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Open thoracoabdominal aortic aneurysm repair in the modern era: results from a 20-year single-centre experience

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Abstract

OBJECTIVES: The efficacy and durability of actual treatments (open, endovascular and hybrid) for thoracoabdominal aortic aneurysm (TAAA) repair are not yet completely defined. Open surgical repair using a multi-adjunct (ADJ) approach has been the standard of care for many years and may still be an effective treatment option. This study aimed to assess the outcomes of open TAAA repair since the introduction of the available ADJ.

METHODS: From 1994 to 2014, 542 consecutive patients underwent open TAAA repair in our institution, routinely receiving aortic distal perfusion and the other ADJ (either for visceral and spinal cord protection). The aetiology of TAAA was identified to be degenerative in 325 (60%) patients and chronic post-dissection in 160 (29.5%) patients. Other causes such as connective tissue disorders, vasculitis and infective aneurysms were less represented (10.5%). Extensive type I and II repair was required in 128 (23.6%) and 285 (52.6%) patients, respectively. All patients were followed up at 3 and 6 months after surgery and yearly thereafter using computed tomography angiogram.

RESULTS: The overall 30-day mortality and paraplegia rates were 8.5 and 4.2%, respectively. Age [odds ratio (OR) 1.07 per year, 95% confidence interval (CI) 1.02–1.13], female gender (OR 2.52, 95% CI 1.27–4.99), urgency (OR 2.78, 95% CI 1.12–6.20) and emergency (OR 3.81, 95% CI 1.00–11.50) emerged as independent risk factors for 30-day mortality. Follow-up was 100% complete (mean 6.32 years). Overall 1-, 5- and 10-year survival was 85.9 ± 1.5, 74.2 ± 2.0 and 61.6 ± 2.5%, respectively. The extent of surgical repair did not significantly influence late hospital death ($P = 0.56$). For patients surviving the first 30 days, a degenerative aneurysm aetiology negatively impaired long-term survival compared with the other diseases [hazard ratio = 1.66; 95% CI (1.13–2.44)]. Five- and 10-year freedom from reoperation was 86.3 ± 1.8 and 80.7 ± 2.3%, respectively, and 8.5% of patients required aortic reinterventions.

CONCLUSIONS: In elective cases, open TAAA repair has to be considered an effective option associated with low necessity of reoperation at follow-up. The extent of aortic resection did not affect long-term mortality. Conversely, survival was mainly determined by patient age and preoperative condition.

Keywords: Thoracoabdominal aortic aneurysm • Spinal cord ischaemia • Aneurysm • Endovascular aortic repair

INTRODUCTION

Despite many advances in surgical and perioperative care, thoracoabdominal aortic aneurysm (TAAA) continues to be a challenging and complex disease. Main reasons are diffuse extension of the aortic pathology and hence, multiorgan involvement. Until recently, open surgical repair was the only true option for these patients, but recent innovations in the field of endovascular aortic repair may prove to be a valid alternative in a subset of patients [1–3]. Contemporary treatment options are therefore open surgical resection, endovascular stent-graft implantation or a combination of both (i.e. hybrid approach).

The introduction of several important adjuncts (ADJs) in TAAA repairs has improved surgical results considerably [4–9]. Protective measures consist of distal aortic perfusion by left heart bypass, moderate hypothermia, cerebrospinal fluid drainage (CSFD), selective visceral perfusion, renal cooling and evoked potential monitoring (EPs). Nevertheless, open surgical repair remains associated with considerable mortality and morbidity especially in case of extensive repair [6–9]. This has encouraged the use of less invasive endovascular procedures as a single or partial therapeutic option in hybrid techniques [10–13]. Despite all this, nowadays, no randomized trials exist for open surgery versus branched and/or fenestrated thoracic endovascular aortic repair (TEVAR) and current evidence relies on non-randomized comparisons and meta-analyses [10]. Our approach in over 800 cases of open thoracic and thoracoabdominal aortic repairs has changed over the years accordingly. Following our first case in 1981, since 1994 however, all ADJ approaches proven to reduce visceral and spinal cord ischaemia have been adopted and implemented in our routine. The purpose of this study is to report the results of a 20-year single-centre experience using this contemporary approach to set a benchmark for recent and future alternative approaches to TAAA repair.

