversion after TEVAR was well reported and known to be challenging procedure, which carries an increased risk.¹² Innovative approaches, such as false lumen occlusion device and aortic fenestration, were potential endovascular treatments for false lumen occlusion, but long-term results are not available.¹³⁻¹⁵ In our study, we would like to demonstrate that open descending aortic replacement (DSR) can be done safely in a high-volume center with a dedicated aortic multi-disciplinary team (MDT).

BACKGROUND OF THE KAWASAKI AORTIC CENTRE

The Kawasaki Aortic Centre (KAC) is a dedicated center for aortic diseases, and it receives referrals from all over Japan. We have a “no turn-down” policy, and we operate on all patients with aortic pathology as long as they or their family members accept our plan of surgical intervention. The total number of open aortic cases performed at KAC has exceeded 4000 in our 14-year history.

METHODS

We conducted a retrospective review of consecutive patients who underwent DSR in our center. Patients were offered open surgery if aortic diameter was greater than 50 mm, aortic diameter enlargement was greater than 5 mm within 6 months, and rupture or impending rupture of aneurysm or dissection was present. Preoperative patient demographic data, bypass strategies, operative details, and postoperative outcomes were reviewed.

According to Japanese guidelines (Guidelines for Diagnosis and Treatment of Aortic Aneurysm and Aortic Dissection),¹⁶ acute dissection is defined as within 2 weeks from the onset of symptoms and the period after the acute phase as the chronic phase. The maximum aortic diameter was based on measurements of all segments of the descending thoracic, thoracoabdominal and abdominal aorta, and the largest diameter was used as the maximal diameter. Preoperative characteristics of the patients are described in Table 1. We follow up our patients actively at our outpatient clinic at 3, 6, and 12-month intervals. After the 12-month follow-up, patients are reviewed annually. Computed tomographic scans were performed for all patients per protocol without exception, resulting in life-long follow-up data for all patients. We depicted survival data using Kaplan-Meier analysis.

Study Variables

The following variables from our cohort were collected and analyzed by statistical test. Regarding the preoperative variable, chronic kidney failure

TABLE 1. Patient demographics

Preoperative demographics	Result
Age (y)	69.0 ± 21.8
Aneurysm size (mm)	54 ± 8
Creatinine (mg/dL)	1.0 ± 0.4
Male sex	122 (72.6)
Comorbidity, n (%)	
Hypertension	123 (73.2)
Dyslipidemia	37 (22.0)
Diabetes	10 (5.9)
Coronary arterial disease	30 (17.9)
Cerebrovascular disease	25 (14.9)
Chronic obstructive lung disease	42 (25.0)
Chronic kidney disease	29 (12.0)
Smoking history	96 (57.1)
Previous aortic intervention	99 (58.9)
Abdominal aorta	22 (13.1)
Thoracic aorta	84 (50.0)
Elective operation	135 (80.4)
Previous elephant trunk	37 (22.0)

Values are presented mean ± standard deviation or n (%).

is defined as a requirement for dialysis, and chronic renal insufficiency is defined as a serum creatinine level >1.5 mg/dL but not yet requiring dialysis.

Postoperative acute renal dysfunction is defined as the need for temporary dialysis during the postoperative period. Spinal cord injury is defined as injury present at discharge. It is further classified according to severity as permanent paraplegia or paraparesis (partial paralysis of the lower limbs).

Pulmonary complications, including pneumothorax, the use of noninvasive positive-pressure ventilation, prolonged ventilation (>48 hours), tracheostomy, and chylothorax were recorded. Gastrointestinal tract complications included bowel ischemia and ileus. Cardiac complications included atrial fibrillation, cardiac tamponade, and postoperative myocardial infarction.

