Total aortic arch replacement with the elephant trunk technique: single-centre 30-year results†

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Abstract

OBJECTIVES: The combined disease of the aortic arch and the descending aorta (aneurysms and dissection) remains a surgical challenge. Various approaches have been used to treat this complex pathology. In the two-stage operation, at the first-stage operation, the aortic arch is replaced through a median sternotomy. Later, at the second-stage operation, the descending thoracic aorta is replaced through a lateral thoracotomy. The elephant trunk (ET) technique was introduced by H.G. Borst at our centre in March 1982, greatly simplifying the second-phase operation. We present our 30-year experience.

METHODS: From March 1982 to March 2012, 179 patients (112 males, age 56.4 ± 12.6 years) received an ET procedure for the combined disease of the aortic arch and the descending aorta (91 aneurysms, 88 dissections (47 acute)). Fifty-six of these patients had undergone previous cardiac operations. Concomitant procedures were performed if necessary. The cerebral protection was done either by deep (till 1999) or moderate hypothermic circulatory arrest and selective antegrade cerebral perfusion (SACP, after 1999).

RESULTS: Cardiopulmonary bypass (CPB) and X-clamp times were 208.5 ± 76.5 min and 123.7 ± 54.8 min, respectively. The intraoperative mortality and 30-day mortality during the first-stage operation were 1.7% (3/179) and 17.3% (31/179, 15 with AADA), respectively. Perioperative stroke was 7.9% (n = 14/176). Postoperative recurrent nerve palsy was present in 18.2% (32/176) and paraplegia in 5.6% (10/176). The second-stage completion operation was performed as early as possible. Fifty-seven second-stage completion procedures were performed, either surgically (n = 50) or through interventional techniques (n = 7). The intraoperative and 30-day mortality after the second-stage completion procedures were 5.2% (3/57) and 7.0% (4/57), respectively. The stroke, recurrent nerve palsy and paraplegia rates were 0, 0 and 7% (4/54), respectively.

CONCLUSIONS: The ET technique has greatly facilitated the two-stage approach to the surgical treatment of combined diseases of the aortic arch and descending aorta. The initial learning curve, acute dissections, re-do and concomitant procedures partially explain the higher mortality rate. Despite the development of new hybrid techniques, there is still a role for the classical ET in selected patients, particularly in the context of proven long-term results and cost effectiveness.

Keywords: Aortic arch aneurysm • Elephant trunk • Aortic dissection

INTRODUCTION

The combined disease of the aortic arch and the descending aorta (aneurysms and dissection) remains a surgical challenge. Various approaches have been used to treat this complex pathology. In the two-stage operation, at the first-stage operation, the aortic arch is replaced through a median sternotomy. Later, at the second-stage operation, the descending thoracic aorta is replaced through a lateral thoracotomy. The so-called elephant trunk (ET) technique was introduced by Borst et al. [1] at our centre in March 1982. In this innovative technique, a segment of the Dacron prosthesis is left to ‘float’ freely within the more distal portions of the aorta, which is subsequently replaced, requiring potentially only one anastomosis, thereby greatly simplifying the second-phase operation [1–5].

The purpose of this study was to assess the long-term results of the classic ET technique for the treatment of combined diseases of the aortic arch and the proximal descending aorta.

MATERIALS AND METHODS

Patients

From March 1982 to March 2012, 179 patients (112 males, age 56.4 ± 12.6 years) received an ET procedure for the combined disease of the aortic arch and the descending aorta (91 aneurysms,
88 dissections (47 acute). Fifty-six (31.3%) of these patients had undergone previous cardiac operations. Concomitant procedures were performed if necessary (aortic valve replacement /aortic valve repair (n = 94) and coronary artery bypass grafting (CABG) (n = 30) among others).

In our series, the first ET implantation was done in March 1982 for thoracic aortic aneurysm. With more experience, we expanded the indication for ET to chronic type A aortic dissection (October 1982), acute type B aortic dissection (June 1990) and finally to acute type A aortic dissection (AADA, May 1994).

When indicated, the second-stage completion operation was performed as early as possible.

Fifty-seven second-stage completion procedures were performed, either surgically (n = 50) or through an interventional technique (n = 7). Among the patients undergoing surgical second-stage completion, 39 underwent descending aortic replacement and 11 underwent thoraco-abdominal aortic replacement, respectively. The duration between the two stages was 491 ± 677 (range 1–2732) days.