MATERIALS AND METHODS

Patient population and definitions

Between March 1994 and May 2014, 542 consecutive patients underwent TAAA repair using aortic distal perfusion and all the other proven contributing ADJ approaches (either for visceral or spinal cord protection) at the St Antonius Hospital in Nieuwegein, Netherlands. Our surgical experience in TAAA surgery started in 1981 but patients operated on before 1994 ($n = 186$) were excluded because the surgical technique was not uniform [14, 15]. We defined emergent procedures as those with aneurysm rupture and clinically haemodynamic instability. Severe symptomatic patients (attributed to vital organ compression or fistulization) eventually associated with haemodynamically stable contained rupture were considered to have urgent procedures. Aneurysmal extent was classified according to Crawford *et al.* [12] and Safi and Miller [16]. Aneurysms limited to the descending thoracic aorta, since 1997 mostly treated by endovascular repair, were not considered in this analysis. Patient demographics are listed in Table 1. Operative indications for aneurysm surgical repair were given according to aortic diameter and clinical presentation. All ruptured and severe symptomatic TAAAs were operated on immediately, regardless of size, if the general condition of the patient allowed it. Since the majority of patients were asymptomatic, a maximal aneurysmal diameter >60 mm was the commonly used criterion to intervene in order to prevent rupture. Aortic diameters smaller than 60 mm (≥55 mm) were replaced to patients with connective tissue disorders.

Paraplegia or paraparesis was categorized as spinal cord deficit, either immediate (upon awakening) or delayed (with a symptom-free interval). In case of unilateral lower extremity deficit with an associated deficit of the ipsilateral arm, a central nervous problem was diagnosed. All patients were followed up in our own outpatient clinic at 3 and 6 months after surgery and yearly thereafter using computed tomography angiography scanning. Preoperative, intraoperative and postoperative data were collected through a hospital database, patients' medical records and contact with the referring physician or general practitioner. The follow-up period ended on 1 July 2014. The study was approved by an institutional review board and did not require individual patient consent.

Surgical techniques

Our standard operative technique has been described in detail previously [7, 17]. Adjuncts for visceral organ protection and prevention of spinal cord ischaemia were routinely used in all the procedures. In brief, the left hemidiaphragm was divided circumferentially keeping a rim of ~1.5 cm of diaphragmatic tissue on the chest wall (to facilitate closure), and the aorta was exposed using median rotation of the viscera (either transperitoneally or, preferably using the retroperitoneal route). Distal aortic perfusion was established by left heart bypass using a centrifugal pump in 473 patients (87.3%). Extracorporeal circulation with deep hypothermic circulatory arrest was used only occasionally, mostly when proximal clamping distal to the left common carotid artery was not deemed feasible or when the aneurysm was so large that a safe entry in the thorax was judged unsafe (69 patients). For left heart bypass, the inflow for the centrifugal pump (BioMedicus, Minneapolis, MN, USA) was obtained by cannulating the left atrium through the left pulmonary vein, which in our experience causes less rhythm disturbances and is easier to control in contrast to the left atrial appendage. Arterial outflow was established through the left common femoral artery or (rarely) the distal aorta. The mean proximal arterial pressure was kept continuously above 80 mmHg by regulating vasopressors and intravascular volume, and the distal perfusion pressure (measured in the right groin) above 70 mmHg.

