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ORIGINAL ARTICLE

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Mid-term results of zone 0 thoracic endovascular aneurysm repair after ascending aorta wrapping and supra-aortic debranching in high-risk patients

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Abstract

OBJECTIVES: Surgical repair of aneurysmal disease involving the ascending aorta, aortic arch and eventually the descending aorta is generally associated with significant morbidity and mortality. A less invasive approach with the ascending wrapping technique (WT), supra-aortic vessel debranching (SADB) and thoracic endovascular aneurysm repair (TEVAR) in zone 0 was developed to reduce the associated risk in these patients.

METHODS: During a 10-year period, consecutive patients treated by the ascending WT, SADB and TEVAR in zone 0 were included. All patients were considered at high risk for conventional surgery. Measured outcomes included perioperative deaths and morbidity, maximal aortic transverse diameter (TD) and its postoperative evolution, endoleak, survival, freedom from cardiovascular reinterventions, SADB freedom from occlusion and aortic valve function during follow-up. Median follow-up was 37.4 [mean = 34; range, 0–65; standard deviation (SD) = 20] months.

RESULTS: Twenty-six cases were included with a mean age of 71.88 (r = 56–87; SD = 8) years. A mean of 2.9 supra-aortic vessels (75) per patient was debranched from the ascending aorta. The mean time interval from WT/SADB and TEVAR was 29 (r = 0–204; SD = 48) days. TEVAR was associated with chimney and/or periscope grafts in 6 (23%) patients, and extra-anatomical supra-aortic bypasses were performed in 6 (23%) patients. Perioperative mortality was 7.7% (2/26). Neurological events were registered in 3 (11.5%) cases, and a reintervention was required in 3 (11.5%) cases. After the WT, the ascending diameter remained stable during the follow-up period in all cases. At mean follow-up, significant shrinkage of the arch/descending aorta diameter was observed. A type I/III endoleak occurred in 3 cases. At 5 years, the rates of survival, freedom from cardiovascular reinterventions and SADB freedom from occlusion were 71.7, 82.3 and 96%, respectively.

CONCLUSIONS: The use of the ascending WT, SADB and TEVAR in selected patients with complex thoracic aorta disease is safe and shows promising mid-term results at 3 years. The combination of these techniques could represent an alternative to the standard open surgical repair, especially in older patients or in patients unfit for cardiopulmonary bypass.

Keywords: Debranching • TEVAR • Wrapping • Ascending • Arch • Aneurysm

INTRODUCTION

Thoracic aortic disease is found in 10.4 persons per 100 000 person years [1]. Thoracic aortic aneurysms involve the ascending aorta in approximately 60% of cases, the aortic arch in 10%, the descending aorta in 40% and the thoracoabdominal aorta in the remaining 10% [2]. According to EuroSCORE.org, the mortality rate for open surgical thoracic aorta repair ranges from 2 to 50%, depending on age, risk factors, redo situation and nonelective setting [3]. This finding might be explained by the fact that

treatment of the ascending aorta and/or arch generally requires aortic replacement with cardiopulmonary bypass (CPB) and circulatory arrest, eventually combined with deep hypothermia [4, 5].

Recently, in patients presenting with an aneurysm involving the aortic arch and the appropriate proximal landing zone in the ascending aorta, thoracic endovascular aneurysm repair (TEVAR) with fenestrated or branched devices eventually combined with rerouting/debranching of the supra-aortic trunks was an attractive alternative to conventional open repair. However, in patients with a dilated or aneurysmal ascending aorta, a stent-graft landing in zone 0 may not be possible or safe. Generally, this population is treated with ascending and arch replacement or ascending replacement combined with hybrid techniques and/or grafts [6]. To avoid cardiopulmonary bypass and/or eventual circulatory arrest in such patients, the ascending wrapping technique (WT) with supra-aortic vessel debranching (SADB) may allow safe and durable TEVAR extending to zone 0. We report herein our results with this technique.

METHODS

From November 2006 to August 2015, data from patients treated by the ascending WT, SADB and TEVAR in zone 0 were obtained from the clinical information system of the University Hospital of Zurich (KISIM 4.901; Dendrite, Dendrite Clinical System, Henley-on-Thames, UK). Indications for treatment were aortic (arch and/or ascending) disease requiring zone 0 TEVAR proximal landing and high-risk profile for conventional surgery (graft replacement) with a EuroSCORE >5% and/or presenting multifocal aneurysm locations. The indication for the ascending WT was an ascending transverse diameter (TD) of >38 mm (small aneurysm considered inappropriate for safe tangential-clamping/debranching and stent-graft landing/sealing) and <70 mm (large aneurysms at high risk of dissection and rupture if addressed off-pump during the WT). All patients were considered at high surgical risk. As reported by Andersen *et al.* [6], comorbidities (age >65 years, coronary artery disease, heart failure, chronic obstructive disease and renal function impairment) and anatomical characteristics (thoracosternotomy incision and two-stage open repair) were considered to define high-risk patients. Interventions were planned after reviewing CT angiographic scans from all patients.

Demographic and clinical data were collected, including the EuroSCORE II risk mode [3]. The New York Heart Association (NYHA) [7] heart function (especially left ventricular function) and the Global Initiative for Chronic Obstructive Lung Disease (GOLD) were used to assess cardiac and respiratory function [8].

Outcome measures included perioperative mortality and morbidity rates, retrograde type A dissection, maximal aortic TD and its postoperative evolution, endoleak, survival, freedom from cardiovascular reinterventions, SADB freedom from occlusion and aortic valve function during follow-up. Informed consent about the procedure itself and the anonymous data collection and analysis was obtained from all patients.

