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Review of Treatment for Thoracoabdominal Aortic Aneurysm, and the Modern Experience of Multi-Branched Endograft in Taiwan

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Thoracoabdominal aortic aneurysm (TAAA) is a complicated aortic disease. Most treatments for other aortic aneurysms have already shifted from conventional open surgery to endovascular operation; but for TAAA, open surgery remains the gold standard treatment. Several alternative treatments such as hybrid operation as well as endovascular techniques are utilized for the treatment of TAAA. Some of the procedures combine off-the-shelf devices such as the chimney procedure. Some other procedures required custom-made specialized stent grafts. A new off-the-shelf multi-branched endograft, T-branch graft, was released in late 2012, though it was not introduced into Taiwan until 2015. Ultimately, also we plan to report the experience of multi-branched endograft in Taiwan.

Key Words: Endovascular surgery • Multi-branch endograft • T-branch graft • Thoracoabdominal aortic aneurysm

INTRODUCTION

Aortic aneurysm is a degenerative disease, a condition where the diameter of the aorta increases gradually. When the diameter of the aorta expands more than 50% of its normal limits, it is called an aortic aneurysm. When the aneurysm is located at the thoracic aorta, it is deemed to be a thoracic aortic aneurysm (TAA); and when confined to the abdominal aorta, it is an abdominal aortic aneurysm (AAA). The thoracoabdominal aortic aneurysm (TAAA) extended from the thoracic aorta to the abdominal aorta. The incidence of TAAA is low, however, wherein approximately only 10 new cases are diagnosed per 100,000 person-years.[1] Depending upon the particular extension of the aneurysm, the most common classification is Crawford classification, which was modified by Safi and Miller in 1999 (Figure 1), and consists of 5 different categories.[2] The most serious complication of aortic aneurysm is rupture. When the diameter of TAAA is more than 6 cm, the annual rupture rate is estimated to be 14%.[3] If left untreated, nearly 80% of the aneurysms will rupture.[4] Since the thoracoabdominal aorta is deep inside the body and derives the vital visceral branches, including the celiac trunk, superficial mesenteric artery (SMA), and bilateral renal arteries, the treatment is complicated. Unlike TAA and AAA, in which endovascular treatment replaces open surgery as first line treatment, open surgery remains the gold standard therapy for TAAA. However, the rapid development of endovascular technique in recent decades makes total endovascular treatment for TAAA possible. We aim to discuss all the treatment strategies for TAAA, as well as the latest devices and techniques.

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MULTI-BRANCHED ENDOGRAFT

The multi-branched endograft is the latest device

developed for TAAA exclusion. Unlike costumed fenestration and branched graft, the multi-branched endograft is an off-the-shelf device and could be available for emergency use. Sweet et al. first introduced an off-the-shelf device,[5] which is anatomically applicable in 88% of TAAA patients. The Zenith t-branch system (Cook Medical, Bloomington, IN, USA) is the first commercialized off-the-shelf multi-branched endograft (Figure 2). The device is loaded in a 22 F sheath, with a 202 mm long tapered main body from 34 mm to 18 mm with four downward branch cuffs. The cuff diameters of the celiac trunk and superior mesenteric artery are both 8 mm, and the length is 21 mm and 18 mm, respectively. Both renal arterial cuffs are 6 mm in diameter and 18 mm in length. The design is suitable for 54% of patients without any adjuvant procedures.[6] With additional maneuvers of TAA stent graft or bypass surgery, the suitability of this procedure is elevated to 63%.[7]

With limited experience, some studies showed the 30-day mortality rate was 0%,[8,9] the technical successful rate 100%, the paraplegia rate was 5-6.6%, the follow-up endoleak rate was 0% and the re-intervention rate was 10%.[8,9]

