Aortic arch aneurysm: short- and mid-term results comparing open arch surgery and the hybrid procedure

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INTRODUCTION

Aortic arch aneurysms are conventionally treated by open surgery using cardiopulmonary bypass (CPB) and cerebral protection measures involving hypothermia with or without selective cerebral perfusion (SCP) [1]. This complex surgery is associated with a high risk of mortality and central neurological injuries. Pre- and postoperative care improvements have now lowered the incidence of these complications but in parallel, hybrid arch procedures have emerged. Nowadays, very little data are available about their mid-term results compared with open surgery.

METHODS: From January 2002 to January 2014, 46 patients had treatment for an exclusive aortic arch aneurysm including 25 open arch surgeries and 21 type I hybrid arch procedures in our institution. All cases involved arch aneurysms involving at least one carotid artery (Zone 0 and Zone 1). Aneurysms of the distal arch and descending aorta were excluded (Zone 2 and beyond). Results from a retrospective database are reported. There were no patients lost to the follow-up.

RESULTS: There was no significant difference in preoperative comorbidities between the two groups. The incidence of in-hospital mortality was similar at 20% (5/25) for open surgery and 19% (4/21) for hybrid procedure (P = 0.830). The incidence of permanent cerebral neurological deficit was comparable at 17.4% (4/23) for open surgery and 21.1% (4/19) for hybrid procedure (P = 1). Median survival was 109.5 months for open surgery and 56.3 months for hybrid procedure. Freedom from all-cause mortality was 78, 63, 57% at 1, 3, 5 and 7 years, respectively in the open surgical group. Freedom from all-cause mortality was 78, 63, 56.3 months for hybrid procedure. Survival rates and incidence of major adverse cardiac and cerebro-vascular event between open surgery and hybrid procedure were not statistically different (P = 0.530 and P = 0.325, respectively). However, incidence of reintervention was in favour of open surgery [14.5 vs 44.8% at 7 years, P = 0.045; 95% confidence interval: (0.06–0.97)].

CONCLUSIONS: The type I hybrid arch procedure fails to demonstrate better results compared with open surgery, regarding morbi-mortality at the short- and mid-term follow-up. Moreover, it increases the risk of reintervention. Patients treated by this technique must undergo a closer follow-up because of this risk. Larger randomized studies are needed to better define the exact indications of this therapy.

Keywords: Aortic arch • Thoracic aortic aneurysm • Surgical procedure • Endovascular procedure • Hybrid procedure

In this context, use of innovative endovascular procedures appear to be a less invasive alternative. Hybrid surgery, associated with an extra-anatomical bypass of the supra-aortic trunks without using CPB and the use of a covered stent, was first described in 1998 by Buth et al. [7]. Since that first report, several retrospective institutional series have been published, and recent reviews present quite similar postoperative results as those obtained with open surgery [8, 9]. Concerning mid-term results, very little data are available and the longest median survival published up to date is about 3 years [10–13]. Some papers report results of series comparing open surgery with hybrid approaches in order to determine the best management for patients suffering from aortic arch aneurysms but only short-term results are available [14, 15].
The aim of this study is to compare the postoperative and mid-term outcomes of open arch surgery with that of the type I hybrid procedure, for aortic arch aneurysms involving at least one carotid artery.

**MATERIALS AND METHODS**

**Patient characteristics**

From January 2002 to January 2014, we identified 25 patients with aortic arch aneurysms exclusively involving the aortic arch with at least one carotid artery (Zone 0 and Zone 1) treated in our institution. In order to compare two homogenous groups, this study excluded aortic arch aneurysms involving ascending aorta, isolated aneurysms of the distal arch or descending aorta (Zone 2 and beyond), acute aortic dissection, infectious aneurysms (contra-indicated for hybrid procedure) and thoracic aortic embolicigenic atherosclerotic plaques. Since 2002, a multidisciplinary team (involving cardiologists, heart and vascular surgeons, interventional radiologists and anaesthesiologists) screened all patients referred for surgery. The decision was made in accordance with anatomical criteria and patients’ information and consent. The hybrid procedure was only proposed when an adequate proximal landing zone and proper vascular access were present based on preoperative computed tomography (CT) scans.

Preoperative patient characteristics are summarized in Table 1.

**Open arch surgery cohort.** From 2002 to 2014, 25 patients including 1 urgent case were treated by conventional surgery for isolated aortic arch aneurysm in our institution. The mean age of patients was 62.4 ±13 years. Aetiologies were represented by atherosclerotic aneurysm in 13 patients (52%) and chronic dissection in 6 patients (24%). Other causes included 3 post-traumatic (12%), 3 congenital (12%) aortic arch aneurysms. Mean preoperative maximum aortic diameter was 74.9 ± 12 mm.