Follow-up consisted of a clinical examination, CTA and echocardiography performed yearly. In case of endoleak with a stable or reduced aneurysm sac, the follow-up with clinical examination and computed tomography angiographic and echocardiographic scans was repeated every 6 months. In case of an increase in sac diameter, imaging follow-up was performed within 3 months. If growth was detected again, a redo procedure was performed. Median follow-up was 37.4 [mean: 34; range: 0–65; standard deviation (SD) = 20] months.

Statistical analysis

Means and SD or median and range were reported for parametric data; absolute values and percentages, for non-parametric data. Differences in preoperative and postoperative maximal aortic TD were assessed using the *t*-test. Kaplan–Meier curves were used to estimate survival and freedom from cardiovascular reinterventions. Statistical significance was considered $P < 0.05$. For Kaplan–Meier curves, confidence intervals (CI) and standard errors exceeding 10% were reported. Statistical analysis was performed using SPSS 16.0 (SPSS Inc., Chicago, IL, USA).

Technique

Both the WT and SADB were carried out in the same operation through a full median sternotomy to achieve an ascending exposure from the sinotubular junction to the brachiocephalic trunk (BCT) or eventually to the origin of the left common carotid artery.

As previously reported [9], the WT was performed with a polypropylene or polyester mesh that was marked before its use to achieve the final transverse aortic circumference by multiplying the intended aortic diameter by 3.14 (π). The marked mesh was placed around the ascending aorta and fixed to the posterior aortic wall with two proximal anchoring stitches (Ticron 4.0) just above the coronary sinuses. The mesh was then sutured, in correspondence with the marked lines, with a polypropylene 3.0 running suture (Blalock suture technique). A second suture line fixing the mesh to the aortic wall was subsequently placed with additional distal anchoring stitches (Fig. 1). During the WT, transoesophageal echocardiography was used routinely to assess the heart and valve function. Generally, the WT was intended to achieve a final ascending TD of about 35 to 38 mm (15–30% diameter reduction).

The SABD was performed after the ascending WT. The wrapped ascending aorta was tangentially clamped with a De Bakey multipurpose clamp in correspondence with the anterior or lateral wall to perform the proximal end-to-side anastomosis. A longitudinal incision involving both the mesh and the ascending aorta was made to perform the proximal anastomosis. According to the diameter used for the SADB conduit, an incision of proper length was made. The SADB conduit suture involved both the ascending aorta and the wrapping mesh in order to obtain the best fixation (Fig. 2). In cases of multiple SADB, the proximal anastomosis was eventually constructed with a Y-shaped Dacron graft in an end-to-side fashion; in the case of a single SADB, a straight Dacron or polytetrafluoroethylene graft was used. A radiopaque metallic marker (external pacemaker wire) was placed in relation to the proximal anastomosis to identify the debranching graft during the TEVAR proximal landing.

Distal anastomoses were constructed end to side or with the ViaBahn Open Revascularisation TEChnique (VORTEC). Generally, the end-to-side anastomosis was used to debranch the BCT; the VORTEC was used for single vessel end-to-end debranching [10]. The Gore hybrid vascular graft (GHVG; W. L. Gore & Associates, Flagstaff, AR) was used in a single vessel with the same technique used for the visceral vessel [11]. TEVAR was occasionally performed during the same operation after the WT/SADB or more commonly

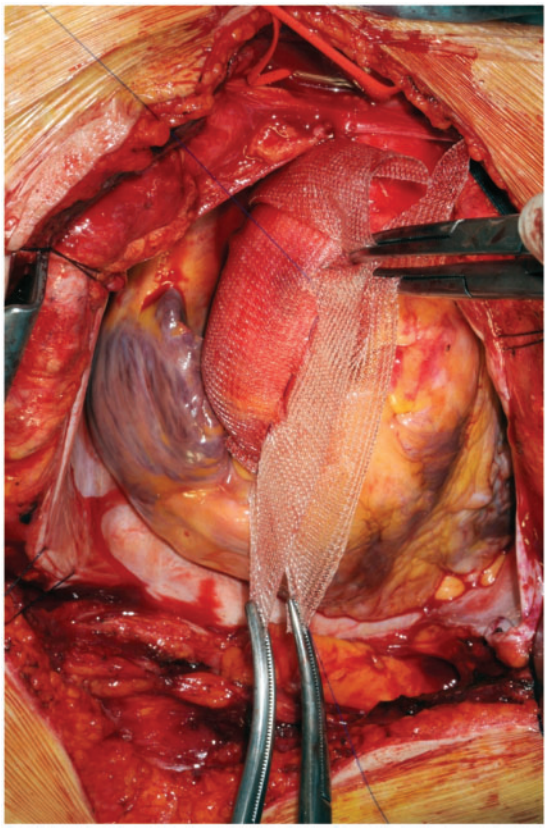

Figure 1: Wrapping technique. The polypropylene mesh is placed around the ascending aorta after its fixation to the posterior aortic wall with two proximal anchoring stitches (Ticron 4.0). The first polypropylene 3.0 running suture (Blalock suture technique) is placed.