In all extensive aneurysm repairs, a sequential clamping technique was used in a cranio-caudal fashion. This allowed the viscera as well as important lower segmental arteries to be perfused from below during construction of the proximal anastomosis (lowering visceral and the spinal cord ischaemic time). Patent intercostal and lumbar arteries between T8 and L2 were directly reattached to the graft (440/542 patients) through an oval, circular or square opening (occasionally via an interposed 6–8 mm Dacron tube when direct reimplantation was technically impossible). CSFD and EPs were used in 471 (86.7%) and 502 (92.6%) patients, respectively. Since 1994, both somatosensory and transcranial motor EPs have been routinely used in every elective patient. Contraindications for EPs

Table 1: Patient demographics and indications for surgery ($n = 542$)

Variable	Overall (%)
Age (years, mean ± SD)	65.0 ± 10.5
Male (%)	292 (53.9)
Hypertension (%)	490 (90.4)
Myocardial infarction (%)	90 (16.7)
COPD (%)	114 (21)
Left ventricle ejection fraction (≤30)	10 (1.8)
Cerebral vascular accident (%)	46 (8.5)
Serum creatinine (≥150 μM/l)	48 (8.9)
Diabetes (%)	30 (5.5)
Previous arch intervention	117 (21.6)
Previous TAA intervention including ET	95 (17.5)
Previous AAA intervention	102 (18.8)
Emergent/urgent procedure	64 (12)
Rupture	48 (8.9)
Aortic disease	
Degenerative chronic aneurysm	325 (60)
Chronic dissection	160 (29.5)
Connective tissue disorder	37 (6.8)
Inflammatory	17 (3.1)
Infective	3 (0.6)

COPD: chronic obstructive pulmonary disease; TAA: thoracic aortic aneurysm; ET: elephant trunk; AAA: abdominal aortic aneurysm; SD: standard deviation.

AORTIC SURGERY

were known neuromuscular disorders of any kind, epilepsy and implanted pacemaker or cardiac defibrillator. A neurophysiologist telemonitored EPs throughout surgery. During the aortic repair, the left heart bypass circuit was used to provide selective perfusion to the coeliac and superior mesenteric arteries, whereas the renal arteries were intermittently perfused (every 30 min) with cold (4°C) ringer's acetate with mannitol and methylprednisolone solution. Finally, the graft was anastomosed above, on or beyond the aortic bifurcation, if necessary the left heart bypass was temporarily stopped in order to make an open distal anastomosis. Occasionally, an aorto mono- or bi-iliac or aorto mono- or bifemoral prosthesis was used. At the end of the procedure following rewarming (rectal temperature of 34 °C), bypass was discontinued and the circuit was emptied through the left atrial cannula. Finally, the cleaned aneurysmal sac was closed over the prosthesis to promote haemostasis and to protect the overlying lung from injury.

Statistical analysis

Continuous variables were expressed as mean ± 1 standard deviation and compared between two groups by the unpaired two-tailed *t*-test. Categorical variables were presented as percentages and compared between two groups by the χ^2 test or Fisher's exact test when an expected cell count was <5. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. For the multivariable logistic regression model for the prediction of the hospital mortality, we took a clinically hierarchical approach, where we first assessed all preoperative variables based on univariable *P*-value ($P < 0.20$) but also on clinical significance (e.g. age and gender take precedence). Subsequently, we added intraoperative variables, trying to avoid over-fitting. Survival curves and freedom from aortic reoperation were estimated for all the survived patients to the first 30 days, at 1-, 3-, 5- and 10 years using the Kaplan–Meier method. Univariable analysis was based on the log-rank test. Besides the reporting of unconditional long-term results, we explicitly looked at long-term survival conditional upon surviving the first 30 days and in hospital period, because we wanted to make a distinction between factors related to the procedure and long-term factors. Independent predictors of long-term survival conditional were determined with Cox proportional hazard analysis. We tested the proportional hazards assumption of the Cox regression models by means of the Grambsch–Therneau test and visual inspection of smoothed scaled Schoenfeld residual plots. No deviations from the proportional hazards assumption were found. Statistical analysis was carried out using 'survival' package for the R system (version 2.38-2. http://www.r-project.org) [18].

