One-stage aortic replacement for type A aortic dissection: using a Vasoring and a conventional elephant trunk graft

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Abstract

**OBJECTIVES:** We used a vascular ring connector (Vasoring) and a conventional elephant trunk graft for complete repair in open surgery for type A aortic dissection. This report described the immediate and mid-term results of this new technique.

**METHODS:** We used a rigid titanic ring as a stent in the vascular graft for rapid sutureless anastomosis in the reconstruction of type A aortic dissection.

**RESULTS:** A total of 65 consecutive patients with Stanford type A aortic dissection underwent open surgery performed by a single surgeon from November 2007 to February 2017. All patients underwent aortic reconstruction with vascular grafts and Vasorings (21 patients in the ascending aorta and 44 patients in the total aortic arch). For total aortic arch replacement, we implanted the conventional vascular graft in the proximal descending thoracic aorta as an elephant trunk graft. Concomitant procedures included the Bentall procedure (9 patients), the David operation (6 patients), coronary artery bypass grafting (9 patients), heart transplantation (1 patient), mitral valve replacement (2
patients) and endovascular aortic repair (1 patient). The mean duration of postoperative endotracheal intubation was 17.0 ± 11.8 h. The average blood loss was 520 ± 743 ml, and 25% of patients required no blood transfusion. The in-hospital mortality rate was 6%.

**CONCLUSIONS:** The combined use of the vascular ring connector and the conventional elephant trunk graft may reduce bleeding and pump time, stop the blood flow in the false lumen and allow the 1-stage total arch replacement to be performed safely. The conventional elephant trunk graft is free from stent graft-induced new entry.

**Keywords:** Aortic dissection • Total arch replacement • Vascular ring connector • Conventional elephant trunk graft • Intraluminal graft • Vasoring

**INTRODUCTION**

The surgical repair of Stanford type A aortic dissection is a challenging procedure, considering risks such as bleeding from anastomosis, prolonged cardiopulmonary bypass and organ ischaemia. To reduce bleeding, the intraluminal sutureless ringed vascular graft has been employed for anastomosis [1–4]. The use of commercial products (Meadox Medical Inc., Oakland, NJ, USA) yields satisfactory initial results but has been later considered unsafe due to pseudoaneurysm formation [5, 6]. After further investigation, we determined that the pseudoaneurysms were caused by ring dislodgement [7].

A new metallic ring with fixation furrow (Vasoring®; Sunwei Technology Co., Taipei, Taiwan) was designed to prevent dislodgement. The Vasoring comprises a biocompatible titanium alloy and is available in various sizes. Since 2007, we have been using the Vasoring for both type A and type B aortic dissections, and early and mid-term results have been excellent [7–9]. In this article, we presented our mid-term results for the combined use of the Vasoring and the conventional elephant trunk graft in patients with type A aortic dissection.

**MATERIALS AND METHODS**

Following the acquisition of the institutional review board approval from Cheng-Hsin General Hospital and Tung’s Taichung Metro Harbour Hospital, we reviewed the data of 65 consecutive patients with type A aortic dissection [48 men, 17 women; mean age of the patients 56.9 ± 14.1 years (range 22–88 years)] treated with 1-stage open reconstruction from November 2007 to February 2017. The requirement for acquisition of informed consent from patients was waived due to the retrospective nature of this study. The mean follow-up duration was 39 ± 33 months (1–116 months), with a median of 30 months (14–54 months, 25–75%). Twelve patients underwent previous surgery for aortic dissection. Furthermore, 2 patients experienced major strokes, and 1 had severe Fournier gangrene before surgery.

**Preoperative assessments**

Multidetector computed tomography (MDCT) of the thoracoabdominal aorta was performed before surgery. The location of entry tear, blood supply to the visceral organs and the side of the common femoral artery arising from the true lumen were assessed. The anatomy of arch branches including the innominate artery, the right common carotid artery, the left common carotid artery and the left subclavian artery was examined. Cardiac MDCT was routinely performed to rule out coronary artery disease. After intubation, we routinely employed transoesophageal echocardiography to detect the entry tear and blood flow in the false lumen.

**Total aortic arch replacement surgical techniques**

Our earlier technique for total aortic arch replacement was described in 2012 [7] (Fig. 1 and Video 1). After July 2014, we have modified the procedure to its current state. The steps of our procedure are as follows:

1. Preparation: prior to induction, pressure cannulae are inserted into both radial arteries. Three 8-mm gel-sealed Dacron grafts are individually anastomosed to the bilateral common carotid arteries and the healthier side of the common femoral artery. To prevent limb ischaemia, we prefer the use of a Dacron graft anastomosed to the femoral artery instead of a cannula directly inserted into the femoral artery for cardiopulmonary bypass. After sternotomy and heparin administration, the right atrium is cannulated, and patients undergo cardiopulmonary bypass using 2 carotid arterial cannulae and 1 venous return cannula in the right atrium.