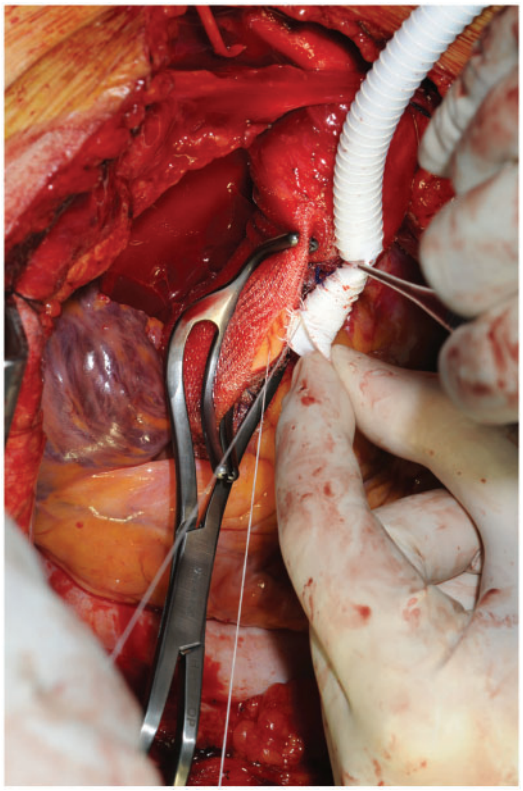

Figure 2: Supra-aortic debranching. A De Bakey multipurpose clamp is placed along the anterior or lateral wall of the ascending aorta to perform the proximal anastomosis.

in a delayed secondary procedure. An extra-stiff wire was passed through a femoral access point to reach the aortic valve. The stent graft was advanced over the wire and placed at the level of the ascending aorta (zone 0). The proximal landing zone was identified by the radiopaque marker placed during the SADB without the need for angiography. A 15 to 25% oversized aortic stent graft was used for proximal landing in correspondence of the wrapped ascending aorta. The size for the wrapped ascending stent graft was available from the operative report and the post-operative CTA. The aortic stent graft was deployed, and angiography was performed at the completion of the procedure. Chimney and/or periscope grafts (CPG) were eventually placed in the supra-aortic branches during the TEVAR procedure (Fig. 3) [12, 13]. CPG were used to reduce the operative time during the WT/SADB in specific circumstances such as the involvement of supra-aortic vessel scar tissue, an anatomical anomaly or a left subclavian artery (LSA)–right subclavian artery not easily reached from a median sternotomy due to aneurysm remodelling or contained rupture. Generally, TEVAR was performed under local anaesthesia.

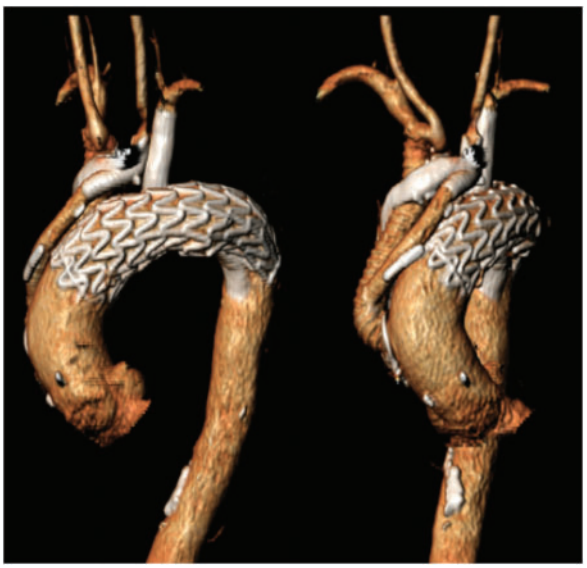

Figure 3: A computed tomography angiogram after TEVAR showing the proximal landing zone in relation to the ascending aorta, a periscope graft in the left subclavian artery and regular patency of the supra-aortic debranching.

RESULTS

We treated a total of 26 cases with a mean age of 71.88 (r = 56–87; SD = 8) years. Comorbidities and risk factors are reported in Table 1.

Twenty-three (89%) patients presented with multiple areas of aortic disease; 7 (27%) interventions were performed emergently. An ascending aneurysm not allowing a stent graft landing (diameter >42–65 mm) was diagnosed in 23 (89%); an ascending dilation not fitting the safe stent graft landing and/or sealing (up to 42 mm) was diagnosed in the other 3 (11%). An arch aneurysm was present in 15 (58%); a descending aortic aneurysm, in 5 (19%); a Crawford type I thoracoabdominal aneurysm (TAAA), in

Table 1: Demographic and clinical preoperative data

Number of patients	26
Mean age, years	72
Over 70 years, *n* (%)	11 (42)
Female, *n* (%)	9 (35)
Hypertension, *n* (%)	24 (85)
Pulmonary disease, *n* (%)	16 (61)
GOLD 1, *n* (%)	10 (38)
GOLD 2, *n* (%)	8 (31)
GOLD 3, *n* (%)	7 (27)
GOLD 4, *n* (%)	1 (4)
Cardiac disease, *n* (%)	15 (58)
Mild aortic valve insufficiency, *n* (%)	8 (31)
Mild valve stenosis, *n* (%)	1 (4)
Coronary artery disease, *n* (%)	6 (23)
NYHA I, *n* (%)	8 (31)
NYHA II, *n* (%)	10 (38)
NYHA III, *n* (%)	6 (23)
NYHA IV, *n* (%)	2 (8)
Lipid disorder, *n* (%)	8 (31)
Peripheral arterial disease, *n* (%)	6 (23)
Cancer, *n* (%)	6 (23)
Cerebral vascular disease, *n* (%)	10 (39)
Hostile chest, n (%)	8 (31)
Preoperative EuroSCORE II	18.19

GOLD: Global Initiative for Chronic Obstructive Lung Disease; NHYA: New York Heart Association.

2 (8%); a Crawford type II TAAA, in 7 (27%); a Stanford type B, in 4 (15%); an abdominal aortic aneurysm, in 2 (8%); a ductus Botalli aneurysm, in 2 (8%); and an aberrant right subclavian artery aneurysm, in 1 (4%) (Table 2). The preoperative EuroSCORE II was 18.19%.

