Aorta

A multi-disciplinary journal for clinicians and researchers with interest in the Aorta and its first-order branches, intended for cardiac surgeons, cardiologists, vascular surgeons, interventional radiologists, geneticists, molecular biologists, engineers, and industry scientists, among others.

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Open Stented Grafts for Frozen Elephant Trunk Technique: Technical Aspects and Current Outcomes

Wei-Guo Ma, MD1,2, Jun Zheng, MD1, Li-Zhong Sun, MD1*, John A. Elefteriades, MD2

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Abstract
With growing experience in patients with aneurysms and dissections in the arch and proximal descending aorta, the frozen elephant trunk (FET) technique has been shown to be safe and effective, and has achieved favorable short to mid-term outcomes. As the FET technique is gaining wider acceptance, there is a growing need for versatile, technically simple, and highly durable open stented grafts involving less complicated deployment mechanisms enabling use in various indications. This paper gives a brief review on the technical aspects and clinical outcomes of currently available open stented grafts used in the FET technique, including the E-vita Open Plus, Thoraflex Hybrid, Cronus, and J Graft. While none of these grafts can claim to be an ideal device, technology continues to improve towards this goal. As newer devices and systems are developed, more widespread use of the FET technique can be expected; such progress promises to improve the clinical outcomes and quality of life for patients with complex aortic diseases.

Key Words
Aorta • Blood vessel prosthesis implantation • Frozen elephant trunk • Surgery • Stents • Aneurysm • Aortic dissection

Diseases of the aortic arch and descending aorta remain among the great challenges in cardiovascular surgery. In March 1982, Dr. Hans-Georg Borst introduced the 2-stage elephant trunk technique in Hannover, Germany, which has greatly facilitated surgical treatment of this special pathologic entity [1]. Nevertheless, the cumulative risks of two major surgical procedures [2-4] stimulated further explorations aimed at achieving complete repair of extensive aortic lesions in one single operation [5, 6]. As the first in-human application of intraluminal stent graft for aortic aneurysms by Juan Parodi had fueled subsequent innovations [7], Dr. Kato proposed a modification to the classic elephant trunk technique [8] based on his early investigations [9-11], in which a covered endovascular stent graft is deployed into the descending aorta through the open aortic arch. The open stented graft (OSG) can be securely fixed at the desired level inside the distal descending aorta, allowing thrombus formation within the space between the graft and the aortic wall. The inventor of the elephant trunk technique, Hans-Georg Borst, named this approach the “frozen elephant trunk (FET)” [12], which has been increasing steadily in use since the late 1990s [13-16].

With growing experience in patients with aneurysms and dissections of the arch and proximal descending aorta, the FET technique has been shown to be safe and effective, with favorable early and long-term outcomes [16-24]. Accordingly, the FET technique is gaining wider acceptance among the cardiovascular surgical community, resulting...
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in a growing need for open stent grafts. This paper aims to review briefly the currently available OSGs used in the FET technique, including the E-vita Open and Open Plus, Thoraflex Hybrid, Cronus, and J Graft open stent graft, with emphasis upon technical aspects and clinical outcomes.

Chavan-Haverich Prosthesis (Non-Commercial)

Designed by Drs. Chavan and Haverich again in Hannover, the custom-made endograft (Curative GmbH, Dresden, Germany) was the prosthesis for FET in the Hannover group before 2007 [25, 26]. It is composed of a proximal unstented Dacron tube and a distal stented tube with Z-shaped stainless steel stents affixed to the inner aspect (Figure 1) [27]. A 5-mm gap between the stents, maintained by two longitudinally oriented stainless steel wires, allows for flexibility of the graft. The stents are 30–46 mm in diameter and individually 22 mm in length. There may be three or four stents, depending on individual patient’s size and anatomy.

The delivery system consists of a 39 French (F) outer sheath, a 34 F inner sheath and a central pusher [12, 28-31]. It is introduced in an antegrade fashion into the descending aorta via a guide wire which is inserted transfemorally. Positioning may be determined with a C-arm or by measurements on preoperative CT scan. The outer sheath is withdrawn while the inner sheath and the pusher are held steady, and the stented portion will be deployed in the descending aorta. The proximal Dacron graft is released by pulling back both sheaths simultaneously while holding the pusher steady. Then the delivery system is extracted completely. The proximal unstented part is sutured circumferentially to the aorta distal to the origin of the left subclavian artery with 3-0 running polypropylene. The arch branches are anastomosed end-to-side to the Dacron graft as a Carrel patch [28-31]. The initial tube graft was unsealed and bleeding was a serious issue. The sealant used in the later version reduced bleeding considerably, however the release of the graft from the delivery system became a problem due to adhesions. Hereafter, while further development was underway, the prosthesis was thus compressed and delivered with a special clamp shaped like a curved tube in two halves (Figure 2). Because the stented part is stiff and the clamp is 28 mm in diameter, it is difficult to implant especially in cases of acute Type A dissections and small descending aortas.

In a report by the Hannover group, the Chavan-Haverich prosthesis was implanted in 65 patients (17 acute dissection, 29 chronic dissection and 19 aneurysm) with a mean age of 61 ± 13 years. The times of cardiopulmonary bypass and selective antegrade cerebral perfusion were 227 ± 63 and 64 ± 20 minutes, respectively. Early deaths occurred in 6 (9%), stroke in 5 (8%), and spinal cord injury in 1 (2%). Distal reintervention was required in 22 cases (33%) and freedom from late distal operation was 83 ± 5%, 74 ± 6%, and 47 ± 14% at 1, 5, and 10 years, respectively. Late death occurred in 11 patients (18%) and the overall survival was 88 ± 4%, 72 ± 6%, and 62 ± 9% at 1, 5, and 10 years, respectively [25].
E-vita Open and E-vita Open Plus

The E-vita Open Plus hybrid prosthesis is an updated version of its predecessor, E-vita Open (Jotec GmBH, Hechingen, Germany). Invented by Dr. Jakob [32], these grafts are similar in design, but the updated version is less blood permeable and obviates the need for pre-sealing with fibrin glue. The E-vita Open Plus is fabricated from a specially texturized polyester yarn and has a water permeability index of 60 mL/min/cm² in contrast to 650 mL/min/cm² of the E-vita Open [33].

The hybrid prosthesis consists of a stented portion with a flexible, Z-shaped nitinol wire (13 to 16 cm long, 24 to 40 mm in diameter) covered by a polyester fabric. A proximal nonstented woven graft (5 or 7-cm long) is fixed circumferentially to the proximal end of the stented portion. The proximal and distal grafts are identical in diameter, and a sewing collar is added between them in the latest design to facilitate anastomosis (Figure 3) [34], which is similar to the Vascutek Hybrid. Radiopaque markers are integrated in the graft to permit radiological imaging.

The delivery system consists of a shaft, a grip handle, catheters, a release switch, and a positioning aid. The delivery system is over 100 cm in length and suitable for patients with large statures. The whole prosthesis is placed over a stiff guide wire inserted transfemorally and deployed with a “squeeze-to-release” mechanism, in which the prosthesis will be introduced 4 mm forward into the proximal descending aorta by every “squeeze” of the lever (Figure 3). The deployment of the stented graft is achieved by the retraction of the retaining sheath (see supplemental Video 1 at http://dx.doi.org/10.12945/j.aorta.2015.14.062.vid.01) [35]. The invaginated unstented graft is then pulled back. Distal anastomosis at a level between the left subclavian artery and proximal descending aorta is completed with continuous stitches of 3-0 polypropylene secured with an external Teflon felt strip [35]. The arch branches are reattached end-to-side to the proximal graft using the 3-vessel Carrel patch technique (Figure 4) [36].