The ethical committee of our institution gave approval for this retrospective study. The patient characteristics are given in Table 1.

Surgical technique of the first stage

Because of the long period, obviously, surgical techniques have evolved down the years (Fig. 1). After a standard median sternotomy, extracorporeal circulation is initiated with cannulation of the ascending aorta is performed even in AADA as has been published by our group [6]. The left side of the heart is vented through the right superior pulmonary vein. Blood cardioplegia has been our preferred technique. Cardioplegia is repeated approximately every 30 min.

The cerebral protection was done either by deep hypothermic circulatory arrest (DHCA) until October 1999, or—since November 1999—moderate hypothermic circulatory arrest (MHCA) with selective antegrade cerebral perfusion (SACP) has been our preferred technique.

Table 1: Patient demographics and preoperative clinical data (first-stage operation)

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>n = 179</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (male/female)</td>
<td>112 M/67 F</td>
</tr>
<tr>
<td>Age (mean) years</td>
<td>56.4 ± 12.6</td>
</tr>
<tr>
<td>Aneurysm</td>
<td>n = 91</td>
</tr>
<tr>
<td>Aortic dissection</td>
<td>n = 88</td>
</tr>
<tr>
<td>Acute type A dissection</td>
<td>n = 47</td>
</tr>
<tr>
<td>Acute type B dissection with retrograde dissection of the aortic arch</td>
<td>n = 4</td>
</tr>
<tr>
<td>Chronic aortic dissection</td>
<td>n = 37</td>
</tr>
<tr>
<td>Marfan syndrome</td>
<td>n = 26</td>
</tr>
<tr>
<td>Previous cardiac operations (56/179 patients)*</td>
<td>n = 56</td>
</tr>
<tr>
<td>Aortic valve replacement</td>
<td>n = 27</td>
</tr>
<tr>
<td>Ascending aortic replacement</td>
<td>n = 41</td>
</tr>
<tr>
<td>Aortic arch replacement</td>
<td>n = 10</td>
</tr>
<tr>
<td>Coronary artery bypass grafting</td>
<td>n = 5</td>
</tr>
</tbody>
</table>

*Some of the patients had received a combined operation (e.g. aortic valve replacement and ascending aortic replacements).

**INSERTION OF THE ‘ELEPHANT TRUNK’**

Early years

After initiating circulatory arrest under deep hypothermia, the aortic arch was opened. The end of the arch graft was inserted distally, and the side of the fabric tube was anastomosed to the origin of the descending aorta with a circular suture (Fig. 1A). This was somewhat cumbersome, with the graft coming in the way during suturing.

Thus, the technique was modified so that the ‘ET’ part of the graft was invaginated retrogradely into the arch graft during suturing of the distal anastomosis. The ‘ET’ was extended in an antegrade fashion into the descending thoracic aorta before completion of the anastomosis.

Early modifications

Another elegant modification was developed by Crawford et al. [2] and Svensson et al. [5] (Fig. 1B). In this modification, a retracting heavy suture is first attached to the end of the future proximal arch portion of the graft. By passing this suture through the graft and pulling, the arch part of the graft is invaginated into the ‘ET’ part of the graft. The resulting double layered graft is inserted into the descending aorta. The distal anastomosis is done by suturing the end of this double layered graft with the wall of the descending aorta. Upon completion of the distal anastomosis, the stay suture is pulled so that the arch portion of the graft comes out of the ‘ET’.

Prefabricated ‘elephant trunk’

Since 2007, we have been using the prefabricated aortic arch graft with an ‘ET’ part. The arch part of the graft has four branches, one for arterial perfusion and three for the anastomoses with supra-aortic branches (Vascutek Siena) (Fig. 1C). There is a sewing collar between the ‘ET’ and the arch parts of the graft, thus further simplifying the distal anastomosis.

Over the past few years, we have standardized the surgical technique as far as possible. During the time, the patient is cooled to a nasopharyngeal temperature of 22–25°C, the aortic root/ascending aortic procedure or other concomitant procedures (e.g. CABG) are performed if necessary.