**Hybrid type I arch procedure cohort.** During the same period, 21 patients including 3 urgent cases were treated for the same pathology. The mean age of patients was 69 ± 9 years. Aetiologies were represented by atherosclerotic aneurysm in 10 patients (47.6%) and chronic dissection in 8 patients (38%). Other causes included 2 post-traumatic (9.6%) and 1 congenital (4.8%) aortic arch aneurysm. Mean preoperative maximum aortic diameter was 69.6 ± 13 cm. All data for hybrid approach follow the recommendations made in 2009 by Turina et al. [16]. The follow-up was achieved by 1-, 3-, 6- and 12-month CT scans, which was continued annually thereafter.

**Surgical techniques**

**Open arch surgery.** Three different surgical techniques were used depending on the localization and the type of aortic arch aneurysm:

1. Total arch replacement with complete revascularization of the supra-aortic trunks was used in 16 patients (64%) presenting with a Zone 0 fusiform aneurysm in 11 cases, a false aneurysm in 4 cases and a saccular aneurysm in 1 case.
2. Patch repair was used in 5 patients (20%) presenting with a Zone 0 or 1 false aneurysm in 2 cases or a saccular aneurysm in 3 cases.
3. The distal hemiarch technique via left thoracotomy and infra left carotid oblique aortic arch cross-clamping was used in 4 patients (16%) all presenting with a Zone 1 fusiform aneurysm.

Cerebral protection was achieved using three different techniques:

1. Deep hypothermia and circulatory arrest (11/25; 44%) using ascending aortic cannulation. Mean circulatory arrest time was 40 min at 18°C.
2. Anterograde cerebral perfusion (involving axillary or selective carotid cannulation) associated with mild hypothermia and a period of circulatory arrest (8/25; 32%). Mean perfusion temperature during the arrest time was 22°C and mean circulatory arrest time was 27 min.
3. Anterograde cerebral perfusion using ascending aortic cannulation with moderate hypothermia at 32°C without circulatory arrest (6/25; 24%).

Mean myocardial ischaemia time under cold blood cardioplegia was 76 ± 37 min and mean total CPB time was 172 ± 32 min. Body temperature was controlled via oesophagus and bladder sensors.

**Type I hybrid procedure.** Two different extra-anatomical bypass procedures were used depending on the location of the proximal landing zone. All extra-anatomical bypasses were made without using CPB:

- Landing Zone 0: Debranching procedure was achieved by median sternotomy in 17 patients (80%). All reconstructions were performed by using an aortic bi-carotid extra-anatomical bypass and a stent covering all supra-aortic trunks. Mean...
endovascular diameter was 38.3 ± 3.8 cm and mean coverage length was 179 ± 55.9 cm.
- Landing Zone 1: this technique was used in 4 patients (20%). It consisted in creating an inter-carotid extra-anatomical bypass followed by covering the left carotid artery and beyond. Mean endovascular diameter was 39.5 ± 1.9 cm and mean coverage length was 120 ± 24.5 cm.

Most of the procedure (71.4%) was made metachronously with an average time of 31 days between the extra-anatomical bypass and the endovascular procedure. All stent grafts were deployed by a retrograde iliofemoral approach but one by transaortic approach. Endovascular devices used in the study were as follows: 8 Valiant®, 2 Talent® and 1 Captiva® endoprostheses (Medtronic, Inc. Minneapolis, MN, USA); 3 TAG® endoprostheses (WL Gore and Associates, Inc., Newark, DE, USA); 1 Proform-TX2® and 1 Zenith® endoprostheses (Cook Medical, Inc., Bloomington, IN, USA) and 4 Relay® endoprostheses (Bolton Medical, Inc., Sunrise, FL, USA).

Data definitions

Preoperative data were collected from patients’ medical history: stroke (defined as permanent neurological deficit associated with an abnormal neurological imaging), heart failure (left ventricular ejection fraction (LVEF) < 50%), prior myocardial infarction, history of coronary artery intervention (sten or bypass grafting), chronic renal failure (creatinine clearance <60 ml/min) and chronic obstructive pulmonary disease [forced expiratory volume in one second (FEV1)/forced vital capacity (FVC) < 70% or patient receiving chronic bronchodilator therapy]. For risk assessment, we used the ‘EuroSCORE II’ available at http://www.euroscore.org/calc.html.

For postoperative results, respiratory insufficiency was defined as a prolonged intubation time (over 48 h); pneumonia as conjunction of abnormal chest radiography associated with positive bacteriological analysis, acute renal failure was defined as the need for haemodialysis. Myocardial infarction was defined as the need of all kinds of surgical or endovascular reintervention. Endoleak was defined as the need for reintervention due to anatomical considerations. One procedure was not completed because the CT scan after the extra-anatomical bypass showed an aortic dissection contraindicating the endovascular second step.