Operative Procedure

Our first-line circulatory strategy is left heart bypass (LHB) whenever proximal aortic cross clamping at distal aortic arch is possible. The LHB circuit included an in-line centrifugal pump with a heat exchanger (Figure 1). For this purpose, a cannula was placed in the left atrium through the left upper pulmonary vein for outflow and the left common femoral artery for inflow. We have described our setup of LHB and procedures in our previous publication.⁵ Anastomosis was done with before continuous suture with 3-0 or 4-0 Poly-Vinylidene Difluoride (Asflex, Kono Seisakusho, Japan) and using full-circumference multiple double-pledgetted sutures. Spinal cord drainage was performed only when the patients showed symptoms of spinal cord injury postoperatively. Intraoperative neurologic measurements, such as motor evoked potential, was not used in our series (Video 1).

When dealing with distal aortic arch pathology, our approach is either single-stage replacement of the whole descending thoracic aorta with proximal anastomosis under deep hypothermic circulatory arrest (DHCA) (Figure 2, A) or a two-stage procedure with first stage total arch replacement and floating elephant trunk (TAR + ET) (Figure 2, B) followed by a second stage DSR. For all TAR, there were only floating elephant trunk and no frozen elephant trunk procedure was performed.

LHB can be utilized if cross-clamping at distal aortic arch and distal descending thoracic aorta is feasible. Some patients' aortic pathologies such

as aneurysmal arch and the presence of heavy atherosclerotic plaques are unfavorable for cross-clamping. In such cases, we chose DHCA with cardiopulmonary bypass and open proximal anastomosis (Figure 2, A). During DHCA, the distal descending aorta was clamped to maintain visceral and spinal cord perfusion. Otherwise, a 2-stage procedure was chosen to reduce the risk of retrograde type A dissection and stroke owing to cross-clamping at diseased distal arch. The first stage is total arch replacement (TAR) and floating elephant trunk (ET), and this was followed by a second-stage DSR with LHB (Figure 2, B). In this case, we could reduce the risk of retrograde type A dissection and stroke owing to cross-clamping at the distal arch.

Statistical Analysis

Categorical variables were presented in absolute numbers and percentages, and continuous variables as median $\pm$ interquartile range. All statistical analyses were performed using JMP 9.0 statistical software (SAS Institute, Cary, NC).

RESULTS

Patient Demographics

Between January 2015 and December 2016, 950 patients underwent open thoracic and thoracoabdominal aortic surgery at KAC. In this study, we examined 168 cases of

VIDEO 1. The patient's preoperative computed tomographic scan is shown. This patient underwent emergent ascending aortic replacement for type A acute aortic dissection. Residual dissection in the descending thoracic aorta showed gradual enlargement during the follow-up period. At the thoracic level, the false lumen was still patent. At the thoracoabdominal level, the chronic dissection has a complex structure with 3 lumens. Celiac artery originates from a false lumen, and the superior mesenteric artery is dissected. At the infrarenal level, an aneurysmal change was observed with a narrow true lumen. Both common iliac arteries were dissected; therefore, thoracic endovascular aortic repair seemed unsuitable for this patient. The patient was placed in the right decubitus position. A double-lumen endotracheal tube was intubated for the preparation for 1 lung ventilation. Left thoracotomy was performed via the fifth intercostal space while a left common femoral artery (LCFA) was exposed and prepared. The whole descending thoracic aorta and left upper pulmonary vein was exposed, and full-dose heparin was given. LCFA was cannulated, and subsequently, the left upper pulmonary vein was cannulated. Left heart bypass was started. The left lung was wrapped with large gauze to prevent unnecessary injury and to make it easy to handle. The intercostal arteries were clipped and cut as far as possible, which makes it easier to control the back flow from intercostal arteries when the aneurysm was opened. The aorta was segmentally slung and clamped. When the proximal aorta was clamped, the systolic blood pressure was reduced to <80 mm Hg in the systolic phase by a perfusionist. The middle descending thoracic aorta was clamped segmentally. The aneurysm was opened, and the dissected intimal flap was resected. The distal aortic arch was completely transected and trimmed. Proximal fenestration was made, and a 24-mm straight graft was prepared. Prior continuous suture with 3-0 Prolene was placed, and subsequently 3-0 Prolene with multiple double-pledgetted sutures were placed to reinforce the anastomosis for the entire circumference. Again, the systolic blood pressure was reduced by a perfusionist, and the proximal clamp was moved onto the graft. The distal descending aorta was clamped, and the second clamp was removed. The aorta was opened, and the intimal flap was opened. The intercostal arteries were ligated properly. The distal descending thoracic aorta was transected and trimmed. Distal fenestration was made. The graft was trimmed. The prior continuous suture with 3-0 Prolene was placed, and subsequently 3-0 Prolene with multiple double-pledgetted sutures were placed to reinforce the anastomosis for the whole circumference. Deairing and declamp were done. After these procedures, left heart bypass was weaned off and hemostasis was checked, and the chest was closed. Video available at: [https://www.jtcvs.org/article/S0022-5223\(18\)32489-9/fulltext](https://www.jtcvs.org/article/S0022-5223(18)32489-9/fulltext).