After reaching the desired temperature, the systemic circulation is arrested and the aorta opened. With the patient in the Trendelenburg position, catheters (Medtronic DPL, Minneapolis, Minnesota, USA) are introduced into the left carotid artery and the innominate artery for SACP. The left subclavian artery is clamped or occluded with a Fogarty catheter (Baxter, Deerfield, Illinois, USA), thus avoiding a steal phenomenon as well as preventing blood flowing into the operative field.

Cerebral perfusion is initiated at a rate of 10 ml/kg/min. The blood temperature of SACP is 20–24°C.

The aorta is transected either between the left common carotid artery and the left subclavian artery or distal to the left subclavian artery. The ET part of the Dacron prosthesis is placed through the
opened aortic arch and deployed, leaving this section ‘floating’ in the descending aorta. A sewing collar between the graft segments simplifies the ‘distal’ anastomosis. In AADA patients, where the distal aortic arch is not aneurysmatic, the distal anastomosis is done between the left carotid and the left subclavian arteries, if possible. During open distal anastomosis, blood perfusion to the lower half of the body is either arrested (in AADA patients) or performed via a Foley catheter placed in the descending aorta (in some aneurysm cases). The ‘distal body perfusion’ flow is set between 2 and 3 l/min. After the distal anastomosis is completed, the left subclavian artery is anastomosed to the third branch of the arch graft. Distal body perfusion via the Foley catheter is stopped and the Foley catheter is then removed (if used) from the descending aorta. The perfusion to the lower part of the body and the subclavian artery is then restarted via the fourth branch of the graft. The proximal end of the graft is anastomosed, either with glue or adapted together during the anastomosis. It may be advisable to use Teflon felt strips or pledgets in order to avoid tearing of the fragile tissue. We slightly ‘oversize’ the graft so that the ‘ET’ presses against the dissected aorta.

In cases of acute dissection, the dissected layers should be united, either with glue or adapted together during the anastomosis. It may be advisable to use Teflon felt strips or pledgets in order to avoid tearing of the fragile tissue. We slightly ‘oversize’ the graft so that the ‘ET’ presses against the dissected aorta.

If the aorta at the level of the distal anastomosis is considerably larger than the diameter of the chosen graft, plication of the aorta may be a reasonable technique. However, the modern grafts with a ‘sewing collar’ at the distal anastomosis site make this redundant.

In case of cannulation of the femoral artery for CPB (retrograde perfusion), it is essential to switch perfusion from retrograde to antegrade to prevent ‘ET’ kinking.

The correct position of the distal anastomosis site is obviously a matter of the surgeon’s choice. If possible, we now prefer to do this anastomosis between the left carotid artery and the left subclavian artery. This allows the surgeon to avoid the area of distal aortic arch in the vicinity of the vagus and the recurrent laryngeal nerves. Moreover, in cases of an acute dissection of a normal-sized aorta, the anastomosis may be technically difficult if done distal to the left subclavian artery.

Surgical technique of the open second stage

After a standard left lateral thoracotomy, the aorta was mobilized in the proximal descending aorta well away from the distal arch. The aorta was also mobilized distally for a second clamp site. Extracorporeal circulation is initiated with cannulation of the femoral vessels. In the early years, a left heart bypass was practised.

The heart was allowed to contract during the whole procedure so that the perfusion of the upper part of the body (above the cross clamp) was done by the patient’s own heart and the perfusion of the lower part of the body was done via the CPB. This technique avoids the blockage of the proximal descending aorta by the free floating ET due to retrograde CPB flow.

The descending aorta was clamped twice, once in the proximal part and another distally. The aorta was opened and the floating ET identified, pulled and clamped again. The descending aorta is then replaced using a Dacron graft that is anastomosed proximally to the end of the ET. Distally, the Dacron graft is anastomosed to the healthy aorta. At least some intercostal and spinal arteries are reimplemented in the Dacron graft to avoid spinal ischaemia. In the

Technical considerations to avoid pitfalls during the first-stage operation

Whatever the technique used, it is of utmost importance for antegrade blood flow through the ET to be possible in order to prevent incomplete unfolding or kinking of the ‘free floating’ ET in the descending aorta. In case of uncertainty, we use an endoscope to view the ET from inside after its placement in the descending aorta.