In retraction of the stented graft, the prosthesis may slide within the aortic lumen, which complicates...
proper positioning. Difficulties during extraction of the delivery system were also reported in early series [37]. In the latest version, the previous design of solid ballpoint tip is replaced by a balloon tip, which facilitates deployment and reduces injury to the aortic intima [34].

The E-vita Open entered the European market in 2005 and was replaced by E-vita Open Plus, which received a CE mark in June 2014. By December 2015, over 5000 patients were successfully treated [34]. The International E-vita Open registry, which was launched in 2005 [38-40], has recruited 575 patients from 10 European centers by August 2014 [41]. Postoperative data was complete in 568 patients, including 211 (37.1%) acute dissections, 187 (32.9%) chronic dissections, and 170 (29.9%) aortic aneurysms, with a mean age of 59, 58, and 67 years, respectively. The times of cardiopulmonary bypass, cross-clamp, and selective antegrade cerebral perfusion were 245, 252, and 220 minutes, 144, 148, and 124 minutes and 66, 88, and 66 minutes, respectively. In-hospital mortality was 18%, 17%, and 12% for each group; permanent stroke occurred in 6%, 1%, and 0; spinal cord injury occurred in 3%, 4%, and 4%, and dialysis in 2%, 5%, and 4%, respectively. Follow-up was completed in 91% (517/568). CT scan was performed in 141, 87, and 89 patients in each group, respectively. At the latest follow-up, complete thrombosis of false lumen was seen in 94% and 86% in patients with acute and chronic dissections, and complete exclusion in 94% of aneurysm patients at the stent graft level. At 5 years, survival was 85%, 79%, and 69% for acute dissection, chronic dissection, and aneurysmal patients. Freedom from endovascular repair was 95%, 73%, and 87%, and freedom from open repair on the downstream aorta was 98%, 91%, and 95%, respectively [41].

**Thoraflex Hybrid**

Designed by Drs. Haverich, Shrestha, and Pichlmaier, the Thoraflex™ Hybrid prosthesis (Vascutek, Inchinnan, Scotland, UK) consists of a proximal unstented sealed woven Dacron tube and a distal stented part made of polyester and nitinol stents. The unstented portion has four integrated side branches: three for arch vessel reconstruction and one for distal and antegrade cerebral perfusion. The stented part is 10 or 15 cm in length and 28–40 mm in diameter (Figure 5). The proximal unstented and distal stented segments of the graft are different in diameter. The unstented part is smaller, which allows for space in the arch for branch reconstruction. There is a sewing collar between the proximal and distal segments, which facilitates suturing of the distal anastomosis, especially in patients with aneurysm of the arch and proximal descending aorta (Figure 6). The design with independent, ring-shaped stents not only allows for better arch curvature and anatomic conformity to the descending aorta but also reduces the radial force on the aortic wall, thus minimizing the risk of intimal injury in patients with aortic dissection. Radiopaque markers are incorporated in...
splittable sheath, and a handle that is made from a range of molded thermoplastic polyurethane. The stented portion is first bent slightly to fit the curvature of the descending aorta, and may then be advanced down over a stiff guide wire by a side rail technique. The sheath is bisected by pulling it through the splitter using the strap thereby enabling the stent to open. The splitter is then removed to free the sewing collar. Before the delivery system can be removed from the hybrid graft, the tip capture mechanism for placement correction has to be released by pulling the release wire clip at the back of the handle (see supplemental Video 2 at http://dx.doi.org/10.12945/j.aorta.2015.14.062.vid.02). The distal anastomosis is performed with the sewing collar using a 3-0 running polypropylene and may be reinforced with a second layer of pledgeted 3-0 polypropylene. The fourth side branch is cannulated to reperfuse the lower body. The arch vessels are reconnected to the side branches of the proximal unstented graft in an end-to-end fashion (Figure 7), occasionally using bridging stents, Viabahn® (W. L. Gore & Associates, Newark, DE) [43].
The integrated side branches represent a unique and highly valuable feature that allows for separate reconstruction of the arch vessels [44], which may be important in patients with a severely atherosclerotic aortic arch, Marfan syndrome and considerable distance between the origins of the arch vessels. Compared to other straight grafts, the 4-branched graft may reduce the time of lower body and myocardial ischemia, which is generally associated with improved outcomes after complex aortic arch reconstruction [45]. A concern may arise after the anastomosis of the sewing collar to the proximal descending aorta is completed and the graft and side branches are fixed in position [46]. Although the side branches can be cut to desired lengths before anastomosing to the arch vessels to avoid kinking and twisting, at this stage it is difficult to rotate the side branches along the long axis of the aorta, should this be required [37]. Manual deployment of Thoraflex hybrid may also be hindered by the four arch branches in the operative field [47]. Its use may also be limited by the aortic anatomy in chronic arch pathologies [48].

The Thoraflex™ Hybrid received CE mark in November 2012 and there were more than 1180 implants by December 2015 [Mr. Jonathan Hargreaves, Personal communication (email), January 2016]. In the first 100 patients of the Hannover group (65 males, mean age 58.7 ± 13.6 years) as of October 2014 [49], surgical indication was dissection in 57 (38 acute) and aneurysm in 43; there were 11 Marfan patients, 28 redo operations, 40 root procedures, and 12 coronary artery bypasses. The times of cardiopulmonary bypass, cross-clamp, circulatory arrest, and antegrade cerebral perfusion were 241 ± 61, 123 ± 62, 57 ± 35 [49], and 85 ± 39 minutes [25], respectively. Early mortality was 6%. The rates of stroke, re-exploration for bleeding, and spinal cord injury were 10%, 13% [49], and 6% [25], respectively. In follow-up, 19 secondary interventions on the downstream aorta were required (7 open, 12 endovascular) [49]. At 1 year, two late deaths occurred; survival was 77 ± 7% and freedom from distal operation was 73 ± 8% [25]. The Munich group implanted the Thoraflex in 38 patients as of September 2014, including 12 acute Type A (32%), 2 acute Type B (6%), and 14 chronic dissections (36%), and 10 aneurysms (26%). Mean age was 62 ± 12 years, and 24 patients (63%) were male. In-hospital mortality was 18% (7/38). Early morbidities included stroke in 2 cases (5%), phrenic nerve injury in 5 (13%) and permanent dialysis in 2 (5%). No spinal cord injury occurred. Late death occurred in one case (2.6%) and a downstream procedure was required in five (13%) [50]. In the Bologna experience with 11 patients (9 with chronic dissection and 2 aneurysms, age 63 ± 9 years), the time of cardiopulmonary bypass and antegrade cerebral perfusion was 227 ± 98 and 81 ± 29 minutes, respectively; no cases of early death, spinal cord injury, or stroke occurred. Early morbidities included reexploration for bleeding in 2 cases, transient ischemic attack in 1, and renal failure requiring temporary dialysis in 1 [51]. Currently Thoraflex Hybrid is not commercially available in the United States.