2. Decision-making: the ascending aorta is incised, and a single shot of histidine-tryptophan-ketoglutarate solution (Custodiol;
Essential Pharmaceuticals LLC, Newtown, PA, USA) is delivered to the coronary arteries. If the intimal tear is located at the mid-ascending aorta, only the ascending aorta is replaced [7]. If the tear is very close to the aortic valve, we proceed with the Bentall procedure or the David operation [7]. If the entry tear is located at the aortic arch, total aortic arch replacement is performed.

3. Replacement of the ascending aorta only (without arch replacement): the size of the true lumen is measured, and a Dacron graft of the corresponding size is chosen. The length of the Dacron graft is equal to the length of the ascending aorta. Two Vasorings are placed at either ends of the Dacron graft and fixed with sutures. The ringed Dacron graft is subsequently inserted into the ascending aorta, and the Dacron tapes are used to secure the Vasorings from outside of the aorta. There are 2 furrows on the outer surface of the Vasoring—namely, the smaller furrow, which is used to fix the ring to the graft by sutures, and the larger furrow, which is used for fixation with tapes between the ring and the aorta.

4. The left common carotid artery to the left subclavian artery transposition (Fig. 1, steps 1–3): we extend the upper sternotomy skin incision obliquely by 4 cm to the left lower neck and divide the sternal head of the left sternocleidomastoid muscle to freely expose the left common carotid and left subclavian arteries. The left common carotid artery is divided and anastomosed to the left subclavian artery in an end-to-side or end-to-end fashion.

5. Creation of an elephant trunk graft: the graft is preferably a less stretchable Dacron graft, such as Gelsoft Plus (Vascutek Ltd., Renfrewshire, Scotland). A Vasoring (20–30 mm in diameter depending on the size of the true lumen) is inserted into the centre of the graft and fixed with sutures. The distal arm is used for the elephant trunk graft. The length of the elephant trunk graft is preferably 13–15 cm.

6. Replacement of the proximal portion of the ascending aorta: a Vasoring is inserted into a Dacron graft with a size corresponding to the true lumen of the aortic root and is fixed to 1 end of the graft. The ringed end of the graft is further inserted into the aortic root and fixed to the aorta with several tapes from the outside of the aorta.

7. Insertion of the elephant trunk graft using the guidewire pulling technique (Video 2): a long guidewire (Radifocus; Terumo Corporation, Tokyo, Japan) is inserted into the common femoral artery graft and is forwarded upwards until it comes out from the aortotomy. The aortic lumen is inspected to ensure that the guidewire is in the true lumen. The tip of the elephant trunk graft is attached to the guidewire and is pulled into the descending thoracic aorta by the guidewire. The Vasoring is subsequently fixed to the aorta with tapes at the mid-aortic arch.

8. Aorto-right common carotid artery bypass and aorto-left common carotid artery bypass: the right common carotid artery graft is disconnected from the perfusion system and anastomosed in an end-to-side fashion to the proximal end of the elephant trunk graft (Fig. 1, step 4). Another 8-mm graft is anastomosed to the right common carotid artery graft to form a Y-shaped side arm (Fig. 1, step 5). The proximal end of the elephant trunk graft is anastomosed to the Dacron graft in the aortic root (Fig. 1, step 6). Systemic perfusion is re instituted by declamping the femoral perfusion cannula. The blood is rewarmed, and the side arm of the right common carotid artery graft is anastomosed to the left common carotid artery graft (Fig. 1, step 7). In heavier patients, as an 8-mm graft is probably insufficient for upper body blood circulation, we suggest the use of a larger bifurcated Y-graft (e.g. 16 mm × 8 mm × 8 mm) or separated anastomotic sites for an aortocarotid bypass.

9. Preventive axillofemoral artery bypass: After the completion of arch replacement and restoration of systemic circulation, blood pressures in the upper and lower extremities are measured. If the pressure gradient is over 30 mmHg, axillofemoral bypass or aortofemoral bypass is immediately performed as a concomitant procedure.

Reoperative surgery for type A aortic dissection

In reoperative cases, the pump is instituted prior to the performance of sternotomy. In the event of aortic injury during sternotomy, the femoral bypass is stopped, and the brain perfusion is maintained by the isolated carotid perfusion at a rate of 1000–1500 ml/min. The remaining procedures are the same as above (https://www.youtube.com/watch?v=iaHrincvz60&t=117s).