RESULTS

Early outcomes

Patients' demographics are listed in Table 1. The patients' age ranged from 16 to 89 years (mean: 65 years), and 292 were men (53.9%). The cause of TAAA was degenerative in 325 patients (60%), chronic post-dissection in 160 (29.5%), due to a connective tissue disorder in 37 patients (6.8%), vasculitis in 17 patients (3.1%) and mycotic in 3 patients (0.6%). A contained rupture was present in 48 patients at the time of surgery (8.9%), associated with severe back pain, haemodynamic collapse or haemothorax in 31 (5.7%), 5 (0.9%) and 12 (2.2%) of all patients, respectively. Forty-six patients were being treated urgently (8.5%) and 18 patients in emergency (3.3%).

Aneurysmal extent was as follows: 23.6% Type I (n = 128), 52.6% Type II (n = 285), 11.4% Type III (n = 62), 8.9% Type IV (n = 48) and 3.5% Type V (n = 19). Permanent paraplegia occurred in 23 patients (4.2%). Paraparesis was noted in 9 additional patients (1.7%). Furthermore, overall perioperative stroke occurred in 23 patients (4.2%). Major postoperative complications according to each type of TAAA repair are listed in Table 2.

Early mortality

Overall 30-day mortality (defined as death occurring within 30 days of surgery) was 8.5% (46 patients). In-hospital 30-day mortality was 8.1% (44/542). Fifty-nine patients (10.9%) died during their initial hospitalization (overall in-hospital mortality). The causes of death (listed in Table 2 according to the type of aneurysm repair) were cardiac or aorta related in 12 (2.2%), multiorgan failure in 22

Table 2: In-hospital outcomes after open TAAA repair according to extent of repair

Variable	Type I (n = 128)	Type II (n = 285)	Type III (n = 62)	Type IV (n = 48)	Type V (n = 19)	Overall (n = 542)
Overall hospital mortality (%)	12 (9.4)	37 (13)	5 (8.1)	3 (6.3)	2 (10.5)	59 (10.9)
Cardiovascular-related	3 (2.3)	9 (3.2)	–	–	–	
MOF	6 (4.7)	11 (3.9)	2 (3.2)	2 (4.2)	1 (5.3)	
Gastrointestinal	1 (0.8)	4 (1.4)	1 (1.6)	–	–	
Respiratory failure	1 (0.8)	5 (1.8)	–	1 (2.1)	1 (5.3)	
Neurological	–	6 (2.1)	1 (1.6)	–	–	
Intraoperative mortality	1 (0.8)	2 (0.7)	1 (1.6)	–	–	
Permanent spinal cord deficits (%)	7 (5.5)	21 (7.4)	3 (4.8)	–	1 (5.3)	32 (5.9)
Paraplegia	6 (4.7)	14 (4.9)	3 (4.8)	–	–	
Paraparesis	1 (0.8)	7 (2.5)	–	–	1 (5.3)	
Stroke (%)	2 (1.6)	18 (6.3)	1 (1.6)	2 (4.2)	–	23 (4.2)
AKI necessitating haemodialysis (%)	3 (2.3)	15 (5.3)	3 (4.8)	2 (4.2)	–	23 (4.2)
Acute myocardial infarction (%)	5 (3.9)	8 (2.8)	–	–	–	13 (2.4)
Tracheostomy (%)	9 (7)	31 (10.9)	1 (1.6)	1 (2.1)	–	42 (7.7)

TAA: thoracic aortic aneurysm; MOF: multiorgan failure; AKI: acute kidney injury.

(4.1%), respiratory failure in 8 (1.5%), neurological in 7 (1.3%) and intestinal ischaemia in 6 (1.1%) patients. Four patients (0.7%) died intraoperatively due to either uncontrollable bleeding (2 emergent patients, both for ruptured aneurysms) or poor preoperative medical status (either cardiogenic shock or diffuse aortic disease involving all ostia of the visceral arteries) in the other 2 patients. Table 3 depicts the univariable preoperative risk factors for 30-day mortality.

