Great Vessel Management for Endovascular Exclusion of Aortic Arch Aneurysms and Dissections

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Objectives. To evaluate a recent approach for the endovascular repair of thoracic aortic aneurysms and dissections involving the aortic arch in high risk patients (HRP).

Methods. Amongst 102 thoracic aortic aneurysms and dissections, we treated 25 patients for aortic arch endovascular exclusion after transposition of the great vessels, of which 14 (56%) had thoracic aortic arch aneurysms and 11 type A and B chronic aortic dissections. Total transpositions were done in 15 cases (60%) and hemi-arch transpositions in 10. We then used Talent®, Excluder® and Zenith® endografts in 12, seven and six cases, respectively.

Results. Surgical transpositions were complicated by one minor stroke, which worsened to a major stroke (4%) after endovascular exclusion. After endovascular exclusions, two patients (8%) died from catheterization related complications. One patient had a delayed minor stroke (4%). The successful exclusion rate was 92%. During follow-up (15±5.8 months), one patient (4%) developed unilateral limb palsy, successfully treated by CSF drainage. The late exclusion rate remained 92%. No stent-related complications were seen.

Conclusions. Transposition of supra-aortic vessels allows the endovascular exclusion of the aortic arch in HRP. Aortic endografting after surgical transposition proved to be feasible and offers good mid-term results. Specialized surgical centers with both endovascular and surgical expertise are required to treat these patients.

Keywords: Stentgraft; Aortic arch; Endovascular exclusion; Aneurysm; Dissection; Transposition; Relocation; Supra-aortic great vessels; Total arch; Hemi-arch; Thoracic aortic arch; Hybrid exclusion; Combined aortic arch treatment.

Introduction

The endovascular treatment of descending thoracic aortic aneurysms and dissections allows high risk patients (HRP) an opportunity to be treated. However, the thoracic aortic anatomy must be favourable to the placement of an endograft. Complex thoracic aortic aneurysms and dissections extending to the aortic arch are thereby excluded from conventional endovascular therapy. Until we know the long-term results of the endovascular approach, conventional aortic arch surgery under cardio-pulmonary bypass (CPB) remains the optimal treatment for low risk patients. We have favoured a hybrid therapeutic solution in HRP that remains less invasive than conventional surgery. This approach involves the transposition of the great vessels combined with endografting. We reviewed the experience of two vascular centers whose indications and techniques for the hybrid procedure were similar and started simultaneously in a prospective study.

Methods

From May 1999 to September 2004, 102 consecutive patients who were high risk for surgery had endoluminal treatment of thoracic aortic aneurysms (TAA) or dissections (TAD) using industrial endografts in two vascular centers. Sixty-three patients were treated at one center and 39 at the other hospital. During the same period, 72 (44 and 28 at center A and B, respectively) open procedures were performed for TAA and TAD. The cohort of this study consisted of a subgroup of 25 patients (24.5%) who were unsuitable for endograft deployment, and required an open adjunctive procedure to create a proximal landing zone in the arch. The selection criteria and treatment protocol were the same in both centers. Pre-operative
assessment included evaluation of patient’s risk factors, imaging and sizing (CT-scan ± calibrated aortography) of the aorta and iliac arteries, and a consensual final decision following a multidisciplinary staff meeting (involving a surgeon, anaesthesist, cardiologist, radiologist, respiratory physician).

Table 1. Risk factors and comorbidities in patients of the cohort

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>Number of patients</th>
<th>Percentage in the cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>High blood pressure</td>
<td>19</td>
<td>76</td>
</tr>
<tr>
<td>Age over 70</td>
<td>17</td>
<td>68</td>
</tr>
<tr>
<td>Severe cardiac impairment: cardiogenic valvulopathy, ejection fraction &lt; 30%, previous coronary bypass and/or MI</td>
<td>12</td>
<td>48</td>
</tr>
<tr>
<td>Chronic pulmonary disease: (FEV1 ≤1 L)</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Previous sternotomy for aortic repair</td>
<td>7</td>
<td>28</td>
</tr>
</tbody>
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Inclusion criteria for aortic arch transposition and endografting were ASA class 3 or 4, documented cardio-pulmonary risk, and age over 50. Exclusion criteria were ASA class 1 or 2, age below 50, the absence of major risk factors and inadequate or small iliac arteries (diameter below 7–8 mm and severe tortuosity). Patients who were not suitable for endografting and those at low risk for surgery were treated by open surgery (three patients during the same period). The average age of the cohort of patients was 71.5±9.9 years old, ranging from 50 to 83, and the male to female ratio was 5.5. Comorbidities are presented in Table 1. Fourteen patients (56%) had atherosclerotic thoracic aortic aneurysms (TAA) with an average length of the diseased aorta of 242.33±82.34 mm. Eight patients (32%) presented with a type B thoracic aortic dissection (TAD) extending to the arch, of which seven were chronic and one acute, and three patients had a type A chronic dissection (Fig. 1).