Cronus

The Cronus open stented graft (MircoPort, Shanghai, China) was designed and introduced by Dr. Sun in 2003 [52]. It consists of a regular Dacron vascular tube and interconnected Z-shaped stents made from conichrome (a Co-Cr-Ni-Mo-Fe alloy). At the proximal and distal ends, there is an extra centimeter of Dacron sewing cuff, to which a conventional hand-sewn anastomosis can be performed (Figure 8). The graft is 4–15 cm in length and 21–32 mm in diameter. Compared with other devices, the Cronus is more compact (15–25 cm in full length) due to the avoidance of the unstented portion, which allows for more accurate deployment deep into the operative field of the descending aorta.

The delivery system consists of a grip handle, a pull wire and a fixation string of 2-0 silk, which holds the prosthesis in a compressed state before deployment. The graft is bent slightly to conform to the arch curvature and inserted into the proximal descending aorta. Deployment simply involves gripping the handle in one hand and pulling out the pull wire with the other hand; the stent graft expands automatically, usually within seconds (see supplemental Video 3 at http://dx.doi.org/10.12945/j.aorta.2015.14.062.vid.03) [53]. Distal anastomosis is located between the left carotid and left subclavian arteries and sutured using continuous stitches of 3-0 or 4-0 polypropylene. The arch
vessels are reconnected end-to-end to the branches of a separate, four-branched graft (Figure 9). To minimize the time of cerebral and cardiac ischemia, the left common carotid artery is reconstructed first, then the proximal ascending aorta, followed by the left subclavian and innominate arteries [54, 55].

Owing to its technical simplicity, over 18,000 patients have been treated successfully with the Cronus in China and South American countries [56, 57]. In a group of 803 patients with Type A dissection (age 46 ± 11 years), the times of cardiopulmonary bypass, selective antegrade cerebral perfusion, and cross-clamp were 193 ± 51, 24 ± 8, and 106 ± 40 minutes, respectively. Operative mortality was 6.5% (52/803) and the incidences of stroke and spinal cord injury were 2.0% (16/803) and 2.3% (19/803), respectively [17]. In another cohort of 291 patients with Type A dissection followed up for 42 ± 18 months, the overall late mortality was 3.5% (10/291), obliteration of the false lumen around the stented graft occurred in 90.8% (256/282), and reintervention was required in 1.7% (5/291) of patients [58].

In a series of 104 dissection patients with an arch entry tear (excluding retrograde dissections arising from the descending aorta), the operative mortality was 8.6% (9/104). Early morbidity included renal failure in 4 cases (3.8%), spinal cord injury in three (2.9%), stroke in 2 (1.9%), limb ischemia in 2 (1.9%), reexploration for bleeding in 2 (1.9%), and recurrent laryngeal nerve injury in 1 (1.0%). Follow-up was complete in 100% for 5.0 ± 2.6 years (range 1.3-11.1). Late death occurred in 2 patients (1.9%). Survival was 88.9% and no late distal reintervention was required at 10 years [59].
The delivery system consists of a 15-cm long grip handle integrated with a shaft, a 2-layer soft sheath attached to a release knob and a fixation string (Figure 10). Before deployment, the stented portion is bent to conform to the curvature of the aorta. In deployment, holding the grip handle in position and pulling back the release knob along with the sheath will release the whole prosthesis (Figure 11) (see supplemental Video 4 at http://dx.doi.org/10.12945/j.aorta.2015.14.062.vid.04). For distal anastomosis, four 4-0 polypropylene stay sutures are placed first, followed by running stitches of 4-0 polypropylene reinforced by a felt strip [62]. The arch vessels are reconstructed with a separate branched graft in an end-to-end fashion [61, 63].

Figure 10. The J Graft open stent graft and its delivery system (Courtesy of Mr. Makoto Takakura and Mr. Hideki Kataoka from Japan Lifeline, adapted with permission).
During its premarketing clinical trial from March 2008 to September 2010, the J Graft OSG was implanted in 60 patients [61, 64]. Mean age was 71.6 ± 8.6 years and there were 44 males (73.3%). Surgical indication was aneurysm in 38 (63%) cases, acute Type A dissection in 6 (10%), chronic Type A dissection in 2 (3%), acute Type B in 1 (2%), and chronic Type B in 13 (22%). In-hospital mortality was 5% (3/60) and early morbidities included stroke in 6 (10%) cases, spinal cord injury in 4 (6.7%), and endoleak in 2 (3.3%). At 1 year, late mortality occurred in 10% (6/60) and secondary thoracic endovascular aortic repair was required in 8.3% (5/60), for distal aneurysmal dilation in 2 cases, thoracoabdominal aortic rupture in 1, and distal endoleak and downstream aneurysmal dilation in 2. Kaplan-Meier survival was 78% at 3.8 years (1400 days). The J Graft OSG received commercial approval in Japan in February 2014 [65]. Between July 2014 and December 2015, J Graft was implanted in 2216 patients. Surgical indications were aneurysm in 51%, Type A dissection in 33%, Type B dissection in 10%, aortic rupture in 3%, type Ia endoleak after TEVAR in 2% and Kommerell diverticulum in 1%. According to incomplete data, spinal cord injury occurred in 1.9% (43/2216), including paraparesis in 13 cases (0.6%) and paraplegia in 30 (1.3%). This incidence was much lower than the 6.7% reported in the premarket trial [61], which may be the result of avoidance of implanting below T8, and earlier distal perfusion after delivery of stent graft [Hideki Kataoka. Personal communication (email), January 2016].
## Table 1. Comparison of currently available open stented grafts.

<table>
<thead>
<tr>
<th>Device</th>
<th>E-vita Open (Plus)</th>
<th>Thoraflex Hybrid</th>
<th>Cronus</th>
<th>J Graft Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of marketing</td>
<td>2008</td>
<td>2012</td>
<td>2003</td>
<td>2014</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Jotec</td>
<td>Vascutek</td>
<td>MicroPort</td>
<td>Japan Lifeline</td>
</tr>
<tr>
<td>Number of implants</td>
<td>&gt;5000</td>
<td>&gt;1180</td>
<td>&gt;18000</td>
<td>&gt; 2200</td>
</tr>
<tr>
<td>(by Dec 2015)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability</td>
<td>Europe, Asia Pacific</td>
<td>Europe, Asia Pacific, Canada</td>
<td>China, South America</td>
<td>Japan</td>
</tr>
</tbody>
</table>

### Technical Aspects

<table>
<thead>
<tr>
<th></th>
<th>E-vita Open (Plus)</th>
<th>Thoraflex Hybrid</th>
<th>Cronus</th>
<th>J Graft Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full length (cm)</td>
<td>18, 22, 23</td>
<td>34, 39</td>
<td>15-25</td>
<td>57</td>
</tr>
<tr>
<td>Diameter of stent graft (mm)</td>
<td>24-40</td>
<td>28-40</td>
<td>21-32</td>
<td>21-39</td>
</tr>
<tr>
<td>Length of stent graft (cm)</td>
<td>13, 15, 16</td>
<td>10, 15</td>
<td>4-15</td>
<td>6, 9, 12</td>
</tr>
<tr>
<td>Proximal and distal diameter</td>
<td>Same</td>
<td>Different</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td>Stent design and material</td>
<td>Z shaped nitinol</td>
<td>Ring shaped nitinol</td>
<td>Z shaped conichrome</td>
<td>Oval shaped 2-layer nitinol</td>
</tr>
<tr>
<td>Arch curvature</td>
<td>Fair</td>
<td>Better</td>
<td>Fair</td>
<td>Possibly best</td>
</tr>
<tr>
<td>Sewing collar</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Distal sewing cuff</td>
<td>No</td>
<td>No</td>
<td>1 cm</td>
<td>No</td>
</tr>
<tr>
<td>Unstented portion</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Arch and perfusion branches</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Delivery method</td>
<td>Squeeze and pull</td>
<td>Pull, press, pull</td>
<td>Pull</td>
<td>Pull</td>
</tr>
<tr>
<td>Need for positioning</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Guidewire or X-Ray</td>
<td>Necessary</td>
<td>Optional</td>
<td>No need</td>
<td>No need</td>
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<tr>
<td>Blood permeability</td>
<td>60 mL/cm²/min</td>
<td>NA</td>
<td>NA</td>
<td>150 mL/cm²/min</td>
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<tr>
<td>Method of arch repair</td>
<td>Carrel patch technique</td>
<td>An integrated 4-branched graft</td>
<td>A separate 4-branched graft</td>
<td>A separate branched graft</td>
</tr>
<tr>
<td>Better indicated in</td>
<td>Aneurysm</td>
<td>Aneurysm and dissection</td>
<td>Dissection</td>
<td>Aneurysm</td>
</tr>
</tbody>
</table>