Multivariable regression showed independent risk factors for 30-day hospital mortality: age (OR 1.07 per year, 95% CI 1.02–1.13), female gender (OR 2.52, 95% CI 1.27–4.99), urgency (OR 2.78, 95% CI 1.12–6.20) and emergency (OR 3.81, 95% CI 1.00–11.50) compared with elective. Type II extent repair did not show statistical significant difference in early survival compared with the other TAAA repairs (P = 0.71). Also, none of the intraoperative variables analysed (various ADJs such as cold renal perfusion, endarterectomy of the renal arteries, whether or not intercostal arteries reimplanted etc.) proved to be significantly related to in-hospital mortality (all P > 0.20).

Long-term results

Follow-up was 100% complete with a mean duration of 6.3 ± 5.7 years (range: 0–20.3 years, 3429 patient-per year). One hundred and twenty-six (25.7%) patients died after 30 days of hospitalization

Table 3: Preoperative risk factors for 30-day mortality in the overall population

Variable	Survived 30 days (*n* = 496)	Deceased 30 days (*n* = 46)	Odds ratio [95% CI]	*P*-value
Age (years; mean SD)	64.5 (10.7)	69.9 (7.1)	1.08 [1.03; 1.13]	0.001
Female	220 (44.4%)	30 (65.2%)	2.34 [1.26; 4.52]	0.007
Arterial hypertension	448 (90.3%)	42 (91.3%)	1.09 [0.41; 3.83]	0.876
Myocardial infarction	78 (15.8%)	12 (27.3%)	2.02 [0.96; 4.01]	0.065
CABG	63 (12.8%)	5 (11.4%)	0.90 [0.30; 2.19]	0.830
PTCA	36 (7.3%)	3 (6.8%)	0.97 [0.22; 2.86]	0.962
LVEF				
>50%	435 (88.1%)	34 (77.3%)	Ref.	Ref.
50–30%	51 (10.3%)	8 (18.2%)	2.03 [0.83; 4.45]	0.115
<50%	8 (1.6%)	2 (4.5%)	3.36 [0.45; 14.4]	0.201
Haemodialysis	1 (0.2%)	0 (0.0%)	0.00 [0.00;]	1.000
Diabetes	24 (4.9%)	6 (13.3%)	3.05 [1.06; 7.54]	0.039
Claudication	16 (3.2%)	2 (4.4%)	1.48 [0.21; 5.50]	0.635
Gastrointestinal disease	21 (4.3%)	2 (4.4%)	1.12 [0.16; 4.02]	0.888
Ascending aorta aneurysm	106 (21.4%)	10 (21.7%)	1.03 [0.47; 2.08]	0.932
Aortic arch aneurysm	85 (17.1%)	6 (13.0%)	0.74 [0.27; 1.69]	0.499
Previous ascending aorta surgery	129 (26.0%)	11 (23.9%)	0.90 [0.42; 1.78]	0.776
Previous aortic arch surgery	110 (22.2%)	7 (15.2%)	0.64 [0.25; 1.40]	0.278
Previous TAA surgery	86 (17.3%)	9 (19.6%)	1.17 [0.51; 2.43]	0.688
Previous AAA surgery	96 (19.4%)	6 (13.0%)	0.64 [0.23; 1.45]	0.302
Concurrent dissection				
No	315 (63.5%)	36 (78.3%)	Ref.	Ref.
Type A	71 (14.3%)	5 (10.9%)	0.63 [0.21; 1.54]	0.335
Type B	110 (22.2%)	5 (10.9%)	0.41 [0.14; 0.98]	0.046
Rupture with pain	25 (5.0%)	6 (13.0%)	2.87 [1.00; 7.05]	0.050
Rupture with haemothorax	7 (1.4%)	5 (10.9%)	8.52 [2.36; 28.5]	0.002
Pain	78 (15.7%)	10 (21.7%)	1.50 [0.68; 3.06]	0.300
Hoarseness	3 (0.6%)	2 (4.3%)	7.58 [0.86; 51.0]	0.065
Dyspnoea	31 (6.2%)	8 (17.4%)	3.19 [1.28; 7.18]	0.015
Marfan syndrome				
No	461 (92.9%)	43 (93.5%)	Ref	Ref
Yes	35 (7.1%)	3 (6.5%)	0.96 [0.22; 2.83]	0.948
Status				
Elective	444 (89.5%)	34 (73.9%)	Ref.	Ref
Urgent	38 (7.7%)	8 (17.4%)	2.78 [1.12; 6.20]	0.029
Emergent	14 (2.8%)	4 (8.7%)	3.81 [1.00; 11.5]	0.049
Status overall				
Elective	444 (89.5%)	34 (73.9%)	Ref	Ref
Urgent/emergent	52 (10.5%)	12 (26.1%)	3.03 [1.42; 6.09]	0.005
Type of TAAA				
1	117 (23.6%)	11 (23.9%)	Ref.	Ref.
2	257 (51.8%)	28 (60.9%)	1.15 [0.57; 2.50]	0.709
3	58 (11.7%)	4 (8.7%)	0.75 [0.19; 2.34]	0.637
4	46 (9.3%)	2 (4.3%)	0.49 [0.07; 1.96]	0.343
5	18 (3.6%)	1 (2.2%)	0.66 [0.03; 3.81]	0.699