Follow-up

All patients except for those who died in the early postoperative period underwent MDCT studies after surgery and were followed up later using MDCT aortography every year. Remodelling of the true and false lumens and recurrence of dissection were
observed. Furthermore, patients were followed up for their late complications or death. A representative MDCT image is shown in Fig. 2.

Statistics

Continuous variables are presented as mean ± standard deviation. Postoperative survival analysis was performed with the Kaplan–Meier survival curve using the IBM SPSS Statistics version 24.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Study population

A total of 65 consecutive patients with Stanford type A aortic dissection underwent open repair by the first author from November 2007 to February 2017 (Table 1). All patients received 1-stage repair with the Dacron vascular grafts and the Vasorings (21 in the ascending aorta and 44 in the total aortic arch). Elephant trunk grafts were used in all patients who underwent total aortic arch replacement. Some patients underwent concomitant procedures, including the Bentall procedure for 9 patients, the David operation for 6 patients, coronary artery bypass grafting for 9 patients, heart transplantation for 1 patient [10], mitral valve replacement for 2 patients and thoracic endovascular aortic repair for 1 patient. Four patients required axillofemoral bypass due to a small true lumen.

Immediate results

Excluding 4 cases of mortality, the duration of endotracheal intubation after surgery was 17.0 ± 11.8 h (Table 1). The average blood loss was 520.8 ± 743.7 ml, and 25% of patients did not require blood transfusion during and after surgery.
Flow in the false lumen on transoesophageal echocardiography

In all cases, transoesophageal echocardiography revealed immediate cessation of blood flow in the false lumen prior to sternal closure.

Complications and hospital mortality

Four hospital deaths occurred (Table 2). Two patients died of sepsis related to poor preoperative conditions: 1 had a major stroke and the other, Fournier gangrene. One patient died of deep sternal wound infection. Two patients had paraplegia, of whom one recovered and the other died. Two patients experienced a late-onset minor stroke during hospitalization. No bleeding complication related to anastomosis was observed. The inhospital mortality rate was 6% (4/65).

Late outcomes and long-term survival

Five late mortalities (8%) occurred due to the following reasons: brain infarct in 2 patients, intracranial haemorrhage in 1 patient, sepsis in 1 patient and prostate cancer in 1 patient (Table 2 and Fig. 3). Three and 2 patients had a minor stroke and peripheral thromboembolism, respectively. None had pseudoaneurysm formation at the anastomotic site of the Vasoring. There was no extension of the elephant trunk graft in patients followed up using MDCT. Three needed readmission for axillofemoral bypass due to intermittent claudication. None of the late mortalities were related to aortic dissection.

DISCUSSION

Total aortic arch replacement in 1 stage

Replacing the ascending aorta, the aortic arch and the proximal portion of the descending thoracic aorta in 1 stage was previously considered difficult due to the anterior location and posterior location of the ascending aorta and the descending thoracic aorta, respectively. The exposure of the distal arch and the frailty of the aortic wall are the critical issues of this type of surgery. The combined use of the Vasoring and the conventional elephant trunk graft may simplify the total arch replacement procedure and feasibly enable its completion in 1 stage. To date, almost all the surgeons in our hospital have successfully performed it independently.

Conventional elephant trunk graft or stent graft?

The elephant trunk graft proposed by Borst et al. [11, 12] is an ingenious idea. During their era, a conventional Dacron graft was used as the elephant trunk graft. The use of the conventional elephant trunk graft can help achieve haemostasis without exploring the distal portion of the aorta in surgeries for aortic aneurysm.
This is even more important in surgeries for aortic dissection. The implantation of a conventional ‘soft’ elephant trunk graft in the aorta may not only prevent the backflow of blood but also protect the fragile intima from further damage. However, the suitable method for soft graft implantation in the fragile aorta remains a technical problem.

Because of the high risks of conventional open surgery, the stent graft (the frozen elephant trunk graft) has been used to treat aortic dissection since 1999 [13–15]. However, some limitations and complications still exist, such as the lack of a healthy landing zone and the risk of stent graft-induced new entry (SINE) [16].

In this study, we listed the advantages and disadvantages of ‘conventional’ and ‘frozen’ elephant trunk grafts:

1. Implantation technique: the frozen elephant trunk graft can be easily introduced into the true lumen in both antegrade and retrograde directions. The conventional elephant trunk graft can only be implanted into the aorta through the aortotomy (i.e. in an antegrade manner). However, pushing a long soft Dacron graft into the aorta without kinking is not only difficult but also risky. We currently propose a simple way to achieve this goal: the guidewire pulling technique (Video 2).