The mean preoperative ascending TD in patients with an ascending aneurysm was 4.92 ($r = 3.4–6.5$; SD = 0.9) cm. The mean preoperative arch/descending aorta diameter was 6.1 ($r = 3–11$; SD = 2) cm.

Seventy-five supra-aortic vessels were debranched (mean of 2.9 vessels per patient) using the SADB technique: 13 (17%) BCTs; 9 (12%) right subclavian arteries; 15 (20%) right carotid arteries (RCA); 25 (33%) left carotid arteries (LCAs); 12 (16%) LSAs; and 1 (1%) left vertebral artery. A standard end-to-side distal anastomosis was performed in 26 (26/75; 35%) vessels; the VORTEC was used for 48 (48/75; 64%) vessels and the GHVG, in 1 (1/75; 1%) (Table 2).

The mean time interval to TEVAR after the WT/SADB was 29 ($r = 0–204$; SD = 48) days. In 9 (35%) cases, the WT/SADB and TEVAR were performed simultaneously.

In addition to the treated vessels, TEVAR was accompanied by CPGs in 6 (23%) patients to maintain blood flow into 6 LSAs and 1 BCT.

Six (23%) patients required additional surgery to maintain blood flow into the supra-aortic branches (1 right carotid artery–LCA–LSA bypass; 5 LCA–LSA bypasses). Three bypasses were performed simultaneously with TEVAR and 3 cases between the WT/SADB and TEVAR.

The perioperative mortality rate was 7.7% (2/26). One death occurred immediately after TEVAR (case #8) due to massive myocardial infarction. The second death (case #3) was registered on the 18th postoperative day due to respiratory insufficiency and spinal cord ischaemia. Complications that were managed conservatively were registered in 4 cases: 2 with myocardial infarction, both presenting with precordial pain and increase of troponin level and, in 1 case, ST elevation; 2 with pulmonary embolism.

Neurological events were registered in 3 cases (amaurosis fugax; transient ischaemic attack; transient spinal cord ischaemia). Reinterventions were done in 3 cases: 1 due to pneumothorax requiring drainage and 2 due to bleeding requiring revision. No type A retrograde dissection was registered.

After the ascending WT, the mean ascending TD was 3.6 ($r = 2.8–4.6$; SD = 0.5) cm with a mean reduction of 1.3 ($r = 0.5–3.0$; SD = 0.7) cm ($P < 0.001$). The ascending diameter remained stable during the follow-up period in all cases (Table 2). At mean follow-up, the arch/descending aorta diameter was 5.5 ($r = 2.8–10.4$; SD = 10.4) cm with significant shrinkage ($P = 0.001$).

A slow flow type 1a endoleak [14] occurred in 1 (3.8%) patient (case #23) after TEVAR and LSA chimney graft; the aneurysm sac decreased postoperatively about 0.6 cm, and it is currently under surveillance. A type III endoleak was registered in 2 cases; in case #11 an increase in the aneurysm sac (1.5 cm) required a secondary intervention 27 months after the initial TEVAR. In case #26, no aneurysm sac change was observed, and the patient is under surveillance. In 4 cases (#6, #9, #15 and #18), a type II endoleak with no enlargement of the aneurysm sac was registered.

The estimated rates for 5-year survival, freedom from cardiovascular reinterventions and SADB freedom from occlusion were 71.7, 82.3 and 96%, respectively (Fig. 4). Aortic valve function during follow-up remained stable in all but 1 patient (case #4) in whom implantation of the transapical aortic valve was planned in advance and performed 6 months after the TEVAR.

DISCUSSION

Surgical repair of aortic arch diseases, especially when they involve the ascending and/or descending aorta, may carry a high surgical risk even in patients who are at low risk for general anaesthesia. Improvements in neurological protections and surgical techniques have been reported over the years. However, a high mortality rate up to 29% and neurological events up to 18% are still reported [15–17].

Totally endovascular solutions with both fenestrated and branched stent grafts have been proposed to land proximally in Ishimaru zone 0. All of these devices are still under investigation in high-risk patients [18]. In addition, the use of parallel grafts in supra-aortic vessels has been reported with promising results even in an emergent setting [19].

The presence of a dilated ascending aorta represents a limitation to the full endovascular approach and zone 0 landing. Generally, a dilated/aneurysmal ascending aorta precludes the total endovascular approaches. In such patients, the gold standard is still conventional ascending and arch graft replacement. Perioperative results of such surgery can be determined using the EuroSCORE II calculator [3]. In more extensive disease, the operative risk is generally higher. LeMaire reported a 2% perioperative mortality, 5% cerebral events and 77.6% 2-year survival rate for patients with aneurysms involving the ascending aorta and the aortic arch [20]. In their experience with the elephant trunk technique in patients presenting with more extensive aneurysmal disease, they observed a 16% overall operative mortality rate, 8% neurological events and 70% 5-year survival rate [21].