FIGURE 1. Left heart bypass. A typical set up of left heart bypass in the Kawasaki Aortic Center.

open DSR using a left thoracotomy. Thoracoabdominal aortic surgery was excluded. During the same period, 36 cases of TEVAR were done. The median maximum aortic diameter was 54 ± 8 mm. There were 122 (72.6%) male

FIGURE 2. Options for proximal anastomosis. A, Deep hypothermic circulatory arrest. In case of deep hypothermic circulatory arrest, femoral-arterial and venous cardiopulmonary bypass was established. Open proximal anastomosis was performed with a vascular graft using continuous suture followed by interrupted 3-0 pledgetted suture. The distal descending thoracic aorta was cross-clamped to allow visceral and spinal perfusion. B, Two-stage operation. In case of previous total arch and elephant trunk surgery, we cross-clamp the floating elephant trunk and distal descending thoracic aorta.

patients, and median age at the time of surgery was 69.0 ± 21.8 years (Table 1). Distribution of etiology was as follow: 8 cases of acute type B; 58 cases of chronic type B; 39 cases of chronic type A (this means residual arch dissection after type A dissection); 62 cases of true aneurysm; and 22 cases were ruptured or impending rupture. Our group had previously described the limited role of TEVAR in ruptured aneurysm that compressed on airways as the compression persisted even after TEVAR.¹⁷ Previous aortic interventions were performed in 99 patients. Eighty-four patients (50.0%) had previous open surgery for thoracic aorta, and 22 patients (13.1%) had previous abdominal aortic surgery. The distribution was as follow: 37 cases of ascending and hemi-arch, 44 cases of TAR, 3 cases of DSR, 5 cases of TEVAR, 3 cases of Crawford extent III replacement, 16 cases of open abdominal aortic aneurysm repair, and 6 cases of EVAR.

Operative Details

Operative details are shown in Table 2. LHB was used in (88.6%) patients and DHCA was used in (9.0%) patients. Aortic intimal flap fenestration was performed in 87 patients, including 80 distal fenestrations in 97 cases of chronic dissection patients. Mean minimum bladder temperature was $33.4 \pm 1.8^{\circ}\text{C}$. Mean operation time was

312 ± 94.0 minutes, and mean extra corporeal circulation time was 105.5 ± 51.8 minutes.

Operative Results

Overall in-hospital death was 1 (0.6%). During this period, we had no in-hospital death in 135 elective cases (Table 3). The cause of death in the 1 case of in-hospital death was organ malperfusion. Pulmonary complication

TABLE 2. Operative details

Detail	Result
Open distal anastomosis	8 (4.7)
Distal fenestration in chronic dissection	80 (82.5)
Circulatory support strategies	
Left heart bypass	149 (88.6)
Deep hypothermia circulatory arrest	15 (9.0)
Partial cardiopulmonary bypass	4 (1.4)
Minimum bladder temperature ($^{\circ}\text{C}$)	33.4 ± 1.8
Operation time (min)	312 ± 94.0
Extracorporeal circulation time (min)	105.5 ± 51.8
Distal Perfusion time (min)	93 ± 48.8
Cross clamp time (min)	95 ± 45.8

Values are presented as n (%) or mean $\pm$ standard deviation.