2. Fixation of the elephant trunk graft: the stent graft can be fixed in the lumen if there is adequate landing zone or if the intimal tissue is sufficiently strong to hold the graft, which is usually impossible in type A aortic dissection. However, there are also difficulties in fixing the proximal end of the conventional elephant trunk graft to the aorta. The conventional strategy is the use of stitches to sew the Dacron graft to the aortic wall. Nonetheless, the ascending aorta and the aortic arch in type A aortic dissection are involved by the dissection flap, making the sewing technique very difficult and time-consuming. Moreover, bleeding from sewing holes may increase the mortality rate. Our technique of using the Vasoring for the proximal anastomosis remarkably reduces the technical difficulties, with an average pump time of 200 min, a circulatory arrest time of 118 min for the viscera and lower body and an acceptable blood loss of only 521 ml.

3. Cost: to use the conventional elephant trunk graft, we need no cost for the delivery system and the expensive stent graft. What are only required are a guidewire and a conventional Dacron graft. The Vasoring is much cheaper than the stent graft.

4. Efficiency in stopping the backflow from the true lumen to the false lumen: in an animal model, we inserted a soft Dacron graft into the porcine aorta that consisted of holes at various distances. Similar to the condition of the conventional elephant trunk graft placed in the dissected aorta with the entry tear. When the aorta was placed on circulation in a close circuit with normal blood pressure, there was no backflow to the hole if it was >3 cm away from the tip of the vascular graft. This indicates that the distal end of a soft Dacron graft 3 cm away from the intimal tear may stop the backflow from the true lumen to the false lumen. Our conventional elephant trunk graft is 12–15 cm in length (measured from the mid-aortic arch), with a tip that is usually 3 cm distal to the intimal tear (even if it is located at the distal arch). This could explain our observation on transoesophageal echocardiography that the backflow to the false lumen in almost all patients could be stopped prior to sternotomy closure. This in vitro study will be submitted for publication in the near future.

5. SINE: our clinical results confirmed that we do not need to be concerned about SINE when using the conventional elephant trunk graft.

### Table 2: Outcomes

<table>
<thead>
<tr>
<th>Outcome</th>
<th>N (%)</th>
<th>Mean ± SD (min–max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Follow-up duration (months)</td>
<td>39 ± 33 (1–116)</td>
<td></td>
</tr>
<tr>
<td>In-hospital mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sepsis from deep sternal wound</td>
<td>1 (2)</td>
<td></td>
</tr>
<tr>
<td>Sepsis from infection</td>
<td>1 (2)</td>
<td></td>
</tr>
<tr>
<td>Paraplegia</td>
<td>1 (2)</td>
<td></td>
</tr>
<tr>
<td>In-hospital mortality related to preoperative critical condition</td>
<td>2 (3)</td>
<td></td>
</tr>
<tr>
<td>Early complications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paraplegia</td>
<td>2 (3)</td>
<td></td>
</tr>
<tr>
<td>Late-onset minor stroke</td>
<td>2 (3)</td>
<td></td>
</tr>
<tr>
<td>Late mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brain infarct</td>
<td>2 (3)</td>
<td></td>
</tr>
<tr>
<td>Intracranial haemorrhage</td>
<td>1 (2)</td>
<td></td>
</tr>
<tr>
<td>Sepsis</td>
<td>1 (2)</td>
<td></td>
</tr>
<tr>
<td>Prostate cancer</td>
<td>1 (2)</td>
<td></td>
</tr>
<tr>
<td>Late minor complications</td>
<td>5 (6)</td>
<td></td>
</tr>
<tr>
<td>Minor stroke</td>
<td>3 (5)</td>
<td></td>
</tr>
<tr>
<td>Peripheral thromboembolism</td>
<td>2 (3)</td>
<td></td>
</tr>
<tr>
<td>Pseudoaneurysm</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Readmission for axillofemoral bypass</td>
<td>3 (5)</td>
<td></td>
</tr>
</tbody>
</table>

SD: standard deviation.
common carotid and left subclavian arteries are very close and located just beneath the sternocleidomastoid muscle. After dividing the sternal head of the sternocleidomastoid muscle, a direct end-to-side anastomosis or an end-to-end anastomosis of the 2 vessels is easy to perform. On the basis of our follow-up observations, repairing this muscle is unnecessary.

Bleeding

Tape fixation for the Vasoring provides a much larger contact surface area at the anastomotic site than the suture technique, thus reducing the risk of bleeding. Moreover, rapid anastomosis may shorten the extracorporeal circulation time, potentially reducing coagulopathy and blood loss. In our series, the average amount of blood transfusion during and after surgery was only 1 unit.