Finally, MACCE (major adverse cardiac and cerebro-vascular event) was a composite criterion including myocardial infarction, stroke and death related to the arch aneurysm. Reintervention was defined as the need of all kinds of surgical or endovascular reintervention after hospital discharge in order to manage complications related to the initial procedure.

Statistical analysis

Comparative statistical analysis was conducted using the Prism version 6 software (GraphPad Software, Inc., CA, USA). Quantitative data were expressed by mean and standard error of the mean deviation and compared by a Student t-test with Welch’s correction. Quantitative data are expressed in absolute numbers and percentage. To compare them, when expected numbers were <5, we used Fisher’s exact test and when they were >5, we used χ² test with Yates’ correction. Survival curves were estimated by the Kaplan–Meier method, and were compared using a log-rank (Mantel-Cox) test.

### RESULTS

Patient characteristics

Medical histories and risk assessments by EuroSCORE II did not differ statistically in both groups (hybrid and conventional). Results showed that patients treated were mostly overweight and hypertensive men, older than 60 years old (Table 1). About one-third of them suffered from chronic renal failure and chronic obstructive pulmonary disease. One-quarter of them had previous ischaemic heart disease. Moreover, ~40% of the patients had already undergone surgery of the thoracic aorta, mostly involving the ascending part. The most frequent mode of diagnosis was the follow-up of previously treated aortic pathology. Arch aneurysms were mostly fusiforms and their mean maximum diameters systematically exceeded 60 mm at the time of surgery. Two-third of aetiologies were represented by atheromatous or chronic dissection diseases.

Specific considerations concerning the hybrid procedure

Hybrid procedure success (Table 2) was defined as a successful deployment of the endoprosthesis without postoperative endoleak, which was 70.6% (12/20). Failures were due to 2 early type I endoleaks, 2 early type II endoleaks and 1 unsuccessful delivery of the stent graft due to anatomical considerations. One procedure was not completed because the CT scan after the extra-anatomical bypass showed an aortic dissection contraindicating the endovascular second step.

During the follow-up, 2 late type I endoleaks appeared at 3.2 and 4.7 months after surgery. Vascular access problem happened in 2 cases; one patient needed an interfemoral bypass and the other one needed an iliofemoral bypass.

### Postoperative and in-hospital morbidity and mortality

Intra-operative mortality reached 8% (2/25) in the open surgery group and 9.5% (2/21) in the hybrid group. In-hospital mortality reached 20% (5/25) in the open surgery group and 19% (4/21) in the hybrid group. Results did not statistically differ between the two groups (Table 3). Intraoperative death included one massive haemoptysis and 1 distal arch massive leak in the surgical group. In the hybrid group, 2 deaths were related to haemorrhagic
shocks during the endoprosthesis deployment. In-hospital mortality in the surgical group was due to two massive strokes at postoperative day (POD) 3 and POD 11 and one multiorgan failure at POD 15 of a massive stroke. In the hybrid group, 2 patients died from an aortic rupture or fistula, 3 other patients presented a myocardial infarction and 2 presented a stroke in the postoperative period. In the hybrid group, in addition to the 3 patients mentioned above who died from an aortic rupture or fistula, 3 other patients presented a myocardial infarction and 2 presented a stroke in the postoperative period. In the hybrid group, 1 had a heart attack at 7 months and 1 died after a reintervention at 25 months.

Overall rates of reinterventions for open surgery compared with hybrid technique (Fig. 3) at 1, 3, 5 and 7 years were respectively 5% (±4.9) vs 18% (±9.5), 5% (±4.9) vs 33.6% (±12.7), 5% (±4.9) vs 33.6% (±14.6) and 14.5% (±10) vs 44.8% (±14.6). Results showed a significant difference in favour of open surgery [P = 0.045, 95% CI: (0.06–0.97)]. In the open group, 1 patient needed a reintervention for a distal false anastomotic aneurysm at 2 months and 1 needed thoracic endovascular aortic repair (TEVAR) at 70 months in the descending aorta for a type B dissection. In the hybrid group, 6 patients needed reintervention. One for bronchial fistula at 2 months, 1 for type I endoleak at 9 months, 1 for type II endoleak at 21 months and 2 needed TEVAR for type B aortic dissection at 14 and 51 months. One needed surgery for acute aortic type A dissection discovered on the CT scan 1 week after the extra-anatomical bypass with an uneventful follow-up.