TABLE 3. Operative results

Result	n (%)
In-hospital death in total	1 (0.6)
Ineffective surgery	0 (0)
Pulmonary complications	17 (10.1)
Vocal cord palsy	42 (25.0)
Gastrointestinal tract complications	2 (1.2)
Cardiac complications	3 (1.8)
Temporary hemodialysis	3 (1.8)
Hemodialysis at discharge	2 (1.2)
Spinal cord injury	8 (4.7)
Permanent paraplegia	8 (4.7)
Paraparesis	8 (4.7)

was observed in 10.6% of patients. Temporary and permanent hemodialysis for acute renal failure occurred in 3 (1.8%) and 2 (1.2%) patients, respectively. Spinal cord injury occurred in 8 patients (4.7%; permanent paraplegia, 0 [0%]; paraparesis, 8 [4.7%]). Of 8 patients with paraparesis, 1 patient showed recovering symptom after cerebrospinal fluid drainage (CSFD). One patient showed spontaneous recovery. In 1 patient, CSF drainage was not attempted because of coagulation problems. In the other patients, no significant change in their paraparesis was observed. Postoperative vocal cord palsy was identified in 42 patients (25%) with bronchoscopy. During this period, we did not have any major wound complications that required operative reintervention. Median length of hospital stay was 18 ± 20 days, and 30-day mortality was 1.2%.

In our center, we have a standardized operative procedure and perioperative management for DSR. There are 8 surgeons who can independently perform DSR in our center (median, 14.0 ± 36.8 cases). Among these surgeons, operative procedures were strictly stratified in detail. There was

no significant difference in the operative results among these surgeons.

Midterm Outcomes

Kaplan-Meier survival analysis showed 95.5% 24-month survival (Figure 3). Seven patients (4.2%) underwent planned second-stage aortic surgery (TAR with aortic root replacement, 4 patients; TAR, 3 patients).

DISCUSSION

Conventionally, open surgery for descending thoracic aortic disease was perceived to have high morbidity and mortality. Cheng and colleagues¹ conducted a systematic review and meta-analysis comparing open and endovascular treatment for descending thoracic aortic diseases in 2010. They reported that open surgery had an average of 13.9% 30-day mortality compared with 5.8% for TEVAR.¹ The report also described an average of 10.6% of wound infection and 6.5% of reoperation for bleeding. For these reasons, they concluded that TEVAR was associated with less early death and reoperation for bleeding and infection. In their study, DSR resulted in 8.2% spinal cord injury (including 4.9% paraplegia). In our previous study, open distal anastomosis was one of the risk factors of paraplegia.¹⁸ After avoiding open distal anastomosis in our current series, spinal cord injury was reduced to 4.7% with no case of paraplegia.

Several articles have mentioned about the efficacy intraoperative CSFD.^{19,20} On the other hand, routine prophylactic CSFD is not without risks. Mazzeffi and colleagues¹⁹ reported a 3.9% rate of complications of CSFD, 2% permanent paraplegia, and 5.9% of 30-day mortality. In our series, there is no permanent paraplegia. Considering the risk and the benefit of CSFD, we do not use prophylactic CSFD in descending thoracic aortic repair in our center.

We believe that limb and gut ischemia is closely related to insufficient lower body perfusion. Intraoperatively, we monitored the bilateral upper limbs and right lower limb arterial blood pressure to maintain a perfusion pressure of approximately 60 mm Hg and to measure hourly urine output. Open distal anastomosis was avoided in most of our patients (95.3%) to maintain a steady lower body perfusion.

To reduce the left thoracotomy wound complications, we adopted interrupted suture closure technique. In left thoracotomy surgery, serratus anterior and latissimus dorsi muscles were divided. In our experience, continuous suture led to a higher rate of wound disruption, and the incidence of wound disruption reduced to zero after we changed our practice to interrupted closure.

Our operative indication for descending thoracic aortic aneurysm was 50 mm. Kim and colleagues²¹ reported the risk of aortic events started to increase with a diameter

FIGURE 3. Kaplan-Meier survival graph of our patients who underwent descending thoracic aortic replacement.