### Clinical Outcomes

<table>
<thead>
<tr>
<th></th>
<th>E-vita Open (Plus)</th>
<th>Thoraflex Hybrid</th>
<th>Cronus</th>
<th>J Graft Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient age (years)</td>
<td>61</td>
<td>59 ± 14</td>
<td>46 ± 11</td>
<td>72 ± 9</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time</td>
<td>239</td>
<td>241 ± 61</td>
<td>193 ± 51</td>
<td>178 ± 40</td>
</tr>
<tr>
<td>Selective antegrad cerebral perfusion time</td>
<td>71</td>
<td>85 ± 39*</td>
<td>25 ± 9</td>
<td>40 ± 37</td>
</tr>
<tr>
<td>Early mortality (%)</td>
<td>15.8 (90/568)</td>
<td>8.7 (13/149)#</td>
<td>6.4 (53/832)</td>
<td>5.0 (3/60)</td>
</tr>
<tr>
<td>Early stroke (%)</td>
<td>2.6 (15/568)</td>
<td>8.0 (12/149)#</td>
<td>2.0 (17/832)</td>
<td>10.0 (6/60)</td>
</tr>
<tr>
<td>Early spinal cord injury (%)</td>
<td>3.5 (20/568)</td>
<td>4.0 (6/149)#</td>
<td>2.4 (20/832)</td>
<td>6.7 (4/60)</td>
</tr>
<tr>
<td>Duration of follow-up (year)</td>
<td>5</td>
<td>1*</td>
<td>5.0 ± 2.6</td>
<td>3.8</td>
</tr>
<tr>
<td>Late survival (%)</td>
<td>69-85</td>
<td>77 ± 7*</td>
<td>89</td>
<td>78</td>
</tr>
<tr>
<td>Late reintervention (%)</td>
<td>2-27</td>
<td>14.1 (24/149)#</td>
<td>6.5 (69/1063)</td>
<td>8.3 (5/60, 1 yr)</td>
</tr>
</tbody>
</table>

# Calculated based on the reports of Ius, Pichlmaier, Shrestha and Di Marco [25, 49-51]
* Ius, et al. [25]
NA = not available.
Comments

From a technical perspective, each of the aforementioned OSGs has its pros and cons (Table 1). For instance, although the Thoraflex and E-vita Open Plus are more sophisticated in design and intended for treating more complex arch and descending pathologies by using a single piece device, their deployment is time consuming and more technically demanding. The stented portion of Thoraflex is not available in sizes of less than 28 mm, which may result in new intimal tears distal to the stent graft, hampering false lumen exclusion and thrombosis in cases of aortic dissections with small or narrowed true lumens [47]. In contrast, the Cronus and J Graft Open are more compact and easier to deploy (no fluoroscopy or guide wires for Cronus), but the Cronus requires a separate proximal graft and is not available in sizes of more than 32 mm for patients with larger aortas. It is important to note that, due to variability in patient and aortic characteristics, the technical merits of each device are difficult to quantify and directly comparing them is even more difficult. An ideal OSG should be capable of successfully treating patients in clinical settings ranging from dissection and aneurysm to associated pathologies like Kommerell diverticulum and coarctation [66, 67]. In addition, an ideal graft should be able to provide satisfactory early and late outcomes for any patient, regardless of etiology [68], anatomy, acuity [48], and patient size, with minimal surgical risks, especially in terms of spinal cord injury, stroke, and endoleak. The “ideal” OSG would also include the following characteristics:

1. **Ease of deployment** (and expansion), without increasing technical complexity and prolonging ischemic and perfusion durations
2. **Avoidance of fluoroscopy and guide wires**
3. **Firm fixation** to the aortic wall without potential for graft migration
4. **High flexibility and conformation** to the curvature of the aorta, without kinking or twisting
5. **Biocompatible surface** with minimal blood permeability
6. **Tapered distal end** to fit well within the descending aorta, especially for patients with chronic dissection

7. **Ease of anastomosis** in secondary distal interventions, if such are necessary

With the evolution and expanded indications for the FET technique [22, 67, 69, 70], there is a growing need for versatile, technically simple, and highly durable systems involving less complicated deployment mechanisms which enable use in various indications. Because the currently available OSGs have not yet obtained FDA approval in the United States, several modified FET techniques using endovascular stent grafts have been proposed as a “bailout” [71-73].

While none of the available OSGs can yet claim to be an ideal device, technology continues to improve towards this goal.

As novel devices and systems are being developed specifically for the FET technique [74, 75] and manufacturers are frequently improving their technology to update their devices, more widespread use can be expected. For example, the 3 zone aortic arch hybrid prosthesis recently designed by Jakob, E-Novia, combines a routine proximal ascending polyester graft in continuity with an uncovered, nitinol stent in the arch portion and a stented graft in the descending aorta [76]. It is aimed at single-stage repair of ascending, arch and descending pathology and preliminary results have been favorable in patients with very high surgical risks [77]. Reports have emerged on the use of branched OSGs with one to three self-expanding stented side branches in an attempt to facilitate distal anastomosis and arch reconstruction [78, 79]. Favorable long-term outcomes have also been achieved with the Matsui-Kitamura stent graft [80].

Continued technologic improvements in FET technology can fairly be expected to result in improved clinical outcomes and quality of life for patients with complex aortic diseases.

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References


Conflict of Interest

Dr. Elefteriades is an investigator for the clinical trial of Thoraflex Hybrid in US. The other authors have no conflicts of interest relevant to this publication.


Open Stented Grafts for Frozen Elephant Trunk

Most Coarctations, Recoarctations, and Coarctation-Related Aneurysms Should Be Treated Endovascularly

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Based on a Presentation at the 2013 VEITH Symposium, November 19-23, 2013 (New York, NY, USA)

Abstract
For patients with coarctation of the aorta (CoA), surgical intervention results in an overall survival rate nearly twice that of medical management. Therefore, surgical correction of CoA has traditionally been warranted in the majority of patients, even though open repair entails its own complications. With the advent of endovascular technology, many interventionalists hoped that this approach would decrease the complications associated with open surgical repair of CoA. Nevertheless, there is still an ongoing debate about the merits of traditional open surgery versus endovascular therapy. In this review, we discuss the role of these two approaches for the management of CoA, recoarctation, and coarctation-related aneurysms.