Brain ischaemia

The brain was continuously perfused with blood throughout the entire procedure; thus, none of our patients developed brain ischaemia during and after surgery.

Spinal cord and abdominal visceral organ ischaemia

Because of the short ischaemic time, none of our patients developed abdominal visceral organ ischaemia. The paraplegia in 2 patients might have been due to the compromised spinal cord arteries that were previously supplied by the upper descending thoracic artery or false lumen.

True lumen remodelling and axillofemoral bypass

One of our unpublished studies (will be submitted for publication in the near future) showed that remodelling of the true lumen after using the conventional elephant trunk graft was similar to the use of the stent graft. In acute dissection, most true lumen sizes returned to normal or near normal. In chronic dissection, most true lumens were also enlarged but to a lesser extent. Only few still had very small true lumen after surgery. As we had more patients referred from other hospitals for surgery, we had more chronic dissection patients (32%). Therefore, the incidence of axillofemoral bypass was higher (4 preventive during the first surgery and 3 after discharge).

Prior to surgical wound closure, we measured the blood pressures in the upper and lower extremities. In the event of a high-pressure gradient across the upper and lower bodies, we performed preventive axillofemoral or aortofemoral bypass. Interestingly, we did not observe visceral ischaemia related to a small true lumen, which might have been due to the preventive axillofemoral bypass that provided retrograde blood perfusion to the visceral organs.

Reoperation for type A aortic dissection

Twelve patients (19%) were referred for reoperation from other hospitals in which only the ascending aorta was replaced. All had residual entry tears at the aortic arch. Reoperation was indicated because of the progressive dilatation of the false lumen, leading to compression syndrome.

As the aorta may tightly adhere to the sternum, resternotomy is very risky. We will initially anastomose Dacron grafts to the bilateral carotid arteries and femoral artery, insert a venous return cannula into the right atrium via the femoral vein and subsequently place patients on cardiopulmonary bypass prior to the performance of resternotomy. If aortic injury occurs upon opening the sternum, femoral perfusion is stopped to prevent exanguination. Moreover, the brain is protected by continuous perfusion through the carotid arteries. We prefer to use a regular sternal saw rather than a sagittal saw, which can still injure the aorta in the presence of severe adhesion. We believe that the use of a sagittal saw will delay the opening time and may result in more blood loss. With this technique, some of our reoperative patients did not even require a blood transfusion (https://www.youtube.com/watch?v=S60OnQn-fgo&t=8s).

Pseudoaneurysm formation

An intraluminal sutureless graft was used for aortic dissection in early years [1–4]. However, its use was discontinued due to pseudoaneurysm formation [5, 6]. Out of curiosity, we removed the Teflon cloth of the ring and observed that it was a plastic ring with a smooth surface. This might be the reason for the dislodgement from the fixation tapes and subsequent pseudoaneurysm formation. In our chronic animal experiments, in accordance with the Food and Drug Administration’s requirements, we implanted the Vasorings in the adult porcine abdominal aorta and explanted them 6 months later. We found that the Vasorings were tightly covered by dense fibrotic tissue, without dislodgement or aortic wall necrosis. The mid-term follow-up of our patients also indicated the absence of pseudoaneurysm formation.

Vasoring design

The Vasoring is made of a biocompatible titanium alloy. The depth of the furrow used to fix the ring to the aortic wall varies with the ring diameter and is related to the security of the tape fixation. The deeper the furrow is, the safer the fixation. We had increased the depth of the furrow in the new-generation Vasoring to make it safer in fixation. To decrease the probability of thromboembolism, we may have to replace the smooth surface of the Vasoring with sintered titanium alloy.

Limitations

This study has some limitations. First, the follow-up duration was not sufficiently long. Second, there exists a concern about thromboembolism due to the use of the Vasoring. Third, the total arch replacement technique is complicated, and a learning curve is required to achieve a high successful rate.

CONCLUSIONS

Based on the obtained results, the following conclusions can be drawn. First, the use of the Vasoring is not only simple but it may also reduce surgical risks, including bleeding and organ
ischaemia. Second, the conventional elephant trunk graft can effectively stop the flow to the false lumen, allow remodelling of the true lumen and is free from SINE. Third, with the use of the Vasoring and conventional elephant trunk graft, 1-stage total aortic arch replacement for type A aortic dissection can be safely performed. Finally, we suggest that the total aortic arch be repaired in 1 stage and that the residual intimal tear not be left for the second surgery. Long-term follow-up is required before a definite conclusion can be drawn.

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