FIGURE 4. Multidisciplinary daily morning round and intensive rehabilitation. A, Multidisciplinary daily morning round. A multidisciplinary team including cardiovascular surgeons, nurses, physiotherapists, speech therapists, medical social workers, and dietitians gathered every morning to review the patient's condition and decided on a daily treatment plan. B, Intensive rehabilitation. During the postoperative period, respiratory complications and lower-limb muscle wasting are not uncommon, especially after thoracotomy. A patient with a tracheostomy was undergoing tilt-table standing exercise in the presence of a physiotherapist to train up his lower-limb muscles and to prevent basal lung atelectasis.

>5.0 to 5.5 cm. According to them, the definite and possible event rates within 1 year rose to 2.7% and 8.1% at an aortic diameter between 50 and 60 mm. Furthermore, in our series, among 22 cases of nonelective surgery for ruptured or impending rupture, diameter was less than 55 mm in 5 cases. The distribution of the diameter was <5.0 cm in 12 cases, 5.1 to 5.5 cm in 75 cases, 5.6 to 6.0 cm in 35 cases, and >6.1 cm in 46 cases. The indications of the group with less than 5.0 cm were rapid enlargement of saccular aneurysms >5 mm within 6 months.

Most importantly, a dedicated aortic MDT is the key to achieve good outcomes after DSR. Our aortic MDT included cardiovascular surgeons, intensive care and ward nurses, physiotherapists, speech therapists, dietitians, and medical social workers (Figure 4, A). We have a daily aortic MDT morning ward round throughout the year with no exceptions. This daily round set targeted patient-specific intensive rehabilitation; for example our, physiotherapist mobilized a patient to sitting position to enhance respiratory

recovery and to prevent atelectasis (Figure 4, B). In our previous report on open surgery for chronic type B dissection, the overall mortality of open surgery was 3.9% between 2008 and 2013.⁵ Our aortic MDT round was established in late 2012. It demonstrated the efficacy of our aortic MDT approach in the management of our DSR patients.

There are certain limitations of our study. First, the study was retrospective and limited to patients who underwent open surgery at KAC. Second, this experience is in a single center with high volume and specialization in open aortic surgery.

CONCLUSIONS

Our results in open descending thoracic aorta replacement showed excellent early to midterm outcome with low reintervention rates, regardless of the morphology of the aortic condition. With a multidisciplinary team dedicated to perioperative management, all surgeons in our center could achieve similar excellent results. Further follow-up is necessary to confirm the long-term outcomes of our study cohort.

We would like to dedicate this article to all members of our aortic multidisciplinary team.