Open Repair versus Endovascular Surgery
Traditional open repair of CoA relies on variable techniques, including direct end-to-end repair, aortoplasty, patch repair, and interposition-graft repair. All of these operations entail the cardiovascular and respiratory risks posed by general anesthesia in addition to procedural and periprocedural complications. Many procedural complications are associated with the need for cardiopulmonary bypass and aortic cross-clamping. In addition, open repair often necessitates a median sternotomy or lateral thoracotomy incision, which can result in significant morbidity. Postoperatively, patients often have a prolonged recovery, with average hospital stays lasting longer...
than 1 week, and need physical rehabilitation. The increased morbidity and prolonged recovery usually result in greater hospital expenses.

After performing resection with extended end-to-end anastomosis for CoA in 201 patients from 1991 through 2007, Kaushal and colleagues [1], of the Children’s Memorial Hospital, in Chicago, reported an early mortality rate of 2%, in addition to the following morbidity rates: septicemia, 4%; recurrent laryngeal nerve paresis, 3%; chylothorax, 3%; pulmonary hypertensive crisis, 1%; and reoperation for ventral-septal-defect closure, mediastinitis, or delayed sternal closure, 2%. Brown and associates [2], of the Mayo Clinic, reported an overall 2.4% mortality rate for 819 patients with isolated CoA who underwent primary operative repair between 1946 and 2005 by means of extended end-to-end anastomosis, patch angioplasty, interposition grafting, bypass grafting, or subclavian flap or “other” repair. Moreover, Preventza and coauthors [3], of the Texas Heart Institute, reported a 1.9% 30-day mortality rate with re-operative surgery in 53 patients with CoA-related aneurysms. In addition, these surgeons reported the following complications: vocal-cord paralysis, 20.8%; need for prosthesis, 5.7%; and need for a tracheostomy, 3.8%.

In the Quebec Native Coarctation of the Aorta Study [4], investigators retrospectively compared surgical repair to transcatheter intervention (angioplasty) in 80 patients (mean age, 12 years) treated between 1998 and 2004. Procedure-related complications were far more common in the surgical group (50%) than in the angioplasty group (18%) ($p = 0.005$). The median hospital stay was 7 days for the surgical group and 1 day for the angioplasty group ($p < 0.001$). At 38 ± 21 months, however, the rate of follow-up repeat intervention was higher in the angioplasty group (32%) than in the surgical group (0%) ($p < 0.0001$).

Proponents of open surgical repair often argue that in endovascular procedures, the short-term benefits of decreased morbidity and mortality are gained at the expense of durability and longevity, but that is not the case. Jenkins and colleagues [5] reported that most patients who undergo open repair are symptom-free for approximately 20 years after their initial operation, but 30% to 75% of these patients later have recurrent hypertension.

The direct end-to-end sutured anastomosis originally described by Crafoord and Nylin [6] in 1945 has largely been abandoned due to high rates of recoarctation, and many surgeons now perform alternative variations [7]. Kaushal and associates [1] reported a 4% reintervention rate after extended end-to-end anastomosis; three of their patients needed balloon angioplasty, and five patients required reoperation. In their study, 75% of reinterventions occurred within the first year after initial surgery. Alternatives, such as patch aortoplasty, have long been associated with high rates of aneurysmal formation (20–40%) [8]. The addition of polytetrafluoroethylene (PTFE) for aortoplasty lowered rates of aneurysmal disease but, unfortunately, increased rates of recoarctation to 25% [9].

In 2013, after analyzing surgical repairs of isolated CoAs performed in 819 patients at the Mayo Clinic over the past 60 years, Brown and colleagues [2] concluded that lifelong surveillance is mandatory after surgical repair. They reported that in comparison to age- and sex-matched populations, patients who underwent open repair had reduced long-term survival. Repair at an early age was an independent risk factor for reintervention. At 30 years’ follow-up, patients who underwent an initial repair before 1 year of age had an average reintervention rate of 31.1%, and patients who underwent an initial repair before 5 years of age had an average reintervention rate of 73.3%.

Endovascular approaches have the advantage of being performed under local anesthesia with sedation, avoiding the risks of general anesthesia. In addition, these procedures can be performed completely percutaneously, avoiding the morbidities that may accompany median sternotomy or lateral thoracotomy incisions. After endovascular treatment, patients often have shorter hospital stays, avoiding many common postsurgical complications such as urinary tract infections, pneumonia, and deep venous thrombosis.

In 2011, the American College of Cardiology’s Congenital Cardiovascular Interventional Study Consortium published a report that compared surgery, stenting, and balloon angioplasty for the treatment of CoA [10]. This multicenter, observational, nonrandomized study involved 350 patients from 36 institutions. Compared with surgery, stent placement appeared to produce hemodynamically equivalent results during follow-up observation. Moreover,
newer lower-profile systems. Theoretically, covered stents have the advantages of reducing the extent of the intimal tear, creating a framework for neointimal growth, and allowing control of the integrity of the aortic wall. For these reasons, they should be the standard of care for managing coexistent aneurysmal disease.

**Conclusion**

In patients with CoA, recoarctation, or a CoA-related aneurysm, open surgical repair is associated with an unnecessary risk of morbidity and mortality. In patients more than 1 year old, endovascular procedures have been shown to yield immediate outcomes similar to those of surgery, defined as hemodynamically controlled hypertension in the follow-up period [4]. Any argument regarding endovascular reintervention, however negligible, is formidable, because such reintervention is associated with the same risks of morbidity and mortality as the initial operation [11]. Furthermore, belief in the longevity of surgical repair

Table 1. Summary of selected series involving the use of stent grafts to treat native coarctation of the aorta (CoA), recurrent CoA, and CoA-associated aneurysms.

<table>
<thead>
<tr>
<th>Year</th>
<th>First author</th>
<th>No. of patients</th>
<th>Mean age (y)</th>
<th>Stent type(s)</th>
<th>Stent model</th>
<th>Mean FU period (mo)</th>
<th>Morbidity rate (%)</th>
<th>Mortality rate (%)</th>
<th>Reintervention rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Tzifa [19]</td>
<td>30</td>
<td>28</td>
<td>CS</td>
<td>Cheatham-Platinum</td>
<td>11</td>
<td>13</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>2007</td>
<td>Butera [13]</td>
<td>33</td>
<td>18</td>
<td>CS</td>
<td>Cheatham-Platinum</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2008</td>
<td>Tanous [18]</td>
<td>22</td>
<td>39</td>
<td>CS</td>
<td>Cheatham-Platinum</td>
<td>12</td>
<td>4</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>2010</td>
<td>Shennib [17]</td>
<td>22</td>
<td>40</td>
<td>BES, CS</td>
<td>Palmaz, Gore-TAG, Cook Zenith</td>
<td>31</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>2010</td>
<td>Bruckheimer [12]</td>
<td>25</td>
<td>—</td>
<td>CS</td>
<td>Advanta V12D</td>
<td>4.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2012</td>
<td>Roselli [16]</td>
<td>59</td>
<td>38</td>
<td>CS, BES</td>
<td>Gore-TAG, Cook Zenith</td>
<td>56</td>
<td>3</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>2013</td>
<td>Preventza [3]</td>
<td>11</td>
<td>39</td>
<td>CS</td>
<td>Gore-TAG, Talent/ Captivia, Medtronic</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2013</td>
<td>Khavandi [14]</td>
<td>17</td>
<td>39</td>
<td>CS</td>
<td>Valiant Medtronic, Cook Zenith</td>
<td>31</td>
<td>23</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

BES = balloon expandable stent; CS = covered stent; FU = follow-up.

stenting was associated with significantly fewer complications [2.3% versus 8.1% for surgery and 9.8% for balloon angioplasty (p < 0.001)] and shorter hospital stays [2.4 days versus 6.4 days for surgery (p < 0.001)]. The reintervention rate was higher in the stent group; however, this finding was attributed to staged procedures or patient somatic growth, and all reinterventions carried a similar low risk of morbidity and mortality.