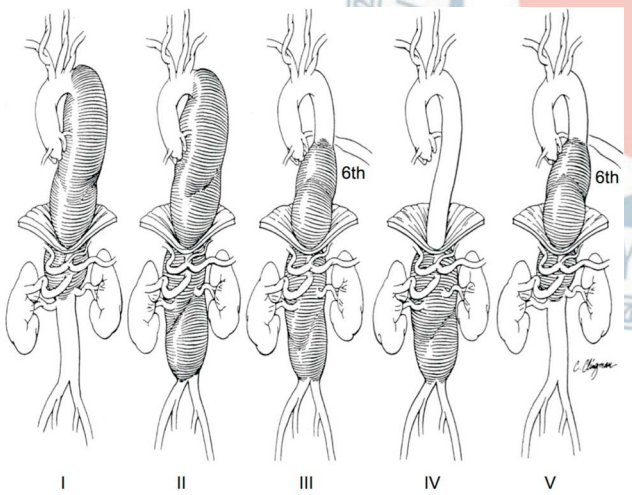

Figure 1. *Classification of thoracoabdominal aortic aneurysm. I – from below the left subclavian artery to above the celiac axis, or apposite the superior mesenteric and above the renal arteries. II – from below the left subclavian and including the infrared abdominal aorta to the level of the aortic bifurcation. III – from the sixth intercostal space tapering to just above the infrarenal abdominal aorta to the iliac bifurcation. IV – from the 12th intercostal space, tapering to above the iliac bifurcation. V – from the sixth intercostal space, tapering to just above the renal arteries. Reprinted from Safi HJ, Miller CC 3rd. Spinal cord protection in descending thoracic and thoracoabdominal aortic repair. Ann Thorac Surg 1999;67:1937-9. Copyright © 1999, Elsevier.*

Beginning in June 18, 2015, we started treating thoracoabdominal aortic aneurysm the total endovascular way, usingt-branch endograft for 5 patients. Four of the patients were male, 2 were classified as Modified Crawford extent II, and the others had Modified Crawford extent III. The mean age was 82.6 years, and 2 of them suffered a prior stroke with bed-ridden status. Three had previous TAA or AAA and received stent grafting, and they were all excellent candidates to be included as high-risk patients for open surgery.

The technical successful rate is 100%, with a total of 19 branches patent initially (Figure 3). One patient had a perioperative stroke but none of them developed spinal

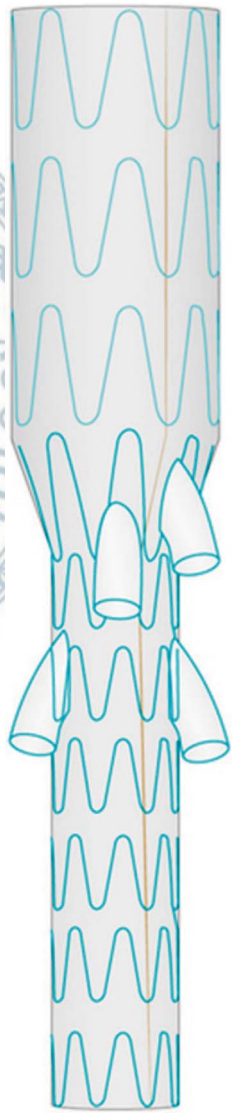

Figure 2. *The diagram of t-branch endograft. Copyright: Cook Medical, Bloomington, IN, USA.*