References

- Cheng D, Martin J, Shennib H, Dunning J, Muneretto C, Schueler S, et al. Endovascular aortic repair versus open surgical repair for descending thoracic aortic disease: a systematic review and meta-analysis of comparative studies. *J Am Coll Cardiol*. 2010;55:986-1001.
- Mutsaers M, Narita Y, Araki Y, Maekawa A, Oshima H, Usui A, et al. Spinal cord protection during a thoracoabdominal aortic repair for a chronic type B aortic dissection using the aortic tailoring strategy. *Interact Cardiovasc Thorac Surg*. 2010;11:15-9.
- Kouchoukos NT, Kulik A, Castner CF. Open thoracoabdominal aortic repair for chronic type B dissection. *J Thorac Cardiovasc Surg*. 2015;149(2 suppl): S125-9.
- Gandjbakhch I, Jault F, Vaissier E, Levasseur JP, Pavie A, Petrie J, et al. Surgical treatment of chronic aortic dissections. *Eur J Cardiothorac Surg*. 1990;4:466-71.
- Fujikawa T, Yamamoto S, Sekine Y, Oshima S, Kasai R, Mochida Y, et al. Operative Results and clinical features of chronic stanford type b aortic dissection: examination of 234 patients over 6 years. *Eur J Vasc Endovasc Surg*. 2015;50: 738-43.
- Fattori R, Cao P, De Rango P, Czerny M, Evangelista A, Nienaber C, et al. Interdisciplinary expert consensus document on management of type B aortic dissection. *J Am Coll Cardiol*. 2013;61:1661-78.
- Corvera J, Copeland H, Blitzer D, Hicks A, Manghelli J, Hess P, et al. Open repair of chronic thoracic and thoracoabdominal aortic dissection using deep hypothermia and circulatory arrest. *J Thorac Cardiovasc Surg*. 2017;154:389-95.
- Joo HC, Youn YN, Lee SH, Lee S, Chang BC, Yoo KJ. Clinical outcomes of different surgical approaches for proximal descending thoracic aneurysm involving the distal arch. *J Thorac Cardiovasc Surg*. 2018;155:2289-98.e1.
- Matsueda T, Ikeno Y, Yokawa K, Koda Y, Henmi S, Inoue T, et al. One-stage replacement of the aorta from arch to thoracoabdominal region. *J Thorac Cardiovasc Surg*. 2018;155:498-504.
- Kanaoka Y, Ohki T, Maeda K, Baba T. Analysis of risk factors for early type I endoleaks after thoracic endovascular aneurysm repair. *J Endovasc Ther*. 2017; 24:89-96.
- Schaffer JM, Lingala B, Miller DC, Woo YJ, Mitchell RS, Dake MD. Midterm survival after thoracic endovascular aortic repair in more than 10,000 Medicare patients. *J Thorac Cardiovasc Surg*. 2015;149:808-20; discussion 20-3.
- Spiliopoulos K, Preventza O, Green SY, Price MD, Amarasekara HS, Davis BM, et al. Open descending thoracic or thoracoabdominal aortic

- approaches for complications of endovascular aortic procedures: 19-year experience. *J Thorac Cardiovasc Surg.* 2018;155:10-8.
13. Rohlfis F, Tsilimparis N, Fiorucci B, Heidemann F, Debus ES, Kolbel T. The Candy-plug technique: technical aspects and early results of a new endovascular method for false lumen occlusion in chronic aortic dissection. *J Endovasc Ther.* 2017;24:549-55.
 14. Wong RHL, Yu PSY, Kwok MWT, Chow SCY, Ho JYK, Underwood MJ, et al. Endovascular fenestration for distal aortic sealing after frozen elephant trunk with Thoraflex. *Ann Thorac Surg.* 2017;103:e479-82.
 15. Wu IH, Chan CY, Luo CM, Wang SS. Modified candy-plug device for aneurysmal false lumen occlusion in chronic type B aortic dissection. *J Thorac Cardiovasc Surg.* 2018;155:1970-2.e2.
 16. JCS Joint Working Group. Guidelines for diagnosis and treatment of aortic aneurysm and aortic dissection (JCS 2011): digest version. *Circ J.* 2013;77:789-828.
 17. Fujikawa T, Yamamoto S, Fujioka S, Sasaguri S. Open surgery of a descending thoracic aortic aneurysm impending rupture with a compression of left main bronchus. *Ann Vasc Dis.* 2016;9:342-4.
 18. Wongkornrat W, Yamamoto S, Sekine Y, Ono M, Fujikawa T, Oshima S, et al. Predictors of paraplegia with current thoracoabdominal aortic aneurysm repair. *Asian Cardiovasc Thorac Ann.* 2015;23:406-11.
 19. Mazzeffi M, Abuelkasem E, Drucker CB, Kalsi R, Toursavadkoti S, Harris DG, et al. Contemporary single-center experience with prophylactic cerebrospinal fluid drainage for thoracic endovascular aortic repair in patients at high risk for ischemic spinal cord injury. *J Cardiothorac Vasc Anesth.* 2018;32:883-9.
 20. Safavi-Abbasi S, Mapstone TB, Archer JB, Wilson C, Theodore N, Spetzler RF, et al. History of the current understanding and management of tethered spinal cord. *J Neurosurg Spine.* 2016;25:78-87.
 21. Kim JB, Kim K, Lindsay ME, MacGillivray T, Isselbacher EM, Cambria RP, et al. Risk of rupture or dissection in descending thoracic aortic aneurysm. *Circulation.* 2015;132:1620-9.

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