All false lumens were patent and extended to the

Fig. 1. Patients’ flow according to aortic diseases and types of great vessels management.
abdominal aorta, while most left renal arteries arose from the false lumen. The location of entry tear was either at the subclavian level in the case of retrograde dissections, or in the ascending aorta in case of extended residual dissections after surgery of type A dissections. Average maximum aortic diameter was $64 \pm 11.3$ mm. None of the pathologies were a result of trauma or Marfan’s syndrome. Four types of aortic arch disease were covered by stentgrafts (Fig. 2).

In order to distinguish from Ishimaru’s anatomical aortic classification using antegrade numbering, we propose a ‘retrograde landing zone classification’. This classification is based on pathophysiology and reflects the extension of the disease and case complexity, with respect to the need for transposition. We define four proximal landing zones (PLZ) as seen in Fig. 3. An endografting procedure at PLZ 1 is an ideal situation and requires no surgical complementary step for both aneurysms and dissections. Starting at PLZ 2 requires either coverage or transposition of the left subclavian artery (LSA). If the origin of the left common carotid artery (CCA) (PLZ 3) is involved, transposition to the right CCA via a carotido-carotid bypass must be performed. We call this adjunctive procedure a hemi-arch transposition. If the disease extends the full length of the aortic arch, requiring coverage of the innominate artery (IA), a bypass to the IA and left CCA is performed through a median sternotomy from the ascending aorta. We refer to this as total-arch transposition (Fig. 4). The PLZs must be at least 2 or 3 cm long if possible, measured on the middle center line of the aortic arch. The terminology of hemi-arch and total-arch transposition is used in order to simplify the discussion, thus avoiding repetition of the different bypasses performed. We excluded from this study isolated LSA transpositions.

In our 25-patient experience, we performed 15 total-arch transpositions and 10 hemi-arch transpositions (Fig. 1). The endografts were deployed during a second step, 1 or 2 weeks later, following the creation of the proximal landing zone. We always used a femoral percutaneous access and an additional percutaneous humeral approach was used in some instances to mark the origin of the native innominate artery.

Carotid and vertebral artery circulation were assessed during the aortic arch angiogram. During the transposition procedure, the stump pressure was checked before clamping the arch vessels. In our institution, stump pressure is routinely used by all vascular surgeons since we find it more convenient than transcranial Doppler, which requires a dedicated technician. We do not use EEG monitoring.

Hemi-arch transposition is performed via a vertical 4 cm cervical approach to both CCA. Then an 8 mm Dacron graft is implanted between the two CCAs in a U shape anterior to the trachea. A bypass to the LSA

Fig. 2. Four types of extending aortic diseases we treated by hemi or total arch exclusion. Top left, CT-scan and aortography of a focal atherosclerotic aortic arch aneurysm; top right, two CT-scan images of an extended descending thoracic aortic aneurysm; left bottom, two CT-scan images of a secondary aortic arch aneurysm after previous endovascular exclusion. The images are showing the aortic arch before and after total arch exclusion; right bottom, CT-scan image of a dissecting aortic aneurysm extending to the aortic arch.
previously implanted on table to the U graft is made in an end-to-side manner. The left CCA and LSA are divided proximally.

Total arch transposition is performed through a median sternotomy. A 12 mm Dacron graft is implanted on the ascending aorta as proximal as possible, using lateral clamping. A 7 or 8 mm A Dacron graft is implanted on the 12 mm tube graft in an end-to-side manner to create a bifurcated graft. Then the 12 mm Dacron graft tube is anastomosed end-to-end to the innominate artery, while the 8 mm tube is anastomosed the same way to the right CCA. The proximal stumps of these vessels are clamped during the anastomosis and sutured with a 5/0 prolene suture after the bypass is opened in order to reduce the clamping time. Depending on the patient’s anatomy, the graft was passed in front or behind the innominate vein, which can be divided and reconstructed if necessary. The LSA was not bypassed, since it is often hard to reach through a standard sternotomy. Moreover, a patent LSA may serve as access to the aneurysm, when coiling is necessary to treat a residual type 1 endoleak. A retrograde type 2 endoleak will appear only if there is an outflow from the sac, such as created by patent intercostal arteries, which are normally thrombosed. In one case only we observed a type 2 endoleak that was easily treated by percutaneous occlusion of the LSA (Fig. 5).

In one patient, the diameter of the native aorta after total arch transposition exceeded 40 mm, which may have been too large to ensure adequate endograft anchorage. Therefore, following the transposition procedure, banding of the ascending aorta was performed distal to the IA bypass graft. Following total-arch transposition, markers (metal clips) or wire loops were placed at the proximal anastomosis to the arch, to define the proximal extent of the PLZ.