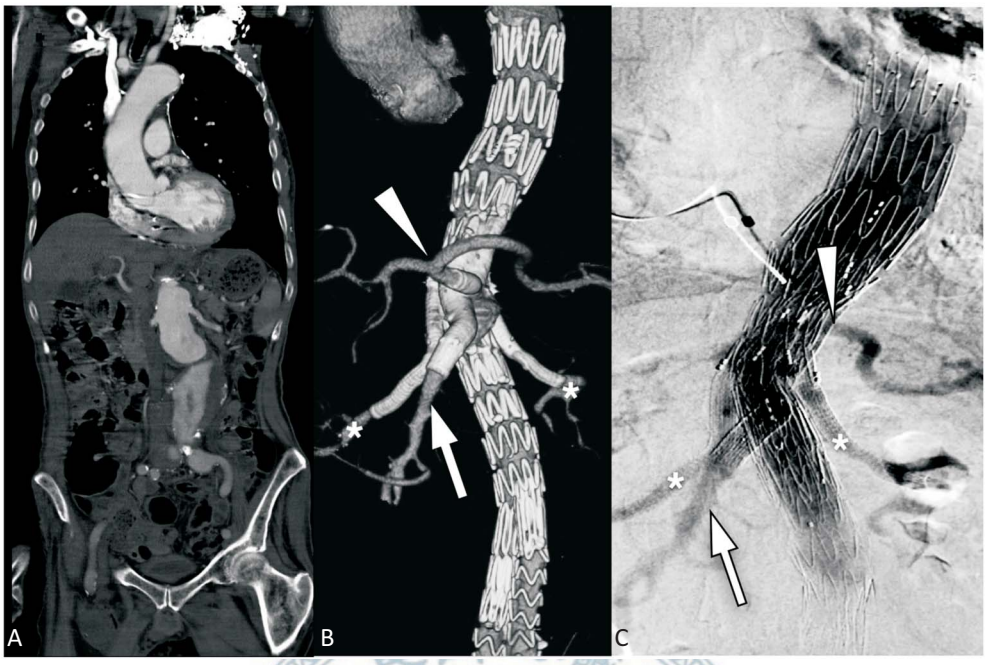

Figure 3. *An example of multi-branched endograft for thoracoabdominal aortic aneurysm (TAAA). A is a coronal section of CT scan before the operation. The aneurysm starts above from the diaphragm level and extended along the whole abdominal aorta to bilateral common iliac artery, compatible with the classification of type II thoracoabdominal aortic aneurysm. B is a 3D CT reconstruction, and C is an aortogram after the operation, all the branches, including the celiac trunk (arrow head), superficial mesentery artery (arrow), and bilateral renal arteries (asterisk) are patent, and no endoleak can be identified.*

cord ischemia (SCI). Two patients had transient renal insufficiency, which improved during the follow-up. There were no patients who needed hemodialysis, and the 30-day mortality rate was 0%. There was 1 patient with a history of AAA rupture who received aortouniiliac (AUI) devices insertion. The patient developed distal limb thromboembolism after repair and received emergent thrombectomy and fasciotomy for acute ischemic limb. However, the condition improved after treatment.

OPEN SURGERY

The first operative treatment for TAAA is open surgery, which was described by Etheredge in 1955.[10] To successfully complete this treatment, a left lateral thoracoabdominal incision or a major thoracotomy is essential, and the visceral branches are reconstructed while replacing the thoracoabdominal aorta (Figure 4).

Despite improvements in perioperative care and surgical technique, including left heart bypass, deep hypothermic arrest, selective visceral perfusion, distal aortic perfusion, and spinal cord protection, early mortality rate remains significant, ranging from 5-15.9%.[11-15] The risk factors of mortality including increased age, decreasing baseline glomerular filtration rate (GFR), extent II or III, emergent operation, coronary artery disease (CAD), aortic clamping time, transfused pRBC, previous cardiovascular accident (CVA), and diabetes.[13,15] With the combination of renal insufficiency, previous CVA, and diabetes, the mortality rate can be as high as 76%.[13] Even if the patient recovers after the operation, 21% need to be transferred to another institution, a figure which increases to 42% if the patient is older than 79 years of age.

The most imperative post-surgical comorbidity is SCI, which has an incidence ranging from 3.8-16% after open repair. Additionally, it has significant correlation with post-operative mortality.[16] According to a 25-year follow-up study, the overall survival at 5, 10, 15, and 20 years is 57.7%, 42.9%, 34.8%, and 31.6%, respectively.[15] However, the survival decreases to 25.5%, 14.9%, 12.8%, and 12.8%, respectively, if the patients suffer from immediate neurologic deficit. Among all types of TAAA, ex-