**DISCUSSION**

The main objective of this report was to compare the short and mid-term results of classic surgery versus hybrid approach in exclusive aortic arch aneurysms. The overall rates of in-hospital stroke (17.4 vs 21.1%) and mortality (20 vs 19%) between the two techniques showed no significant difference. Mid-term results showed significant lower rate of reinterventions in open surgery patients at 7 years (14.5 vs 44.8%, P = 0.045).

Results in the literature for open surgery showed an in-hospital mortality rate between 6 and 20% and a postoperative stroke rate
Figure 1: Short and mid-term results: mortality. NOPAR: number of patients at risk.

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<td>Mean (SEM)</td>
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<td>Mean (SEM)</td>
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Figure 2: Short and mid-term results: MACCE. NOPAR: number of patients at risk; MACCE: major adverse cardiac and cerebro-vascular event.
between 8 and 15\% [2–6]. The use of SCP induces a significant lower rate of postoperative stroke independently from the length of SCP [6, 17]. Almost all of the cited studies used SCP, which is nowadays a recommendation (‘class IIa level of proof B’) [1], whereas in our study, only half of the patients benefited from SCP. Also in our study, 44\% of the patients in the surgical group had previous thoracic aortic surgery including 24\% of type A dissection (5.7 to 24.2\% in cited studies [2–6]), inducing a high rate of in-hospital reoperation for bleeding and blood transfusion. Redo thoracic aortic surgery is also an independent factor for higher rate of in-hospital mortality and stroke and more specifically after surgery for type A aortic dissection [6, 18].

Results in the literature for hybrid approach depend on two major factors: the level of emergency surgery and the landing zone for the prosthesis. In our study, 28.7\% of the patients were symptomatic and 14.3\% were urgent cases. In numerous published series, the proportion of emergencies is zero or not clearly described. In a series where it is clearly described [10, 19, 20], it can reach one-third of the patients inducing higher rates of in-hospital mortality varying between 19 and 24\% (17.6\% in our study). Urgent surgery is known as an independent factor for in-hospital mortality [10]. The landing zone is also an important factor, a recent meta-analysis shows a 2-fold increased mortality for implantation in Zone 0 versus in Zone 1 (15.1 vs 7.6\%) [9]. In our study, 81\% (17/21) of our procedures were in Zone 0 and all in-hospital deaths of this group were attributed to this procedure.

Mid-term results in mortality for the hybrid group (55\% at 3 years and 46\% at 5 years) are consistent with other published papers. They report, with a mean follow-up of 30 months, a survival rate of 60\% at 3 years [10–12] and 48\% at 5 years [11, 13]. In our study, results at 7 years show a late fall in survival after the fifth year, which is correlated with the rise of MACCEs (all were related to ruptured aneurysms). Moreover, rate of reinterventions in the hybrid group is 37\% at 3 years, rising up to 45\% at 5 years, and is statistically higher than in the open group (5\% at 5 years). These results are comparable with other studies at 27.6\% at 3 years [10] but much higher than the other group reaching 13\% [12] at 5 years. It underlines the need for strict presurgical selection based on anatomical criteria and regular imaging during the follow-up in the hybrid group in order to prevent lethal complications.

Finally and more generally, recent papers trying to compare outcomes between the two approaches on aortic arch pathologies are struggling to find any difference in terms of morbidity and mortality at postoperative and 2 years of the follow-up [14, 15]. The only factor identified is an age older than 75 years that appears to increase postoperative mortality in the open surgical group [14]. Since there is a multitude of possible operative approaches, results are difficult to compare. For example, some teams do not perform Zone 1 proximal landing to reduce the risk of endoleak [11] whereas their surgical group is mainly treated by complete arch resection [14]. To minimize this bias, our study was based on an anatomical criterion involving exclusively the transverse part of the thoracic aorta and at least one carotid artery, for both techniques.

To our knowledge, this is the longest report of hybrid arch repair. However, this is a retrospective study with a small cohort of patients analysed during a long study period. Hence, we cannot give intention-to-treat results. Moreover, two causes of death in the open surgical group are unknown, but attributed to the aortic aneurysm in the analysis. Finally, because of the small prevalence of this pathology, patients are rare and results are hardly
endoprostheses. Randomized studies are challenging to design due to ethical concerns and less late death related to the aneurysm. Larger studies are expected, and must be compared with the gold standard represented by open surgery. Our follow-up because of the risk of reintervention. Nowadays, long-term results of this technique are expected, and must be compared with the gold standard represented by open surgery. Our paper suggests that there is no difference in short-term complications, but that open surgery has still more durable results with less reinterventions and less late death related to the aneurysm. Larger randomized studies are challenging to design due to ethical considerations and new technologies are arising, such as branched endoprostheses.

Conflict of interest: None declared.

REFERENCES