Recently, use of covered stents has been advocated for CoA, recoarctation, and CoA-related aneurysms (Table 1) [3, 11-19]. In 2009, Botta and associates [11] reported their experience using thoracic stent grafts in the treatment of CoA. They reported a 100% technical success rate, a 0% mortality rate, and a 0% reintervention rate after a mean follow-up period of 44 months. The incidence of procedural complications was 14%. Five years later, Perera and coworkers [15] reported similar rates of technical success, mortality, and reinterventions; in addition, their procedural complication rate was 0%, most likely because of increased experience and advances in technology with
for CoA is erroneous, as a large percentage of these repairs are plagued with recoarctation and CoA-related aneurysms [5]. Unfortunately, reoperative surgery in these patients entails increased risks of morbidity and mortality [3].

With the application of endovascular surgery to CoA, interventionalists have gained a new armamentarium for addressing this condition. Both interventions and reinterventions are associated with low risks of morbidity and mortality. As technology continues to evolve, the role of endovascular surgery will be further defined, clearly demonstrating that this approach is optimal for managing the majority of CoA and finally silencing this debate.

Conflict of Interest

The authors have no conflicts of interest relevant to this publication.

References


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Two-Stage Procedure for Infected Aortic Graft Pseudoaneurysm
10-Year Follow Up after Omental Prosthesis Wrapping

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Abstract
Prosthetic graft infections with mediastinitis following aortic surgery are rare, yet represent grave complications yielding high morbidity and mortality. We present the case of a 57-year-old female patient with past history of emergent surgery for iatrogenic Type A dissection treated by supracoronary ascending aortic replacement. Four months after the initial surgery, a sternal fistula had formed and due to severe bleeding emergent reoperation was required. Imaging and pathology on admission revealed an infected pseudoaneurysm at the distal aortic prosthesis and mediastinitis with methicillin-resistant Staphylococcus aureus. Rescue surgery was performed by means of a two-stage approach, with extensive debridement, graft replacement and continuous antiseptic lavage in a first step and an omental wrapping of the new prosthesis in a second stage 24 hours later. During 10 years of follow-up, no recurrent infection occurred. The operative approach and general considerations for management of infected pseudoaneurysms are discussed.

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Key Words
Pseudoaneurysm • Omental wrapping • Graft infection • Aneurysm • Aorta • Carotid artery

Introduction
Prosthetic infection following aortic surgery is a rare but grave complication, which yields an early mortality as high as 25%–42% [1]. In coexistence with prosthetic pseudoaneurysm, chest entry for reoperation is complicated due to the potential danger of aortic injury [2]. Current treatment of choice for infected prosthetic pseudoaneurysm includes aggressive graft resection with extensive debridement and negative-pressure wound therapy [1, 3]. Utilization of omental wrapping has also been described and can be performed with and without concomitant graft replacement [4, 5]. Surgery for omental prosthesis coverage, however, usually requires the patient to be in stable condition. We herein describe the case of a 57-year-old female patient who underwent successful treatment by means of a two-stage approach with aortic prosthesis replacement, extensive debridement and antiseptic lavage in a first step, followed by an omental flap wrapping of the new graft in a second step 24 hours later. The operative approach and general considerations for arterial cannulation prior to re-sternotomy are discussed.

Case Presentation
A 57-year-old female patient was referred to our clinic from a tertiary care center in poor general condition due to a sudden sternal bleeding.
Four months prior to this incident, the patient underwent emergent surgery due to an iatrogenic Type A dissection after an unsuccessful angioplasty revascularization attempt of a chronically occluded right coronary artery. At the time, supracoronary aortic replacement and a single venous bypass originating from the ascending prosthesis were performed. During this first operation the right subclavian artery was used for arterial cannulation. Postoperatively two re-explorations were mandated: due to significant pericardial effusion on postoperative day 11 and mediastinitis on postoperative day 14. Pathology identified methicillin-resistant Staphylococcus aureus (MRSA) as the causative pathogen. After antiseptic situs irrigation and parenteral antibiotic treatment with vancomycin the patient could be discharged with normal wound condition, no signs of infection and negative pathology for MRSA.

Upon admission the patient was in hypovolemic shock and unconscious. Computed tomography prior to transportation indicated an infected pseudoaneurysm of the ascending aortic graft at the distal anastomosis forming a sternal fistula (Figure 1). After adequate fluid and vasopressor administration on the cardiac intensive care unit the patient regained consciousness just before emergent reoperation. Intubation was not required preoperatively. Relevant heart valve involvement was ruled out by means of transesophageal echocardiography.

As safety precaution prior to median re-sternotomy—due to the impending danger of pseudoaneurysm rupture and adjacent adhesions of the right subclavian artery—in addition to the femoral artery the right carotid artery was surgically exposed for direct cannulation.

Cardiopulmonary bypass (CPB) was then established via arterial perfusion through the right carotid and the femoral artery. Venous cannulation was via the right femoral vein. After cooling to an esophageal temperature of 18°C, femoral perfusion was discontinued. During low flow antegrade perfusion via the carotid artery, median re-sternotomy was performed. The sternal bone structure showed good blood supply and no signs of infection. The old hematoma was carefully removed and the pseudoaneurysm at the distal anastomosis of the aortic prosthesis identified. Upon inspection partial detachment of the prosthesis due to suture dehiscence was evident. Owing to mediastinal adhesions, the brachiocephalic vein sustained injury and was repaired using a small pericardial patch. Cold cardioplegia (Bretschneider HTK solution; Köhler Chemie, Alsbach-Hähnlein, Germany) was administered into the left coronary ostium and into the venous bypass graft to the right coronary artery. The right coronary ostium was obliterated.

The infected prosthesis was removed and sent for pathology, isolating MRSA again as the underlying pathogen. After completion of the distal anastomosis and before finishing the proximal anastomosis, the prosthesis was clamped (22 mm Dacron, Hemashield Platinum, Flagstaff, Arizona, USA) and the rewarming process initiated. Circulatory arrest time under hypothermia was 20 minutes. The venous bypass graft was reinserted into the ascending prosthesis. Total CPB time was 194 minutes including 75 minutes of ischemia. After extensive wound debridement and antiseptic surgery site irrigation (Povidon-Iod, Betaisodona, Mundipharma GmbH, Limburg, Germany), drainage tubes for continuous lavage were inserted and the sternum was closed.

Twenty-four hours later, the second look followed. At that time the mediastinal swab taken during the first operation did not show bacterial growth. The sternum was reopened and old hematoma removed. Again, wound debridement was performed. Through an epigastric median laparotomy, the greater omentum was

![Figure 1. Preoperative computed tomography. (Red asterisk) Ascending aortic prosthesis. (Red arrow) Infected aortic prosthesis pseudoaneurysm with adjacent hematoma.](image-url)
exposed along the transverse colon and gastric portion. The omentum was then translocated as a pedicle retrosternally into the mediastinum and wrapped around the ascending aortic prosthesis (Figure 2). After placement of drainages the sternum was closed.