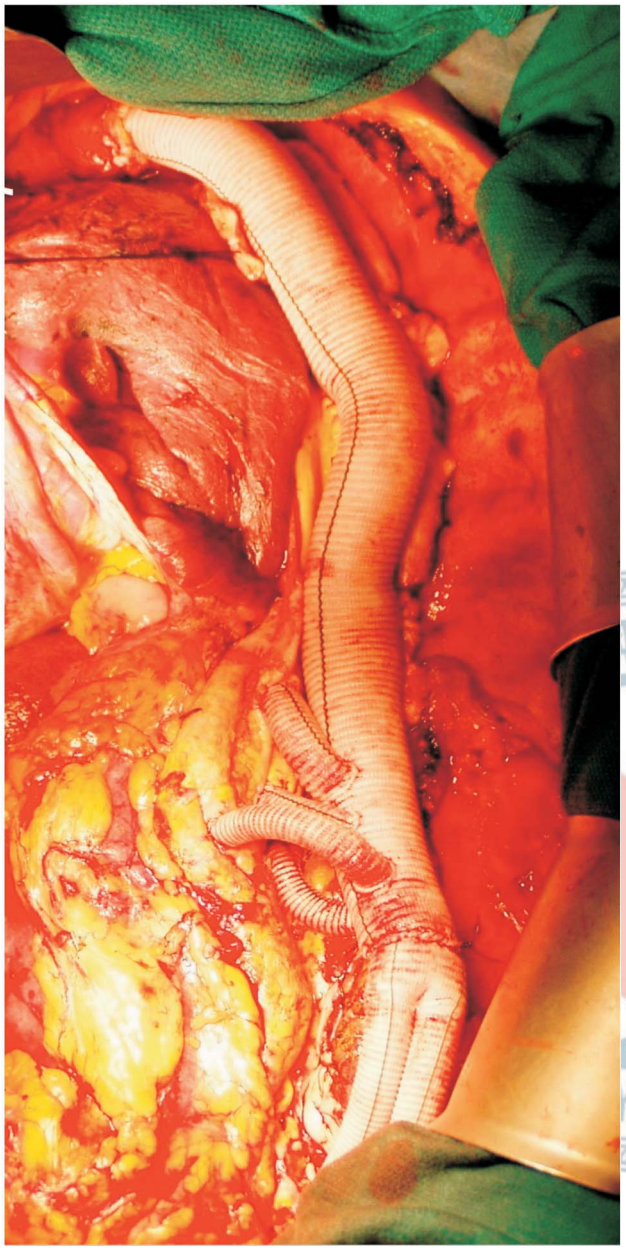

Figure 4. *An example of TAAA treatment to open surgery by thoracoabdominal incision and bypass surgery.*

tent II has the highest risk of SCI development after open surgery. The incidence can be as high as 50% if the aortic clamping time exceeds 45 minutes.[11] Several adjuncts have been developed to prevent SCI, including distal aortic perfusion (DAP) and cerebrospinal fluid drainage (CSFD). They can prevent immediate paraplegia for extent II and extent III patients, and the incidence of extent II can even decrease from 39% to 4%. However, this does not suggest that patients are free from paraplegia; actually, delayed paraplegia increased after the use of adjuncts.[15]

Another important complication is renal failure, which has an overall incidence ranging from 5.6-24.3%.[11-15] The study by Coselli et al. reportedon results from selective high-volume centers, where the mortality, paraplegia, and renal failure rate for a total of 2286 consecutive patients can be as a low as 7%, 4%, and 6%, respectively, whereas open surgery continues to have significant mortality and morbidity for TAAA repair.[12]

HYBRID OPERATION

To avoid thoracotomy, single lung ventilation, supraceliac aortic cross clamp, cardiopulmonary bypass (CPB), and deep hypothermic arrest in ahybrid operation with the combination of extra-anatomic bypass of the visceral vessels and endovascular stent graft was first described by Quiñones-Baldrich in 1999.[17] This technique can be achieved by use of a commercialized stent graft for TAA or AAA. These stent grafts are commonly available at most institutions and represent a fascinating alternative for TAAA treatment, especially for patients categorized as high-risk due to open surgery. Such a hybrid operation can also limit the visceral ischemia to one organ at the time, and may have fewer organ failure episodes. Although the technique is most beneficial for extent I, II, III patients in avoiding the need for thoracotomy, some studies also report a non-inferior result compared to open surgery in extent IV and pararenal aneurysm.[18,19]

The anastomosis site

For this technique to succeed, the surgeon should perform debranching for the visceral branches. The extra-anatomic bypass can either be constructed by the surgeon during the procedure, or a prefabricated multibranched graft (Vascutek, Ann Arbor, MI, USA) can alternatively be used (Figure 5). The graft includes an additional 10 mm limb to eliminate the need for additional vascular access for stent grafting.[20] There is a variety of this graft most efficacious for proximal anastomosis, including the distal aorta and iliac artery. If the patient received distal aortic replacement before, it can also be