SADB and TEVAR in zone 0 have been reported in patients with a normal ascending aorta who are considered unfit for

Table 2: Patient aortic disease and surgical detail

ID	Diagnosis	WT	SADB	TEVAR
1	1. Ascendens an 2. Arch an	Polyester mesh Asc TDR: 9 mm	1. BCT-E/S 2. LCA-E/S 3. LSA-VORTEC	1. TAG[a] 37/20
2	1. Ascendens an 2. Arch an 3. Thoracic an	Polyester mesh Asc TDR: 7 mm	1. BCT-E/S 2. LCA-VORTEC	1. TAG[a] 34/20
3	1. Ascendens an 2. Crawford II TAAA	Polyester mesh Asc TDR: 12 mm	1. BCT-E/S 2. LCA-VORTEC 3. LSA-VORTEC	1. TAG[a] 34/20
4	1. Ascendens an 2. Arch an 3. AAA	Polyester mesh Asc TDR: 7 mm	1. BCT-E/S 2. LCA-VORTEC	1. TAG[a] 34/20
5	1. Crawford I TAAA	Polypropylene mesh Asc TDR: 18 mm	1. RSA-E/S 2. RCA-E/S 3. LCA-VORTEC 4. LSA-VORTEC	1. TAG[a] 40/20
6	1. Ascendens an 2. B dissection	Polypropylene mesh Asc TDR: 20 mm	1. BCT-E/S 2. LCA-VORTEC	1. TAG[a] 40/20
7	1. Ascendens an 2. Arch an	Polypropylene mesh Asc TDR: 18 mm	1. RSA-E/S 2. RCA-VORTEC 3. LCA-VORTEC 4. LSA-VORTEC	1. EVITA[b] 44-40/20 2. EVITA[b] 40/15
8	1. Ascendens an 2. Crawford II TAAA	Polypropylene mesh Asc TDR: 12 mm	1. RSA-E/S 2. RCA-VORTEC 3. LCA-VORTEC 4. LSA-VORTEC	1. TAG[a] 40/20 2. TAG[a] 40/20 3. TAG[a] 40/20
9	1. Ascendens an 2. Thoracic an 3. B dissection	Polypropylene mesh Asc TDR: 14 mm	1. BCT-E/S 2. RCA-VORTEC 3. LCA-VORTEC 4. LSA-VORTEC	1. TAG[a] 31/15 2. TAG[a] 40/20 3. TAG[a] 40/20 4. TAG[a] 40/20
10	1. Ascendens an 2. B dissection	Polypropylene mesh Asc TDR: 5 mm	1. RSA-E/S 2. RCA-VORTEC 3. LCA-VORTEC 4. LSA-VORTEC	1. TAG[a] 37/20 2. TAG[a] 31/20
11	1. Ascendens an 2. Arch an	Polypropylene mesh Asc TDR: 30 mm	1. BCT-VORTEC 2. LCA-VORTEC 3. LVA-VORTEC	1. TAG[a] 37/20 2. EVITA[b] 40/23
12	1. Ascendens an 2. Arch an 3. Thoracic an	Polypropylene mesh Asc TDR: 8 mm	1. RSA-VORTEC 2. RCA-VORTEC 3. LCA-VORTEC	1. TAG[a] 34/37
13	1. Ascendens an 2. ARSA an	Polypropylene mesh Asc TDR: 6 mm	1. RSA-E/S 2. RCA-E/S 3. LCA-E/S 4. LSA-E/S	1. TAG[a] 31/15
14	1. Ascendens an 2. Ductus Botalli an	Polypropylene mesh Asc TDR: 16 mm	1. RSA-E/S 2. RCA-VORTEC 3. LCA-VORTEC 4. LSA-VORTEC	1. TAG[a] 37/15 2. TAG[a] 31/15
15	1. Ascendens an 2. Crawford II TAAA	Polypropylene mesh Asc TDR: 10 mm	1. RCA-E/S 2. LCA-VORTEC	1. TAG[a] 34/20
16	1. Ascendens an	Polypropylene mesh Asc TDR: 8 mm	1. BCT-E/S 2. LCA-VORTEC	1. TAG[a] 40/15
17	1. Ascendens an 2. Crawford II TAAA	Polypropylene mesh Asc TDR: 6 mm	1. RCA-VORTEC 2. LCA-VORTEC	1. TAG[a] 34/20 2. TAG[a] 34/20
18	1. Ascendens an 2. Crawford II TAAA	Polypropylene mesh Asc TDR: 19 mm	1. BCT-E/S 2. LCA-VORTEC 3. LSA-VORTEC	1. TAG[a] 40/15 2. TAG[a] 40/15
19	1. Arch an	Polypropylene mesh Asc TDR: 8 mm	1. RSA-E/S 2. RCA-VORTEC 3. LCA-VORTEC	1. TAG[a] 34/20
20	1. Ascendens an 2. Arch an 3. Crawford II TAAA	Polypropylene mesh Asc TDR: 9 mm	1. BCT-E/S	1. TAG[a] 45/15 2. TAG[a] 45/15 3. TAG[a] 45/15
21	1. Arch an 2. Crawford II TAAA 3. B dissection	Polypropylene mesh Asc TDR: 13 mm	1. BCT-E/S 2. RCA-VORTEC 3. LCA-VORTEC 4. LSA-VORTEC	1. TAG[a] 37/20

Continued

Table 2 Continued

ID	Diagnosis	WT	SADB	TEVAR
22	1. Ascendens an 2. Arch an 3. Thoracic an	Polypropylene mesh Asc TDR: 24 mm	1. RSA-E/S 2. RCA-VORTEC 3. LCA-VORTEC 4. LSA-VORTEC	1. TAG[a] 45/20
23	1. Ascendens an 2. Arch an 3. Crawford I TAAA	Polypropylene mesh Asc TDR: 25 mm	1. BCT-VORTEC 2. LCA-GHVG	1. TAG[a] 45/20
24	1. Ascendens an 2. Arch an 3. Thoracic an	Polypropylene mesh Asc TDR: 10 mm	1. RCA-VORTEC 2. LCA-VORTEC	1. NEXUS[c]
25	1. Ascendens an 2. Arch an 3. Ductus Botalli an	Polypropylene mesh Asc TDR: 7 mm	1. BCT-E/S 2. LCA-VORTEC	1. TAG[a] 37/15
26	1. Ascendens an 2. Arch an 3. AAA	Polypropylene mesh Asc TDR: 7 mm	1. RCA-VORTEC 2. LCA-E/S	1. TAG[a] 45/20 2. TAG[a] 45/20