In case of chronic dissection, all clots should be carefully removed from the false lumen and the intimal flap should be resected to a length longer than the length of the ET in order to avoid entrapment of the ET. The resection of the intimal flap will also ensure that both the lumina remain perfused distal to the ‘ET’.

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Figure 1: Evolution of ET implantation over the decades: (A) 1983 Borst, (B) 1992 Svensson-modification including side-arm and (C) 2006 Vascutek Siena branched graft.
Perioperative stroke occurred in 7.9% \((n = 14/176)\) of the cases. Three of these patients were re-do cases and 8 were AADA patients. Postoperative recurrent nerve palsy was present in 18.2% \((32/176)\). Six of these patients were re-do cases and 6 more were AADA patients. Postoperative paraplegia occurred in 5.6% \((10/176)\).

Rethoracotomy due to postoperative bleeding and haemodialysis due to postoperative acute renal failure were necessary in 17.3% \((n = 31)\) and 7.3% \((n = 13)\), respectively. Postoperative tracheostomy due to respiratory insufficiency was performed in 10.7% \((n = 19)\) patients.

The intraoperative data are given in Table 2. The 30-post-operative-day mortality was highly significant between elective and emergency operations \((10.7% \text{ in elective patients vs } 31.6% \text{ in emergency patients, } P < 0.001)\).

As reported above, cerebral protection was done either by deep \((\text{until October 1999) or MHCA and SACP (after November 1999). Statistically, there were no differences between these two groups in terms of demographics (sex, height and weight) and postoperative complications such as recurrent nerve palsy, paraplegia, respiratory insufficiency and 30-day mortality. However, there were significant statistical differences in several other parameters (Table 3). Figure 2 shows the Kaplan–Meier survival curve after ET operation in three different decades. Figures 3–5 show the Kaplan–Meier survival curves after ET implantation in emergency (Fig. 3), re-do (Fig. 4) and electively operated (Fig. 5) patients, respectively.

After the second stage

The second-stage completion operation was performed as early as possible. In fact, in 3 patients both the first-stage and the second-stage operations were done on the same day. In 2 patients, the ET was trapped in the small true lumen and there was a big pressure gradient between the upper and lower parts of the body and thus the patient had to undergo an immediate second-stage operation.

In the third patient, the descending aortic aneurysm caused a blockage of the left main bronchus leading to the collapse of the left lungs. The descending aorta was thus replaced on the same day. In 5 other patients, both stages of the operation were done in the same hospital stay.

Fifty-seven second-stage completion procedures were performed, either surgically \((n = 50, 87.7\%)\) or by interventional

### Table 2: Intraoperative data (first-stage operation)

<table>
<thead>
<tr>
<th>Description</th>
<th>DHCA</th>
<th>MHCA and SACP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total patients with ET implantation (n)</td>
<td>179</td>
<td>150</td>
</tr>
<tr>
<td>with ascending aortic replacement (n)</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>With aortic valve replacement/repair (n)</td>
<td>94</td>
<td>94</td>
</tr>
<tr>
<td>With coronary artery bypass grafting (n)</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>With descending aortic replacement (n)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Cardiopulmonary bypass (208.5 \pm 76.5) min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aortic cross-clamp time (123.7 \pm 54.8) min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circulatory arrest time (HCA) (48.9 \pm 23.1) min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total operation time (336 \pm 114) min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCA (n)</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Selective antegrade cerebral perfusion (n)</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>Aortic arch replacement (Island technique) (n)</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>Aortic arch replacement (separate graft technique) (n)</td>
<td>23</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Postoperative results after ET implantation under DHCA and MHCA with SACP