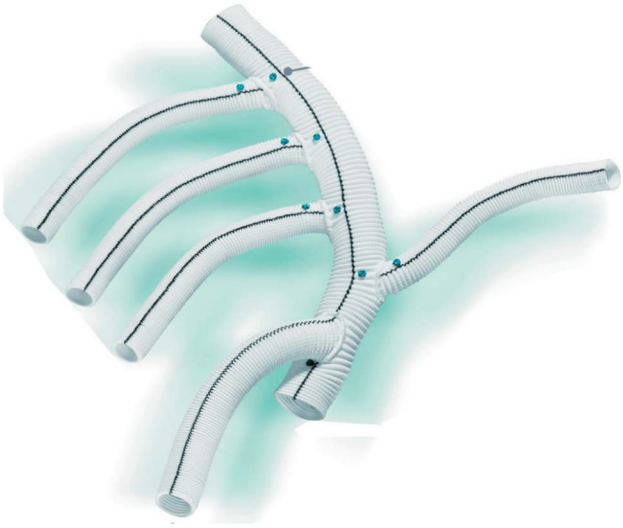

Figure 5. *Copy right: Gelweave, thoracoabdominal graft with radiopaque markers (Vascutek, Ann Arbor, MI, USA).*

placed at the aortic graft or iliac limb.[21] A large majority of surgeons perform retrograde bypass; although this may generate some questions regarding long-term results, there is no difference in patency between antegrade bypass and retrograde bypass.[22]

Simultaneously versus staged operation

Both the extra-anatomic bypass and stent grafting procedures for the aneurysm can be performed simultaneously or separately. Proponents of the simultaneous approach claim that access for deployment of stent graft can be facilitated while the abdomen is explored. This can minimize access and site-related complications, and the visceral grafts can be protected from embolization. Furthermore, patency can also be re-checked easily after the procedure.[23,24] When the procedure is conducted as a staged operation, stent graft deployment can occur 3-7 days after the bypass surgery. This period can be prolonged if necessary, but extended delay may also increase the risk of aneurysm rupture during the period. In one study, 3 of 18 patients who underwent staged operations suffered from rupture.[23] The proponents of staged operation claim it can reduce renal injury after debranching, when followed by simultaneous contrast administration. Staged operation also can decrease the incidence of paraplegia, total operation time, blood transfusion, and increase the extubation rate during surgery.[21,25]

To achieve stent graft deployment, access can occur through another cut down from the femoral artery, common iliac artery, direct from distal abdominal aorta, or through the conduit of the retrograde graft. In staged operations, some surgeons construct a subcutaneous conduit to minimize injury and reduce the amount of contrast injection.[19,21] Some commentators also claim deployment through a conduit can avoid tortuosity of the access avenue, risk of dissection and artery injury.[26]

The outcomes

Although the hybrid technique can eliminate the risk of aortic cross clamping, intraoperative hypotension, and reperfusion injury for SCI in open surgery, the aortic side branches are certainly occluded after the deployment of stent graft.[27] As a result of high variation of paraplegia incidence ranging from 0%-30%, the prevention of SCI by hybrid operation is controversial.[21,23,26,28,29] There is no guarantee that hybrid operation produces reduced SCI. Therefore, we can only consider it to be a non-inferior alternative treatment.

Hybrid operation is also considered to have less early mortality and reduced death of high-risk patients compare to open surgery.[18,26,29,30] However, recently published data reveals that early mortality of hybrid operation ranges from 8.5-19.4%, which is similar to results noted in open surgery.[14,21,23,24] On the other hand, the overall 2-year and 5-year survival after hybrid operation is 70.7-76% and 57.9-75.8%, a result not significantly better than open surgery.[19,21,29]

There are other interesting elements that should be underscored. The overall technical successful rate of hybrid operation is 90%-100%.[23,26,31] However, the outcome is poor for those patients whose operation is not completed. The follow-up graft patency is excellent, ranging from 86-100%.[29,31-33] Most patients do not suffer serious complications after graft occlusion, but some may develop gut infarction, renal failure, or even death. The other complication of concern is endoleak; the incidence of endoleak after hybrid operation has remained high since its inception, with little improvement, ranging from 20-42%.[19,23,24,26,29] Despite the fact that incidence of aneurysm rupture and aortic reintervention is not significantly higher, these comorbidities may discourage other surgeons from performing hybrid operation.

In short, hybrid operation should not be a substitute

for open repair. It continues to be an alternative option for high-risk patients who underwent prior aortic surgery, multiple comorbidities, with contraindication for aortic clamp and CPB. To date, the overall outcome for hybrid operation is similar to open surgery.

THE CHIMNEY GRAFT, PERISCOPE, AND SANDWICH TECHNIQUE

The open surgery and hybrid operations both required extensive exploration to treat TAAA. On the other hand, the chimney graft, periscope, and sandwich technique are all stage options that can be used before commercialized devices are available for total endovascular repair. The incision is minimalized, surgical risk is decreased, and post-operative complications also can be reduced. All of these techniques are established by the use of commercialized stent grafts, and are routinely available at most institutions.