WT: wrapping technique; SADB: supra-aortic debranching; TEVAR: thoracic endovascular aneurysm repair; BCT: brachiocephalic trunk; RSA: right subclavian artery; RCA: right carotid artery; LCA: left carotid artery; LSA: left subclavian artery; An: aneurysm; TAAA: thoraco-abdominal aneurysm; AAA: abdominal aortic aneurysm; Asc TDR: ascending transverse diameter reduction; VORTEC: ViaBahn Open Revascularisation TEChnique; GHVG: Gore hybrid vascular graft.
[a]W.L. Gore & Associates, Flagstaff, AZ, USA.
[b]Jotec, Hechingen, Germany.
[c]Endospan, Herzlia, Israel.

conventional open repair [6, 22]. The WT/SADB followed by TEVAR may be a less risky procedure compared to open graft replacement in patients presenting with dilation or aneurysm (<70 mm) of the ascending aorta. The WT reduces and reinforces the whole ascending aorta, allowing the best anastomosis site for SADB and the best landing zone for TEVAR [23]. In addition, reducing the aortic diameter decreases the aortic wall stress, which may lower the risk of aortic dissection while clamping/declamping the aorta during SADB or TEVAR in the ascending aorta. The fact that no aortic dissection occurred during or after WT/SADB and TEVAR seems to confirm our hypotheses. Moreover, the WT has been shown to be effective and durable over time in the treatment of isolated ascending aneurysms [9]. A meta-analysis of ascending WTs showed in-hospital mortality and mortality rates during the follow-up period of 1.5 and 0.3%, respectively. Re-dilatations and reinterventions were observed in 1.7 and 1.8% in cases where the mesh was not sutured to the aorta [24]. During the SADB, the aorta is tangentially clamped to a section with a lower diameter after the ascending WT. It was shown that after WT, shear stress is significantly reduced; therefore, the risk of plaque disruption, atheroembolization and aortic dissection due to aortic clamp application is lower [25].

The VORTEC and the GHVG were used in 65% of the distal anastomoses (49 supra-aortic vessels) to reduce the ischaemic time, overall procedure time and bleeding sources from the debranched vessels [10, 26]. The cost of the device represents a relevant limitation of the VORTEC and GHVG.

The early and mid-term outcomes achieved with WAT/SADB/TEVAR have a perioperative mortality and neurological events rate of 7.7 and 11.5%, respectively; the estimated 5-year survival rate of 71.7% is acceptable, especially considering that this approach was used in high-risk patients unfit for conventional surgery.

In comparison, Preventza *et al.* reported their results with a lower-risk cohort of 29 patients requiring a zone 0 TEVAR proximal landing without ascending aorta involvement. In that series, perioperative mortality was 6.9%; the neurological events rate was 10.3% and the estimated 2-year survival rate was 79.3% [27].

As reported in case #24, the WT can be used in association with fenestrated/branched stent grafts to expand their application in patients presenting with an enlarged ascending aorta.

Basically, in our patients, the enlarged or aneurysmal ascending aorta required replacement (type II hybrid arch repair (HAR)), but with the WT technique, the ascending aorta was made fit for a stent graft landing (type I HAR). In a series including 36 patients undergoing the type I–II HAR, results were similar to those with WT/SADB-TEVAR, with a reported overall mortality rate of 8%, 14% permanent neurological events and 8% renal failure [28]. Severe aortic valve stenosis and insufficiency requiring valve repair are limitations of the WT. Slight regurgitation, especially due to a disturbance of the sinotubular junction, may be corrected with the WT. If not, the approach depends on severity of regurgitation and the general condition of the patient. Transcatheter aortic valve implantation should be considered, especially in cases of appropriate aortic annulus size. Coronary artery disease is not an exclusion criterion for WT/SADB because it can be managed off pump or by percutaneous coronary intervention [29].

The WT should be avoided in cases with an ascending aneurysm larger than 70 mm because of the thinness of the arterial wall and the related risk of the surgical exposure of the aorta and the pulmonary artery [9]. Severe calcifications and/or visible plaques are considered contraindications to the WT due to the risk of plaque rupture during aortic mobilization and mesh tightening.

Combining an LSA periscope graft, eventually as a sandwich, into the repair strategy may be critical because it maintains