<table>
<thead>
<tr>
<th>Parameters</th>
<th>DHCA</th>
<th>MHCA and SACP</th>
<th>Test</th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant differences</td>
<td></td>
<td></td>
<td>T-test</td>
<td>(P &lt; 0.05)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>56 ± 13.2</td>
<td>60 ± 12.4</td>
<td>T-test</td>
<td>0.024</td>
</tr>
<tr>
<td>Duration of operation (min)</td>
<td>307 ± 108</td>
<td>363 ± 115</td>
<td>T-test</td>
<td>0.012</td>
</tr>
<tr>
<td>Hospital stay (days)</td>
<td>23.1 ± 11.1</td>
<td>18.9 ± 11.0</td>
<td>T-test</td>
<td>0.012</td>
</tr>
<tr>
<td>Highly significant differences</td>
<td></td>
<td></td>
<td>Fisher’s exact test</td>
<td>(&lt;0.001)</td>
</tr>
<tr>
<td>AADA (%, (n))</td>
<td>9.1% ((n = 4))</td>
<td>45.7% ((n = 43))</td>
<td>Fisher’s exact test</td>
<td>(&lt;0.001)</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time (min)</td>
<td>175 ± 53</td>
<td>232 ± 82</td>
<td>T-test</td>
<td>(&lt;0.001)</td>
</tr>
<tr>
<td>Circulatory arrest time (min)</td>
<td>42 ± 19</td>
<td>54 ± 25</td>
<td>T-test</td>
<td>(&lt;0.001)</td>
</tr>
<tr>
<td>Rethoracotomy</td>
<td>9.5% ((n = 7))</td>
<td>25.6% ((n = 27))</td>
<td>Fisher’s exact test</td>
<td>0.005</td>
</tr>
</tbody>
</table>
techniques [thoracic endovascular aortic repair (TEVAR)] \( n = 7 \), 12.3%). Out of these 7 patients undergoing a second-stage procedure with TEVAR, six procedures were technically successful. In 1 patient, there was a fistula between the descending aorta and the azygos vein. The TEVAR was not successful in this patient. The patient underwent an emergency open procedure but unfortunately did not survive.

Eleven (19.3%) patients underwent thoraco-abdominal aortic replacement, whereas 39 (68.4%) underwent descending thoracic replacement.

The intraoperative and 30-day mortality after the second-stage completion procedures were 5.2% (3/57) and 7.0% (4/57), respectively. The stroke, recurrent nerve palsy and paraplegia rates were 0, 0 and 7.0% (4/54), respectively.

**Follow-up**

The operative records of all 179 patients were analysed. Altogether, ten patients were lost to the follow-up; several of them came from other countries.

One hundred and twenty-two (68.2%) patients underwent only the first-stage operation. Of these, 34 patients, died in hospital and 3 others were lost to the follow-up. Of these 85 patients, 40 were still alive and 45 had died. The causes of death were cardiac \( n = 11 \), aortic \( n = 5 \), others \( n = 12 \) and unknown \( n = 17 \), respectively.

Of 53 patients who were discharged from the hospital after successfully undergoing the second-stage completion operation, 21 (39.6%) were still alive, 25 (47.2%) had died and 7 (13.2%) were lost to the follow-up.

**DISCUSSION**

Combined disease of the aortic arch and the proximal descending aorta remains a surgical challenge. Classically, a two-stage operation was performed. Alternatively, a single-stage operation can be performed either through a clam-shell incision or a combined median sternotomy and a lateral thoracotomy [7, 8]. In recent
years, either hybrid operations or surgery with a frozen ET has been proposed [9-11].

The ET technique was initially developed to facilitate staged aortic replacement with the help of intravascular placement of a surplus distal graft part during the initial operation. The ET can thus be placed in the proximal descending aorta during the total aortic replacement. The main advantage is that due to the ET, a proximal anastomosis between the distal aortic arch and the descending aortic graft during the second-stage operation becomes unnecessary. This anastomosis is technically difficult and potentially dangerous, particularly due to adhesions after a previous aortic arch replacement. During the second-stage operation, the surgeon only needs to open the descending aorta and anastomose the ET with a new graft, staying away from the aortic arch. Initially, this ET was performed in aneurismal diseases. Over the years, the indication has been expanded to include aortic dissections, both acute and chronic. With improvements in operative techniques as well as organ protection, we have been able to treat more complex patients with this technique.

It is controversial whether such an ‘aggressive’ technique should be used in AADA patients [12-14]. Some surgeons advocate only an ascending aortic replacement with or without replacement of the proximal arch. Ando et al. [14] proposed a total aortic arch replacement with a conventional ET to achieve a stronger distal anastomosis and facilitate possible subsequent operations on the downstream aorta. Total replacement of the ascending aorta and the aortic arch with an ET implantation in AADA patients does demand high technical skills. In spite of this, we still believe in such a strategy, either with a classic or frozen ET to improve long-term outcome in cases of AADA with intimal tear or re-entry in the aortic arch or the dissecting aorta (DeBakey type I). Of course, such a strategy can only be implemented in centres of excellence and only if it is absolutely necessary and not routinely performed in all acute dissection patients [15, 16].