The chimney graft and periscope technique

The chimney graft typically is first introduced as a bailout technique to salvage a renal artery covered by an endograft. It was first described by Greenberg et al. in 2003 to extend the proximal landing zone for short neck.[34] Since the technique is generally uncomplicated and the devices are available off-the-shelf, many vascular specialists have started to employ the technique for juxta-renal aneurysm.

The chimney graft and periscope technique are similar, and they both include the deployment of a stent graft into the visceral branch, as well as an endograft to exclude the aneurysm sac. They are positioned as parallel stents while the visceral stent is located between the aortic endograft and the aortic wall. If the visceral stent is placed in the proximal part of the aortic endograft, which maintains antegrade blood flow, it is called chimney graft (Figure 6). On the contrary, with the periscope technique, the visceral stent is placed in the distal part, making the blood flow to the visceral artery flow retrogradely. There is no evidence indicating which technique produces the better patency rate. The periscope technique is used to preserve visceral arteries while repairing a ruptured TAAA with short distal neck, but it can also be used to preserve left subclavian artery while repairing the aortic arch.[35]

These several techniques include a risk of wire perforation, which may cause internal bleeding and intra-abdominal infection. Since visceral stents cannot be implanted from the periphery, multiple accesses are needed from the brachial, axillary, subclavian, or the femoral site. They also increase the risk of endoleak, or gutter leak. To decrease the gutter area, the oversizing of the aortic endograft should be increased. However, excessive oversizing can also increase endograft in folding, which can produce type I endoleak, collapse, lesser proximal fixation and migration. Mestres et al. proved that the optimal oversizing for endografts is 30%.[36] These authors also found that self-expanding stents have a significantly higher compression rate than balloon-expandable stents, which may cause further thrombosis. On the other hand, de Bruin et al. showed that balloon-expandable stents have larger gutters compared with self-expanding stents.[37] Some vascular specialists deploy an additional bare metal stent inside the visceral stent for reinforcement and to decrease tortuosity.[38-40]

Use of the chimney graft has produced promising early results. The technical success rate is 94-100%, the

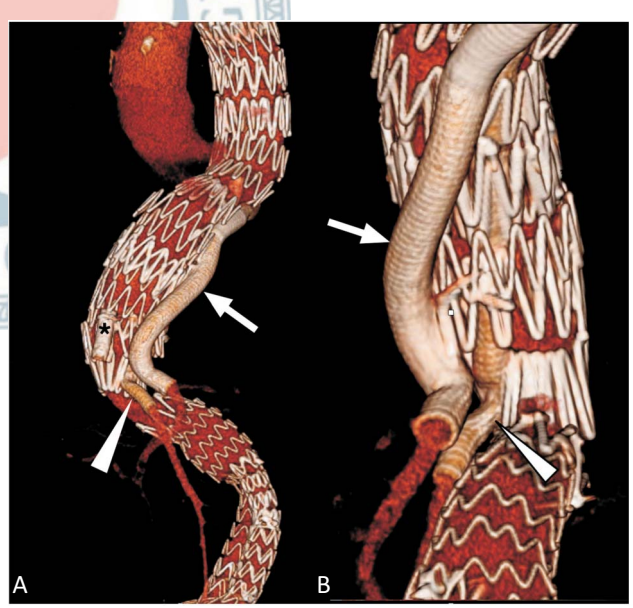

Figure 6. *An example of TAAA endovascular treatment combined chimney graft and sandwich technique (A), with close-up viewing (B). The covered stent connects to the celiac trunk (arrow) and is a chimney graft being parallel with the aortic endograft. On the other hand, the covered stent connect to SMA (arrow head) and right renal artery (asterisk) is inside and between two overlapped aortic endografts, represent as a sandwich technique.*

1-year visceral stent patency is 84-100%, the early type I endoleak rate is 0-13%, and the intra-operative stroke rate is 0-3.2%.[41,42] However, the chimney graft and periscope techniques are mostly used for juxta-renal AAA, and not applicable in extent I, II, and III TAAA because the distance of the visceral stents is too long to reach the proximal or distal neck.[39]