CI: confidence interval; Ref: referent; SD: standard deviation; CABG: coronary artery bypass grafting; PTCA: percutaneous coronary balloon angioplasty; LVEF: left ventricular ejection fraction; TAA: descending thoracic aortic aneurysm; AAA: abdominal aortic aneurysm; TAAA: thoracoabdominal aortic aneurysm.

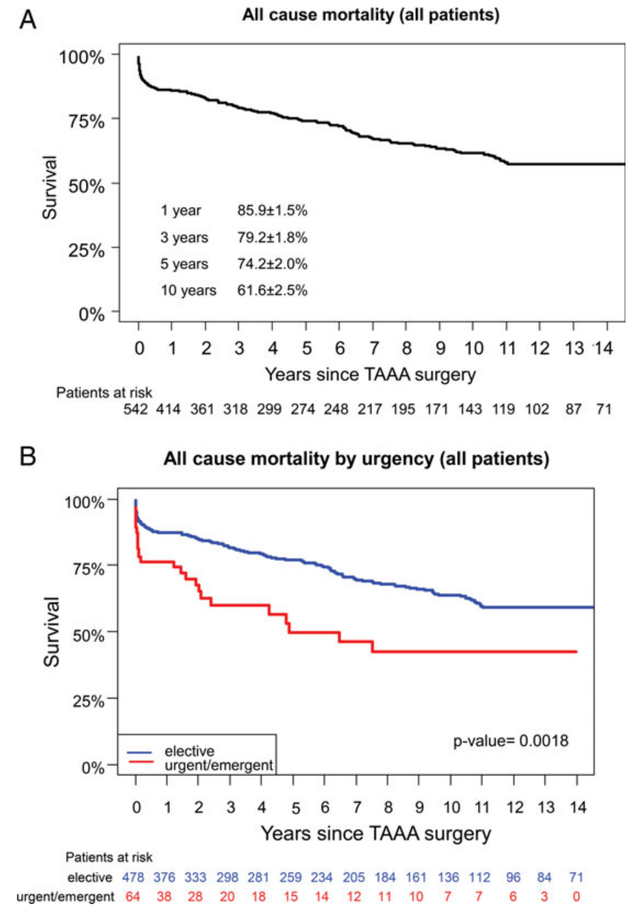

Figure 1: Kaplan–Meier estimate overall survival (A) and elective versus urgent/emergent procedure (B). TAAA: thoracoabdominal aortic aneurysm.