As discussed above, implantation techniques, as well as the grafts used for the ET approach have undergone several modifications over the years. Modern grafts with four side branches as well as sewing collars for the distal anastomosis have helped to further ‘simplify’ the ET implantation. These modern grafts incorporate radio-opaque identifications at the distal end of the ET. Previously, the distal end of the ET was marked by placing metal clips during the first operation. The radio-opaque marks are of great help to identify the distal end of the ET when planning the second-stage operation, particularly in cases of endovascular completion [17, 18]. Our series includes patients operated on with the ET technique since its introduction 30 years ago. Initially, the pioneers of this technique went through much ‘sweat and tears’ to fine tune this technique. Initially, it was not known what the ideal length of the ET was. Therefore, relatively longer ETs were implanted. The organ-protection techniques in use several decades ago were also not as developed as those of today. This is one of the reasons for the higher mortality and other complications such as paraplegia and stroke. We now believe that a length of 8-10 cm for the ET is enough, as its primary purpose is to simplify the second-stage operation. Shorter ET lengths may make it difficult to retrieve the ET during the second-stage procedure. Similarly, one should be aware of the pitfalls when implanting an ET in aortic dissections. In cases of chronic dissections, the intimal flap should be resected to a length longer than the length of the ET in order to avoid entrapment of the ET as well as to ensure that both the lumina remain perfused distally to the ET.

In cases of acute dissection, the dissected layers should be united, either with glue or adapted together during the anastomosis.

The ideal time interval between the initial ET procedure and the second-stage completion is a matter of discussion. In our series, 5 patients underwent the completion procedure on the same day and 5 more, within the same hospital stay (in total 17.6%). All these patients had urgent indications for completion. Ideally, the second-stage completion should be done as soon as possible. However, the patients should have recovered adequately and be fit enough to undergo the second-stage operation, which can also be quite traumatic. The surgeon should always find a balance between waiting too long with the risk of rupture of the downstream aorta to operating too early on an unfit patient. We advise that the patients should be put on close follow-up to determine the ideal time for the second-stage operation. In selected patients, the second-stage completion may be performed via new endovascular techniques. This would allow for shorter intervals between the two stages.

In our series, a majority of the patients did not receive a second-stage operation. This is due to the fact that we were quite liberal in doing an ‘ET’ procedure in patients with indication for total arch replacement even if some of them did not have clear indication for an ET implantation. We believe that patients with an indication for a total aortic arch replacement should also get an ‘ET’ as the potential second-stage operation, if needed, would then be technically easier and less traumatic. We believe that there is no significant added risk in implanting an ‘ET’ in addition to a total aortic arch replacement compared with isolated total arch replacement.

Critics of this approach point to the need for two operations with its associated mortality and morbidity as well as the fact that at least some mortality in the interval between the two operations is due to the rupture of the untreated segment of the aorta. These surgeons advocate a single-stage operation either through a clamshell incision or a combined median sternotomy and lateral thoracotomy to repair the aortic arch as well as the descending aorta. However, such a strategy is quite invasive for the patient and technically difficult for the surgeon, and as such has been followed only by few centres [7, 8].

In recent years, endovascular stent-graft techniques have been introduced [9, 10]. However, a totally endovascular treatment of the aortic arch pathology is still difficult because of the supra-aortic vessels. A combination of the classic ET technique and the endovascular stent technology resulted in the so-called ‘frozen elephant technique’ (FET) [11]. In this potentially single-stage technique, the ascending aorta along with the aortic arch is replaced conventionally, and an endovascular stent graft is placed into the descending aorta in an antegrade manner through the open aortic arch. The distal landing site of the stent graft can be at the non-diseased portion of the descending aorta. Several centres including ours have embraced this FET technology in recent years.

Between August 2001 and January 2012, 131 patients underwent aortic arch replacement with FET prostheses in our centre.