Endovascular procedures were performed under general anaesthesia in the operating room equipped with a C arm. We started the procedure with Terumo hydrophilic guidewires, and then we switched to Superstiff® guidewires from Boston Scientific. Careful surveillance of the latter is necessary to prevent ventricular perforation. The precise positioning of the endograft at the proximal neck was also assisted by a pigtail catheter from the right brachial artery, injecting contrast medium in the left oblique anterior view. We did not use adenosine induced transient cardiac asystole. Endografts were oversized by 20% for aneurysms and 10% for dissections. The distal diameter of the endograft was initially slightly reduced with non-tapered devices. Since, this series, we have been treating dissections with a tapered endograft whose 24 mm distal diameter better fit the distal landing zone. Stentgraft deployment was monitored with transesophageal-echography (TEE) and intravascular ultrasound (IVUS) assessment for aortic dissections. We avoided using dilatation balloons unless it was necessitated by a residual endoleak. This was especially true for dissections. When it was necessary, a compliant ‘Reliant®’ balloon from Medtronic or a WL Gore trifoliate balloon was used for dilatation.

To treat aneurysms, we used a mean covered length of 280.33±82.34 mm (184–388) with mean proximal and distal diameters of 43.33±2.07 and 38.00±2.19 mm, respectively, and an average endograft number of 2.5±1.05. These values for aortic dissections were an average length of 223.33±111.01 mm (113–335) with mean proximal and distal diameters of 43.33±2.31 and 42.00±2.00 mm, respectively, and an average number of endografts of 2±1.
Data such as pre-operative sizes, patients' condition, risk factors, and post-operative control information were collected during regular working meetings, and they were put together in a single Excel® file.

Following hospital discharge patients were regularly contacted either by mail or telephone and they were asked to undergo both CT-scan and plain X-ray examinations at 3 (in case of post-operative residual minor type 1 endoleak), 6, 12, 18 and 24 months post-operatively, and yearly thereafter.

Patients were seen by the surgeons after each CT-scan examination. Interpretation of images was done in each center by independent radiologists.

We calculated crude rates of survival, neurological complications and endoleaks because the cohort of the study was not large enough to carry out a life-table analysis (minimum required: 30 records).

Results

Immediate results

Following arch transposition patients were monitored on ICU for a maximum of 24 h. The surgical transposition step was complicated by one minor stroke in the group of hemi-arch transposition (10 patients). In the group of total arch transposition (15 patients) one proximal dissection occurred at the site of lateral clamping, which sealed spontaneously. During the endovascular step, the stentgraft deployment was successful in all patients and we had no misplacement of the endografts. We observed one worsening minor stroke in the group of hemi-arch transposition, while no neurological complication occurred in the group of total arch exclusion. During the in-hospital course, one patient had a minor stroke within 48 h due to the occlusion of the left CCA bypass, which was resolved by a cervical carotid–carotid bypass. The stroke rate was 8%. Two patients (8%) died post-operatively from catheter related
complications: one a few hours after the procedure from left ventricle perforation due to uncontrolled stiff guide wire movement, which could not be sealed even after open surgery with extra-corporeal circulation. The other patient died at 3 days from multiorgan failure after rupture of the iliac artery. The major adverse event (MAE) rate, including early deaths and major strokes, was 12%. At discharge three minor residual type-1 endoleaks (12%) were observed, and were left untreated since they may thrombose spontaneously in the post-operative course. These patients underwent early surveillance at 3 months. The first residual endoleak thrombosed spontaneously and the second was successfully treated by graft extension. The third was due to an uncovered entry tear in the ascending aorta and would have required total arch transposition, which was rejected by the patient. We also had one type-2 endoleak in an aorto-esophageal fistula.

Follow-up period

Three-dimensional CT-scan and X-ray examinations were obtained for all the patients before their discharge to serve as control images. During an average follow-up period of 15±5.8 months, no patient was lost to follow-up. No new late endoleaks were observed. The aneurysmal sac exclusion rate was 100%. The rate of non-patent thoracic false lumen was 91%, while we observed 27.3% patent abdominal false lumens, of which the maximum aortic diameter was <50 mm. No endograft migration or fracture was observed, nor stentgraft related complications such as aorto-esophageal fistula.

None of the patients had new cerebral neurological adverse events. One patient (4%) developed a unilateral lower limb deficit at 17 days and was readmitted to hospital. The unilateral motor deficit resolved following CSF drainage. According to independent neurological assessment, this deficit could be due to medullar ischemia, based on cerebral and medullar MRI findings. One patient with COPD died 3 months after the procedure from acute respiratory failure, giving an overall crude survival rate at 15 months of 88% (22/25).