The postoperative course was uneventful without neurologic sequelae. The antiseptic lavage was continued for 72 hours postoperatively and changed to clear irrigation solution for additional 48 hours. The drainage tubes were then removed four days later after consecutive negative pathology results. The patient was discharged on postoperative day twelve. Computed tomography 3 days and 3 years postoperatively revealed a patent aortic prosthesis with no signs of recurring infection or aneurysm (Figure 3). At the last routine follow-up 10 years after the first surgery the patient was in good health, suffering only from mild dyspnea due to unrelated comorbidities.

Discussion

Formation of pseudoaneurysm after aortic surgery is a known complication warranting a carefully planned approach for reentering the chest during reoperation in order to circumvent free perforation [2, 6]. Graft infection and mediastinitis—also rare complications following aortic surgery—represent additional challenges for the re-operating surgeon in their own right [1, 3]. In case these conditions coincide, a coherent surgical approach is mandatory for successful surgery.

Reoperation for an aortic pseudoaneurysm becomes necessary after up to 0.5% of all cardiovascular surgical cases, and the initial approach for re-entering the chest is of major importance [2]. In our case the right carotid artery was used for direct arterial cannulation and antegrade cerebral perfusion. The possibility of being incapable of safely exposing the right subclavian artery due to pronounced adhesions and furthermore not being able to clamp the innominate artery without endangering the pseudoaneurysm located in the near vicinity—and subsequently failing selective cerebral perfusion—led to this decision.

Successful re-sternotomy using comparable preemptive techniques for selective cerebral perfusion in patients with large pseudoaneurysms have already been described [2, 7]. Although in some cases—where direct carotid cannulation was used for selective cerebral perfusion—adverse neurologic events were reported, our patient did not suffer from any neurological deficit, neither temporary nor permanent.

Another important comment concerning hypothermic arrest prior to entering the chest is hypothermia induced ventricular fibrillation. Although this complication did not occur in our patient, it may potentially lead to left ventricular distension due to volume overload, causing permanent cardiac damage.

Figure 2. Intraoperative picture during omental wrapping procedure. (White asterisk) The mobilized omentum. (White arrow) Exposed new ascending aortic graft.

Figure 3. Computed tomography 3 years postoperatively. (Red arrow) The omental wrap. (Red asterisk) The new aortic prosthesis covered by the omentum.
To prevent this, emergency vent placement into the left apex—analogous to the transapical transcatheter approach for valve implantation—represents a feasible option [8].

Current recommendations for a therapeutic algorithm of vascular graft infections include wound debridement, vacuum assisted closure therapy and subsequent myoplastic reconstruction if necessary [3]. In cases with abscess or pseudoaneurysm, early graft replacement should be performed [1], preferably using biological tissue grafts. It has been shown that graft coverage by means of the greater omentum may function as a feasible alternative to graft removal for patients with graft infection and mediastinitis in stable condition [1, 4, 5]. Owing to the patient’s critical condition prior to and during the initial reoperation and resection of the infected prosthesis, we chose to perform the omentum-plasty in a second stage. A variation of our strategy may have been to leave the thorax open after the first stage. Due to the good condition of the sternum we decided in favor of a primary sternal closure giving more stability and effectively ensuring continuous antiseptic lavage between stages.

The described two-stage procedure for an infected aortic graft pseudoaneurysm is a feasible method for rescue surgery of critically ill patients. Primary carotid artery cannulation for antegrade selective cerebral perfusion during hypothermic circulatory arrest plus extensive prosthetic replacement with situs irrigation, followed by an omentum flap, wrapping the new prosthesis in a second stage, may yield excellent long-term results in highly selected patients.

Conflict of Interest

The authors have no conflict of interest relevant to this publication.

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EDITOR’S QUESTIONS

1. Do you feel that a laparotomy is necessary for omental harvest? We sometimes do the harvest through the diaphragm at the bottom of the sternotomy incision. Please comment.

Omentum harvest through the diaphragm is an elegant and less invasive approach feasible in many patients. However, as depicted in figure 2, the dimension of the patients’ omentum was quite big. Such an omentoplasty would have been very difficult or impossible to perform without a laparotomy. The surgeon in charge of that operation (Battellini RR) has been 10 years an abdominal surgeon before coming...
into cardiac surgery and deemed the presented approach appropriate in this case.

2. Please comment on what role homograft and tubed pericardium may play in such cases.

Replacement of infected prostheses using aortic homografts are regularly used in these cases at our institution and could have given a complete solution without the need for a second stage omentoplasty. The first emergency operation, however, was done at 3 am in the morning. At this time a homograft suitable in size for the patient was not available.

3. Do you think one day was enough time to assure sterility before the definitive omental wrapping?

The mediastinal swab from the first operation was still sterile 24 hours later. Since the patient was in stable condition a second look with a new wound debridement, situs irrigation and omentoplasty seemed logical.
Acute Type B Aortic Pathology Mimicking Acute Type A Intramural Hematoma with Organ Malperfusion

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Abstract
The management of acute Stanford Type A intramural hematoma (IMH) of the aorta remains controversial. Most surgeons advocate emergency surgery in a manner similar to frank acute Type A dissection. Others recommend a conservative approach to this distinct clinicopathological entity. We describe a case of acute aortic pathology initially diagnosed as Type A IMH with organ malperfusion, subsequently identified as acute Type B pathology with retrograde and antegrade extension. An endovascular approach was successfully used to exclude the site of origin.

Case Presentation
A 56-year-old white female with a history of hypertension, heavy smoking, and chronic obstructive pulmonary disease was admitted to another hospital complaining of severe chest and abdominal pain. Electrocardiogram showed nonspecific ST-T changes. Initial troponin I levels were within normal limits. The patient was transferred immediately for cardiac catheterization with a presumed diagnosis of acute coronary syndrome. Coronary catheterization demonstrated external compression and distortion of the left main coronary artery with no discrete coronary stenoses. The patient was transferred to the acute cardiac care unit where 2-D echocardiogram showed moderate-to-severe left ventricular...
dysfunction, normal right ventricular function, no significant valvular abnormalities, and suspected acute aortic dissection.

Shortly thereafter, the patient deteriorated into cardiogenic shock with florid pulmonary edema. The patient was sedated and intubated, and inotropic support was initiated and an intra-aortic balloon pump was inserted.

After stabilization, a CT angiogram of the chest and abdomen was obtained. This test was interpreted as Type A IMH starting at the sinotubular junction and extending down to the iliac bifurcation (Figure 1). The IMH was complicated by external compression of the left main coronary artery, as well as liver, right kidney, and colon malperfusion. A large intercostal artery was observed in the proximal descending thoracic aorta (Figure 2). Correspondingly, metabolic acidosis and marked elevation of liver enzymes and international normalized ratio (INR), were observed. Cardiac surgery consult was obtained, but the patient was deemed to be too ill to undergo a major aortic procedure. The initial course was further complicated by Gram-negative sepsis, likely originating from a right lower lobe pulmonary infiltrate. At this time point, this desperately ill patient was transferred to our care.