In-hospital mortality was 15%, which is similar to that of the classic ET. Freedoms (%) from distal aortic operation were 81 ± 4, 67 ± 5 and 43 ± 13, respectively. Thirty-six patients underwent 40 distal aortic operations, either open surgical (n = 22, 55%) or endovascular (n = 18, 45%). Chronic aortic dissection was identified as an independent risk factor for distal aortic operation [19]. Therefore, for a true single-stage operation with FET, the disease has to be limited to the upper part of the descending aorta. If the
patients are not carefully selected or if the disease progresses into the downstream aorta, second-stage operations may be imperative, thereby negating the potential benefits of the FET [16]. An additional disadvantage of the FET is the extremely high cost of the hybrid grafts compared with the grafts used for the classic ET.

Therefore, we believe that in the mega-aortic syndrome with the pathology extending to the distal descending or abdominal aorta, requiring a descending aortic/thoraco-abdominal aortic replacement at a later stage, the classic ET is still the ‘gold-standard’ in terms of cost as well as treatment effectiveness.

Limitations

The main limitation of this study is the extremely long time (>30 years) since the initial ET procedure and the many modifications in the operative techniques made since then. Due to the same reason, many patients are long deceased. In addition, the observational nature of the study makes the subgroup comparison difficult. Thus, one has to be cautious during interpretation of the data.

CONCLUSIONS

Over the years, the ET has greatly facilitated the two-stage technique for the surgical treatment of combined diseases of the aortic arch and descending aorta. Despite the development of new hybrid techniques, there is still a role for the classic ET in selected patients, particularly in the context of proven long-term results and cost effectiveness.

Conflict of interest: none declared.

REFERENCES


APPENDIX. CONFERENCE DISCUSSION

Dr M. Schepens (Brugge, Belgium): I think this is a historical series coming from what might be called the mecca of aortic surgery where the elephant trunk was born. It describes a very large series, probably one of the largest in Europe: 179 patients over a time period of three decades, using the so-called classic Borst or free-floating elephant trunk, eventually followed by second-stage open or endovascular repair.

It strikes me that your results show a relatively high mortality: 17% for the first stage and 7% for the second stage, or, in total, a cumulative mortality of 24%. One out of four patients would not survive. Compared to our own series previously reported (though I realize that comparisons are hardly possible because patients are different, time frames are different, techniques are different), this is substantially higher.

My first question is: Aren’t you afraid that despite the fact that your series covers a timespan of three decades in which surgery evolved tremendously, despite the fact that one-third of your operations were redos, despite the fact that 25% of the patients were operated upon for type A dissections, aren’t you afraid that the critics of this wonderful technique will now use your results to break it down in the future? Could you comment on that, please.

My second question relates to the spinal cord problems. You said that the length of the trunk was probably, in the beginning, too long, causing spinal cord problems and paraplegia. Could it not be that the temperature management and the duration of the arrest also played a very important role? And my third question is: Later on you are presenting a paper describing the Hannover results with the frozen elephant trunk technique. I would like to know what is your actual preferred method, how do you choose which technique is used in Hannover actually?

Dr Shrestha: In response to the first question, what I learned right from the beginning of my training in Hannover is that we are always very open about our results. I think it doesn’t help us if we come here and say that we either have 0% stroke or 0% mortality. We learn from our mistakes. And the reason that we have that high mortality and morbidity is that, as I said before, this is a 30-year experience. If I had reported only two-year results, they would have been a lot better. And in those times at least (I had a long talk two weeks ago with Professor Borst and we were discussing this), with every single step there was a lot of improvisation. We didn’t know, or he did not know, nobody knew at...
that time, what was the best technique. And even putting in an elephant trunk in the beginning was difficult. So you have to take that into account, I think.

Concerning your further comment, the point is, of course, that we have a lot of type A dissections. And if you take all this away, I think the results will not be that bad. I still think that we have to be very honest about our results. That’s why I put in everything. I’m not afraid that someone may come and says that stentings are better, because they have to have 30-year results with stenting and have the same results before they can say it’s better. The second question was - sorry, I forgot that.

**Dr Schepens:** About the length of the trunk.

**Dr Shrestha:** Yes, I think here you are right. One of the reasons may have been that the floating part was too long. The second point is also that until ’99 it was deep hypothermic circulatory arrest at 14–15 degrees, and we now know that maybe that was not that good. But having said that, of course, in those days it was early days for aortic surgery. There were a lot of things that we now know, we take for granted, which we didn’t know in those days.