Discussion

Although there has been considerable progress in endovascular techniques, anaesthesia and intensive care management, the surgical repair of descending thoracic aortic aneurysms and dissections remains a high risk procedure. Based on the eight largest (over 40 patients) recent series published, the 30-day stroke/death rate after aortic arch surgical repair is up to 25.6% (mean 17.5%). An alternative to surgical repair of the aortic arch is combined stentgrafts and great vessels transposition. Inoue et al. have reported one case of triple-branched stentgraft use and Chuter has recently reported a branched stentgraft to the innominate artery. Nevertheless, we do not know the mid-term results of this technique.

Several case reports of combined procedures have presented solutions to treat thoracic aortic aneurysms and dissections extending to the aortic arch. Criado et al. published their experience with retrograde bypass from the right common iliac artery to the innominate artery. This alternative does not appear satisfactory with regards to the brain vascularisation and must be considered as an exception. Sternotomy has proved to be low risk, even in HRP, allowing a more physiological antegrade blood supply to the brain. Allenberg et al. reported three cases of total arch and five hemi-arch exclusions with no neurological complication.

We only recommend transposition of LSA when it supplies coronary circulation through the left internal mammary artery (LIMA), when the contralateral vertebral artery (VA) is stenosed or hypotrophic and when there is an incomplete fusion of both VAs at C1. We also recommend transposing the LSA in association with the left CCA when they are included in the aneurysm, except during total transpositions since the LSA is difficult to reach by median sternotomy. In all other cases, LSA transposition is only required later if the coverage becomes symptomatic.

Great vessels transposition appears to be safe. There were no major strokes or deaths related to transposition. There were two early deaths (8%) after the endovascular step, that were either access or guidewire related. The first case has now led our team to carefully evaluate the femoral access and to not hesitate to implant an iliac conduit by a retro-peritoneal approach. The second case is easily avoidable if the guidewire is not inserted through the aortic valve into the left ventricle and strictly controlled during all maneuvers.

In the group of total arch exclusion, no immediate neurological complications occurred during either surgical or endovascular steps. On the other hand, in the group of hemi-arch exclusion, we observed one major stroke. This may be due to catheter manipulation in front of a patent innominate artery ostium, in a patient with an atherosclerotic aorta. A possible way to reduce embolic complications may be to perform...
pre-operative trans-esophageal echography (TEE) to better select the patients. Total arch transposition allows availability of a longer PLZ, easily reaching 3 cm in length for a better anchoring of the endograft. It also avoids stent-graft deployment within the arch curvature, which may cause endoleaks and migration. In selected cases of conical or larger aortas exceeding 40 mm in diameter, the banding technique may be useful in association with total arch transposition to allow a better proximal landing zone.

We prefer a staged procedure for the following reasons: the operating time is decreased; bleeding volume is lowered; it may lower the risk of graft infection, since endovascular and imaging manoeuvres are not performed in front of an open chest. Considering our encouraging results, we have decided in our department to extend the use of total arch transposition to HRP with acute type A aortic dissection. We are combining the replacement of the ascending aorta with the transposition of the IA to the ascending aortic graft. This allows secondary arch coverage for recalcitrant dissection.

The future of this challenging approach is dependent on whether the endografting technology will be reliable or not. Improvement of stent-grafting is needed in terms of flexibility to improve aortic arch navigation and reduce the embolic risk. Our experience started with the Talent® endograft, but we required several devices to cover the whole diseased aortic portion. Thereby, we moved to longer endografts such as TAG®, Zenith® TX1 and recently the Valiant®. Longer endografts of at least 20 cm long allow a one piece coverage of the arch, thus avoiding the trombone technique, which frequently leads to endoleaks. Indeed, we believe that overlap between endografts increases the risk of device migration and of type 3 endoleaks. Furthermore, newly developed endografts allow an easy deployment. Keys for success are the selection of the best device and selection and management of the landing zone. Ideally, the more flexible devices such as TAG® are preferred to treat dissections. Since, this graft was discontinued, we have been using the tapered LeMaitre Vascular Endofit® device, which appears more adapted to treat chronic dissections.

In conclusion, we report mid-term results of a staged hybrid treatment of aortic arch aneurysm and dissection, including the first surgical transposition of supra-aortic carotid arteries followed by an endovascular procedure. Transposition of great vessels is safe although neurological complications may occur after secondary endograft deployment. Combined treatment for HRP offers as good results as conventional surgery for low risk patients. Total arch transposition may be safer than hemi-arch transposition, allowing a better PLZ. Since, our results are encouraging, they allow vascular surgeons to treat HRP with aortic arch diseases. Nevertheless, meticulous technique is mandatory in order to avoid embolic complications, ascending aorta dissection or myocardial perforation due to guide wires. The long-term results of this technique are awaited.

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References


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