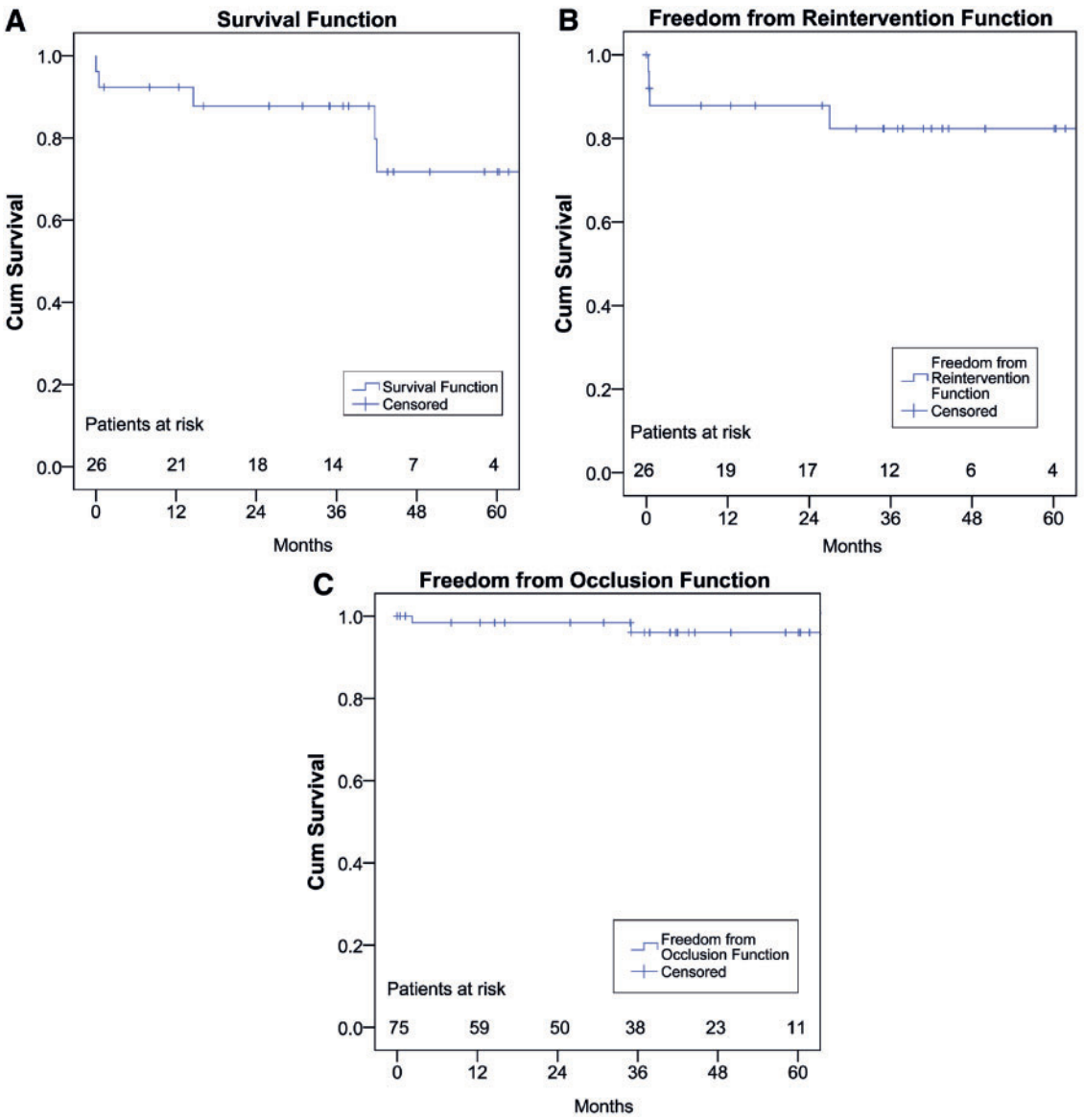

Figure 4: Estimated 5-year Kaplan–Meier curves. (**A**) Survival. SE does not exceed 10% at 5 years for the survival curve (SE = 4.9; CI = 45–64). (**B**) Freedom from reintervention. SE does not exceed 10% at 5 years for the freedom from reintervention curve (SE = 4.6; CI = 46–65). (**C**) Freedom from occlusion. SE does not exceed 10% at 5 years for the freedom from occlusion curve (SE = 1.2; CI = 61–66). SE: standard error; CI: confidence interval.

transaxillary access to the abdominal aorta and the pelvic or lower limb vessels. Although low, an increased risk of gutters and endoleaks is possible [30].

The lack of a comparison group treated with conventional open repair during the same period may represent a study limitation. However, based on the positive outcomes achieved in this high-risk population, it appears difficult to argue for an open surgical approach.

In conclusion, the ascending aorta WT, SADB and TEVAR used in high-risk patients presenting with complex, extensive thoracic aorta aneurysms involving the ascending aorta and considered unfit for conventional open graft replacement showed promising early and mid-term results. These techniques may be considered a valid alternative to conventional open-heart surgery in this group of patients, especially if a larger cohort of patients and a longer follow-up period validate these data.

Conflict of interest: none declared.

REFERENCES

[1] Clouse WD, Hallett JW, Jr., Schaff HV, Gayari MM, Ilstrup DM, Melton LJ, III. Improved prognosis of thoracic aortic aneurysms: a population-based study. JAMA 1998;280:1926–9.
[2] Isselbacher EM. Thoracic and abdominal aortic aneurysms. Circulation 2005;111:816–28.
[3] Nashef SA, Roques F, Sharples LD, Nilsson J, Smith C, Goldstone AR *et al*. EuroSCORE II. Eur J Cardiothorac Surg 2012;41:734–44; discussion 44-5.