The sandwich technique

The sandwich technique was first described to preserve the internal iliac arteries, but thereafter used to preserve the visceral arteries in TAAA.[43]

In the sandwich technique, a tubular aortic stent graft is deployed first in the proximal thoracic aorta. The distal end is placed close to the celiac axis, and used as an artificial neck. For extent II TAAA, AAA stent grafts can also be deployed in advance. The visceral chimney grafts and another aortic endograft are then implanted into the tubular stent graft to exclude the aneurysm. Since the visceral grafts are placed between two aortic endografts, this technique was given the name of "sandwich" (Figure 6). However, surgeons should avoid deploying multiple chimney grafts into a calcified and narrow aorta.[40]

To address endoleak, the visceral stents should overlap at least 5 centimeters to avoid type III endoleak.[44] Additionally, the visceral stents are cannulated from the proximal. Some surgeons also prefer to use periscope technique for renal arteries to decrease accesses from the upper limbs.[45]

Nonetheless, the overall result is limited. The technical successful rate is 91-92%, and the 30-day mortality is 6.2-7.7%, the paraplegia rate is 0-3.1%, the complication rate is 15.6-20%, and the endoleak rate is 34.3-46.7%.[40,44] Consequently, it is important to enroll more patients and undertake extended surveillance to confirm the real outcome and long-term patency.

THE FENESTRATION AND BRANCHED GRAFT (CUSTOM-MADE DEVICES)

Fenestrated and branched grafts are customized endografts. The fenestrated grafts are primarily used in cases involving juxta-renal aneurysms or for a single visceral artery;[45] branched grafts are primarily used for multi-branched diseases such as TAAA. This technique can be used to treat TAAA employing the total endovascular approach, avoiding gutter leakage similar to use of the chimney and sandwich technique. However, this option takes 8-12 weeks for the entire production, and is not feasible for cases involving emergency surgery. Furthermore, the cost is expensive, and not appropriate for patients with compromised access or tortuous aneurysms.

There are two ways to undertake fenestration. The first avenue is reinforced fenestration, which stands for fenestration with a circumferentially reinforced nitinol ring. This approach can improve joint integrity of mating stent graft, and can also minimize the angle from the aorta to the target vessels.[46] However, the aortic seal wall may need to be extended above the origin of the branch, increasing the risk of paraplegia. Since there is no overlapping, balloon expandable stent graft should be used for enhanced fixation.

The other option is to use directional branches, which are predominantly helical in design. A polyester graft is sutured to the main endograft, and can be positioned antegradely or retrogradely. A catheter and wire are preloaded through the branches, which can be snared from the upper limb access and make cannulation easier; this can also increase the profile size of the delivery system by 1-2 F. Since the overlap of helical branch is as long as 30 mm, self-expanding stent graft is appropriate for fixation. By using the directional branch approach, the risk of endoleak and component separation is minimized, though the procedure should generally be used when the patient has extensive aneurysm and large lumen.[47]

The first fenestrated endograft was deployed in 1999 for juxta-renal AAA, which was followed in 2005 by reinforced fenestration endografts used to save visceral artery.[48,49] However, using a fenestrated and branched graft cannot eliminate the risk of SCI, renal dysfunction and myocardial infarction for the treatment of TAAA, but can significantly decrease the risk of pulmonary complication, which makes it a fascinating alternative management technique for high risk patients.[50] Some studies even use spinal anesthesia or regional anesthesia for most of the patients, which further decreases the risk associated with general anesthesia.[50]

The 30-day mortality after fenestration and bran-

ched graft is 2.3-9.1%, the risk of SCI is 0-7.1%, and the risk of endoleak is 0-18%.[14,47,49,50] The follow-up patency rate of the grafts is 92-100%. According to the largest comparison study, although patients receiving endovascular treatment have more comorbidities and are older, there is no difference in 30-day mortality, 12-month mortality, and the incidence of SCI compared to open surgery.[14]

CONCLUSIONS

TAAA is a complicated aneurysmal disease. Open surgery remains the treatment golden standard for patients with tolerable risk. However, hybrid operation and total endovascular treatment provide alternative options for high-risk patients. Total endovascular approach reduces the risk of pulmonary complications. The custom made devices and off-the-shelf multi-branched endografts may be associated with a lower risk of endoleak. However, continuing surveillance is mandatory to confirm the long-term graft patency rate and survival.

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DECLARATION OF CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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