The third point is that now with the frozen elephant trunk we still think that (except in type A dissection, where I think a frozen elephant trunk is a lot easier and better) in cases of aneurysms, mega-aortic syndromes, where you know that you have to go for a second-stage operation, that the classic elephant trunk still has a role, and I still believe that in terms of both the cost and the treatment effectiveness it remains the gold standard.

**Dr M. Karck** (Heidelberg, Germany): Let me ask one more question. If less than one-third of the patients come back for the second-stage operation, doesn’t this mean that the indication is maybe taken too liberally? Didn’t these patients need a second operation, or was there a problem with the follow-up?

**Dr Shrestha:** I think that, because we lost only 11 patients to follow-up, maybe we are liberal, yes. But everyone who has performed total arch replacement knows that they’re just putting in one more graft. Especially with the new techniques and new grafts which we have now, the risk would not be higher. I personally do not believe that the risks are higher if you put in an elephant trunk. When you have to do a total arch replacement anyway, it’s not that difficult. Because the alternative is that if they do come back, then having to do this proximal anastomosis from the left side and to go in to repair in the old operated area is fairly difficult. So I think that I would still say that we have to be liberal, I think it makes our life a lot easier.

**Dr T. Sioris** (Tampere, Finland): I noticed you recommended cutting the membrane when you insert the elephant trunk, cutting the dissection membrane, in one of your slides. Now, this is quite the opposite idea with the frozen elephant trunk. I can understand that if you have a small lumen and you have the conventional elephant trunk, it will not expand because it’s not a nitinol-reinforced thing. So my question is: Are you concerned about the perfusion of both lumina, as in your slide, or is it more of just getting the floppy trunk to fit in?

**Dr Shrestha:** The point I made was only for chronic dissections, not for acute ones.

**Dr Sioris:** For chronic, yes.

**Dr Shrestha:** So in the chronic one, because it’s a free-floating elephant trunk, it can never push it and it will just kink. So you have to cut it if you are putting a normal elephant trunk.

**Dr Sioris:** Yes, this I understand. It was just that on the slide it said there was a concern about the perfusion of both lumina.

**Dr Shrestha:** No, I mean, that was lower down. Because up to the end of the elephant trunk, I would cut the flap. But after that, then both lumina are perfused. I think these are the patients that could come anyway for second stage. So if you are putting an elephant trunk, I think it’s very important that the distal perfusion remains there. If it kinks, as with one of the patients that I operated (I think it was the middle of the night) I had to cannulate the groin (it was a redo), I put in an elephant trunk, and then I forgot to change it immediately. For the first one minute, we couldn’t understand what was happening, then suddenly we realized. Because these are long operations, especially if you do redos, they are 6–7 hours, your concentration decreases, it’s difficult. So these are the points that you have to know. I thought that maybe I should mention the mistakes I made, I don’t know.

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**EDITORIAL COMMENT**

**The most versatile and useful appendage on earth**

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At first glance, this paper by Shrestha *et al.* [1] is a standard analysis and evaluation of a single-centre experience using the elephant trunk technique for total arch replacement. About one-third of the operations were followed by a second-stage procedure, mostly a descending thoracic replacement, only in 11 cases by a thoracoabdominal repair. The focus of this paper clearly lies in the first surgical step.

When studying this paper more thoroughly, it becomes obvious that it is not just an average description and common analysis of the surgical results as we can find almost monthly in all well-respected cardiovascular journals. It is much more than that. It is a wonderful piece of history describing the evolution of the elephant trunk technique starting with its introduction three decades ago by its inventor Hans Borst. Needless to say that the idea of inserting a free-floating vascular prosthesis into the downstream aorta and that in doing so, avoid re-entering in a surgical field that is crowded with major vascular, bronchial, neurological, lymphatic and gastrointestinal structures almost merits the Nobel prize in cardiovascular surgery, if it existed. Technical modifications were later introduced by some outstanding pioneers in cardiovascular surgery (such as Crawford and Svensson) in order to facilitate the technique and to reduce complication rate. Very often, these modifications were just simplifications, which is of course characteristic of the influence of great surgeons.

Of special importance are the alterations concerning cerebral protection: for 17 years, deep hypothermic circulatory arrest was the mainstay and in 1999 antegrade selective cerebral perfusion was introduced and is actually a main pillar to success.