[4] Bavaria J, Milewski RK, Baker J, Moeller P, Szeto W, Pochettino A. Classic hybrid evolving approach to distal arch aneurysms: toward the zone zero solution. J Thorac Cardiovasc Surg 2010;140:S77–80; discussion S86-91.
[5] Kent WD, Herget EJ, Wong JK, Appoo JJ. Ascending, total arch, and descending thoracic aortic repair for acute debakey type i aortic dissection without circulatory arrest. Ann Thorac Surg 2012;94:e59–61.
[6] Andersen ND, Williams JB, Hanna JM, Shah AA, McCann RL, Hughes GC. Results with an algorithmic approach to hybrid repair of the aortic arch. J Vasc Surg 2013;57:655–66.
[7] Dolgin M, Committee NYHAC. Nomenclature and criteria for diagnosis of diseases of the heart and great vessels. In: Dolgin M. (ed). The Criteria Committee of the New York Heart Association. Boston: Little, Brown, 1994.
[8] From the global strategy for the diagnosis, management and prevention of copd, global initiative for chronic obstructive lung disease (gold) 2016. Http://goldcopd.Org/ (3 November 2016, date last accessed).
[9] Pecoraro F, Shingaki M, Steuer J, Chaykovska L, Rancic Z, Weber A *et al*. Treatment of isolated ascending aortic aneurysm by off-pump epiaortic wrapping is safe and durable. Interact CardioVasc Thorac Surg 2016;23:286–91.
[10] Donas KP, Rancic Z, Lachat M, Pfammatter T, Frauenfelder T, Veith FJ *et al*. Novel sutureless telescoping anastomosis revascularization technique of supra-aortic vessels to simplify combined open endovascular procedures in the treatment of aortic arch pathologies. J Vasc Surg 2010;51:836–41.
[11] Setacci F, Pecoraro F, Chaykovska L, Mangialardi N, Shingaki M, Veith FJ *et al*. The gore hybrid vascular graft in renovisceral debranching for complex aortic aneurysm repair. J Vasc Surg 2016;64:33–8.
[12] Lachat M, Mayer D, Pfammatter T, Criado FJ, Rancic Z, Larzon T *et al*. Periscope endograft technique to revascularize the left subclavian artery during thoracic endovascular aortic repair. J Endovasc Ther 2013;20:728–34.
[13] Vicente S, Glenck M, Mayer D, Veith FJ, Lachat M, Pecoraro F. Chimney and periscope grafts to facilitate endovascular treatment of aortic transection in a patient with aberrant right subclavian artery. J Endovasc Ther 2014;21:123–6.
[14] Pecoraro F, Veith FJ, Puippe G, Amman-Vesti B, Bettex D, Rancic Z *et al*. Mid- and longer-term follow up of chimney and/or periscope grafts and risk factors for failure. Eur J Vasc Endovasc Surg 2016;51:664–73.
[15] Hiraoka A, Chikazawa G, Tamura K, Totsugawa T, Sakaguchi T, Yoshitaka H. Clinical outcomes of different approaches to aortic arch disease. J Vasc Surg 2015;61:88–95.
[16] Patel HJ, Nguyen C, Diener AC, Passow MC, Salata D, Deeb GM. Open arch reconstruction in the endovascular era: analysis of 721 patients over 17 years. J Thorac Cardiovasc Surg 2011;141:1417–23.
[17] Estrera AL, Miller CC, III, Lee TY, Shah P, Safi HJ. Ascending and transverse aortic arch repair: the impact of retrograde cerebral perfusion. Circulation 2008;118:S160–6.
[18] Spear R, Haulon S, Ohki T, Tsilimparis N, Kanaoka Y, Milne CP *et al*. Editor's choice - subsequent results for arch aneurysm repair with inner branched endografts. Eur J Vasc Endovasc Surg 2016;51:380–5.
[19] Bosiers MJ, Donas KP, Mangialardi N, Torsello G, Riambau V, Criado FJ *et al*. European multicenter registry for the performance of the chimney/snorkel technique in the treatment of aortic arch pathologic conditions. Ann Thorac Surg 2016;101:2224–30.
[20] LeMaire SA, Weldon SA, Coselli JS. Total aortic arch replacement: current approach using the trifurcated graft technique. Ann Cardiothorac Surg 2013;2:347–52.
[21] LeMaire SA, Carter SA, Coselli JS. The elephant trunk technique for staged repair of complex aneurysms of the entire thoracic aorta. Ann Thorac Surg 2006;81:1561–9; discussion 69.
[22] Vallejo N, Rodriguez-Lopez JA, Heidari P, Wheatley G, Caparrelli D, Ramaiah V *et al*. Hybrid repair of thoracic aortic lesions for zone 0 and 1 in high-risk patients. J Vasc Surg 2012;55:318–25.
[23] Pecoraro F, Pfammatter T, Lachat M, Mayer D, Veith F, Rancic Z. A new off-pump hybrid open and endovascular repair to treat ductus botalli and ascendens aneurysms. Vasc Endovasc Surg 2012;46:172–5.
[24] Plonek T. A metaanalysis and systematic review of wrapping of the ascending aorta. J Cardiac Surg 2014;29:809–15.
[25] Harringer W, Stud ICEM. Capture of particulate emboli during cardiac procedures in which aortic cross-clamp is used. Ann Thorac Surg 2000;70:1119–23.
[26] Rancic Z, Pecoraro F, Pfammatter T, Mayer D, Veith FJ, Lachat M. Less invasive (common) femoral artery aneurysm repair using endografts and limited dissection. Eur J Vasc Endovasc Surg 2013;45:481–7.
[27] Preventza O, Bakaeen FG, Cervera RD, Coselli JS. Deployment of proximal thoracic endograft in zone 0 of the ascending aorta: treatment options and early outcomes for aortic arch aneurysms in a high-risk population. Eur J Cardiothorac Surg 2013;44:446–52; discussion 52-3.
[28] Vallabhajosyula P, Szeto W, Desai N, Bavaria JE. Type i and type ii hybrid aortic arch replacement: postoperative and mid-term outcome analysis. Ann Cardiothorac Surg 2013;2:8.
[29] Pecoraro F, Wilhelm M, Kaufmann AR, Bettex D, Maier W, Mayer D *et al*. Early endovascular aneurysm repair after percutaneous coronary interventions. J Vasc Surg 2015;61:1146–50.
[30] Donas KP, Lee JT, Lachat M, Torsello G, Veith FJ, Investigators P. Collected world experience about the performance of the snorkel/chimney endovascular technique in the treatment of complex aortic pathologies the pericles registry. Ann Surg 2015;262:546–53.