After initial stabilization, to better strategize treatment plan, we elected to repeat the imaging studies, 5 days after initial presentation. A transesophageal echocardiogram showed moderate left ventricular dysfunction, moderate aortic insufficiency, extensive Type A IMH, and a large left pleural effusion. Repeat CT angiography demonstrated stable hematoma in the ascending aorta (Figure 3), a newly developed pseudoaneurysm originating within an intimal ulcer in close proximity to the noted large intercostal artery in the proximal descending aorta (Figures 4 and 5) and a new large pleural effusion.

The diagnosis was revised to acute Type B aortic pathology with proximal and distal extension, and we elected to proceed with TEVAR aiming to exclude the intimal tear. Using routine endovascular techniques, a 26×100 mm C-Gore Tag-R Type (W L Gore &
median sternotomy using deep hypothermia and circulatory arrest. Due to very high mortality and morbidity associated with this approach, an alternative strategy comprised of emergency percutaneous or open distal aortic fenestration, followed by delayed complete repair, was described [3]. The latter approach re-establishes organ perfusion, allowing the patient to recover and reach the complete repair in a much better condition. By definition, this strategy, however, is not applicable in Type A IMH due to lack of proximal intimal tear. Our patient was, therefore, considered for an open conventional repair, but deemed too ill. Repeat imaging was highly suggestive that the site of origin of the acute aortic

Figure 3. CT angiography axial view demonstrating the pseudoaneurysm (yellow arrow) with extravasation of dye into the hematoma.

Figure 4. CT angiography coronal view demonstrating the pseudoaneurysm (yellow arrow) at the site of the intercostal branch seen in Figure 2.

Assoc. Inc. Flagstaff, AZ, USA) stent was successfully implanted via the left femoral artery. Due to the fact that the procedure was performed in an acute dissection phase, the balloon at both ends of the stent was not inflated, and an oversized stent was not used.

The patient was extubated 3 days after the procedure. The patient fully recovered and was discharged home on the thirteenth postoperative day. Pre-discharge CT angiography showed a well-positioned stent graft, no endoleak, and marked decrease in the ascending aortic IMH as well the descending aortic pseudoaneurysm. Thirteen months after surgery, the patient is asymptomatic. Follow-up CT angiography showed complete resolution of the IMH, elimination of the intimal ulcer and remodeling of the pseudoaneurysm (Figures 6, 7, and 8).

**Discussion**

Emergency surgery is nearly always recommended in patients with acute Type A aortic pathology and organ malperfusion. The most important principle of surgical repair of typical Type A dissection includes resection and reconstruction of the aortic segment containing the intimal tear initiating the dissection. This is most commonly achieved via a
pathology was, in fact, a locus minoris adjacent to a large intercostal artery in the proximal descending aorta. We therefore, elected to exclude the site using standard endovascular techniques. To minimize the risk of spinal cord injury, we covered only the suspicious segment. Two other important technical considerations included avoidance of stent-graft oversizing and balloon dilation [4]. TEVAR resulted in rapid clinical improvement and marked, sustained reverse aortic remodeling.

This case underscores the importance of frequent surveillance imaging in patients with acute aortic pathology treated medically (rather than surgically) aiming to better define the pathology and/or identify interval changes suggestive of pending rupture. In the current case, it enabled us to identify a very uncommon event of organ malperfusion secondary to retrograde and antegrade extension of IMH originating from a Type B aortic pathology. This resulted in a dramatic shift in the operative strategy to a much less invasive approach of TEVAR.

**Conflict of Interest**

The authors have no conflicts of interest relevant to this publication.
Levy, E. et al.

Case Report


References

Figure 7. CT angiography coronal view 9 months after the procedure, demonstrating the stent graft in the descending aorta and the disappearance of the aortic pseudoaneurysm.

Figure 8. CT angiography 3D reconstruction 9 months after the procedure, demonstrating the stent graft in the descending aorta and the disappearance of the aortic pseudoaneurysm.

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EDITOR’S COMMENTS AND QUESTIONS

Editor’s Comments

Anneke Damberg, MD
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Levy et al. report a case of intramural hematoma/Type B dissection with proximal and distal extension

Levy, E. et al.

Stent-Treated Intramural Hematoma
and an entry in the descending thoracic aorta, which was treated by stent graft covering of the entry.

This well presented case is of interest for the aortic surgeon since major aortic surgery was avoided by an endovascular procedure in a patient in serious condition. However, it should be pointed out that the initial decision that the patient was too sick for surgery bore a very high risk for mortality in this relatively young patient (56 years old) since she had a Type A extension of the dissection and an intramural hematoma, with abdominal organ malperfusion and compression of the left main coronary artery. Most surgeons would have regarded surgery as being absolutely indicated because the chances of survival with surgery still exceed by far those without [1].

Covering the entry detected on follow up CT angiogram with a stent graft led to full resolution of the hematoma. The procedure described is an elegant option to avoid major aortic surgery in this setting, even though it was risky to initially refrain from surgery or intervention in view of the malperfusion that was unlikely to resolve without therapy.

Finally, it should be mentioned that the approach presented is not new: it was described in a case series by Grimm et al. [2].

Editor’s Questions

1. What happened to the LV function and AI? When the patient arrived to our hospital the LV function was moderately to severely reduced, it was improved to moderate after the procedure and at discharge it became mild to moderately reduced. The AI was moderate before the procedure and improved to mild AI afterwards.

2. What happened to the left main coronary artery compression? When the patient first arrived to the other hospital, she had chest pain, abdominal pain, nonspecific ST-T changes, and the troponin I was not elevated, the left main artery compression was found by coronary catheterization that was done assuming that the patient had acute coronary syndrome, after the diagnosis of acute Type A IMH was established there were no signs of cardiac ischemia in the ECG, no elevation of troponin I, and the chest pain disappeared after the endovascular treatment, we assume that the distortion of the left main resolved, resulting with improvement of the LV function.

3. What happened to the liver and kidney malperfusion? The liver functions and the liver enzymes were improved after the treatment, and were back to normal when the patient was discharged. The right kidney remained malperfused but the kidney function test were normal.

References


List of Upcoming Meetings

January 2016

1. Controversies and Updates in Vascular Surgery
   January 21-23, 2016
   Paris, France
   Meeting information available at:
   www.cacvs.org

2. Society of Thoracic Surgeons 52nd Annual Meeting and STS/AATS Tech-Con 2016
   January 23-27, 2016
   Phoenix, Arizona
   Meeting information available at:
   www.sts.org/annualmeeting

February 2016

1. Aortic Valve Repair: A Step by Step Approach
   L’Institut Mutualiste Montsouris
   February 4-5, 2016
   Paris, France
   Meeting information available at:
   www.caviaar.com

2. 62nd Annual Meeting of Indian Association of Cardiovascular and Thoracic Surgeons
   February 18-21, 2016
   Lucknow, UP, India
   Meeting information available at:
   www.iactsconlucknow2016.org

3. University of Virginia 8th Annual Cardiac Symposium: Debates and Controversies in Cardiovascular Disease
   Wintergreen, VA
   Meeting information available at:
   www.cmevillage.com

4. 34th Cardiovascular Surgical Symposium (CSS)
   February 27-March 5, 2016
   Zurs, Austria
   Meeting information available at:
   www.surgery-zurs.at

March 2016

1. 12th International Congress of Update in Cardiology and Cardiovascular Surgery
   March 10-13, 2016
   Antalya, Turkey
   Meeting information available at:
   www.uccvs2016.org

2. Society for Cardiothoracic Surgery in Great Britain & Ireland 80th Annual Meeting
   Birmingham, United Kingdom
   Meeting information available at:
   www.scts.org