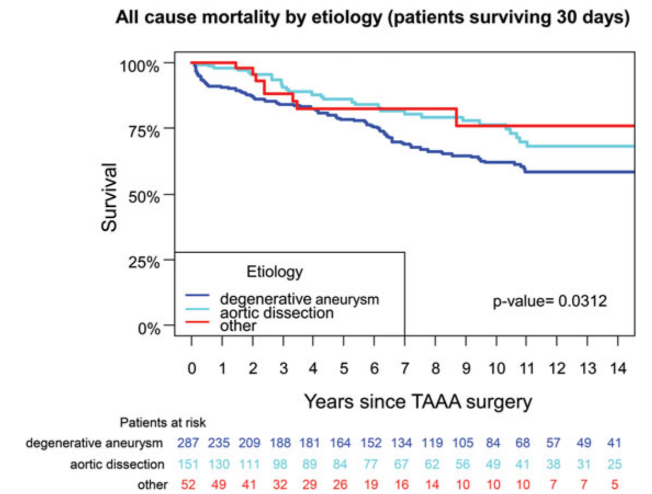

Figure 2: Kaplan–Meier estimate of survival according to underlying aortic disease for patients surviving the first 30 days: degenerative aneurysm, aortic dissection and other aortic pathologies (connective tissue disorders, vasculitis, infection). TAAA: thoracoabdominal aortic aneurysm.

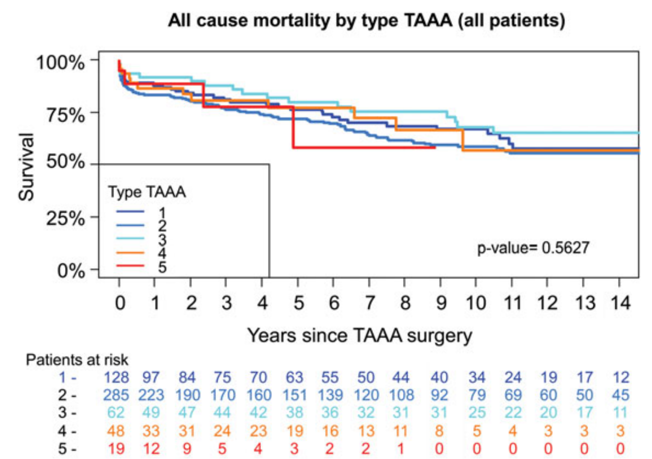

Figure 3: Kaplan–Meier estimate of survival according to the type of TAAA repair. TAAA: thoracoabdominal aortic aneurysm.

during the subsequent long-term follow-up. Kaplan–Meier estimate of survival at 1-, 3-, 5- and 10 years was 85.9 ± 1.5, 79.2 ± 1.8, 74.2 ± 2.0 and 61.6 ± 2.5%, respectively (Fig. 1). Invariably urgent/emergent procedures significantly impaired long-term survival ($P = 0.002$), also for patients surviving the first 30 days ($P = 0.036$). Female gender did not affect long-term survival ($P = 0.93$ and $P = 0.12$ for patients surviving the first 30 days) same as patients with Marfan syndrome surviving hospital discharge ($P = 0.12$).

The presence of a degenerative, atherosclerotic TAAA was a significant negative prognostic factor on long-term survival compared with other causes of aortic disease ($P = 0.003$). As shown in Fig. 2, this was also true for patients surviving the first 30 days ($P = 0.031$). In particular, the hazard of dying when the aetiology was a degenerative atherosclerotic aneurysm was 1.66 times higher compared with the other causes [hazard ratio (HR) = 1.66; 95% CI (1.13–2.44); $P = 0.009$].

Using Cox regression for all patients, age at increments of 1 year [HR = 1.05; CI (1.03–1.07); $P = 0.001$], preoperative acute myocardial infarction [HR = 1.66; CI (1.16–2.26); $P = 0.005$] and urgent procedure [HR = 2.04; CI (1.35–3.10); $P < 0.001$] emerged as independent predictors of late death.

None of the intraoperative variables analysed had a negative impact on long-term survival as well as early outcome (all $P > 0.2$). Figure 3 is showing overall survival according to the type of TAAA surgical repair. For patients surviving the first 30 days, age at increments of 1 year [HR = 1.04; CI (1.02–1.07); $P = 0.001$], preoperative acute myocardial infarction [HR = 1.62; CI (1.07–2.47); $P = 0.024$] and urgent procedure [HR = 1.71; CI (0.99–2.93); $P = 0.053$] were independent predictors of late death.

Freedom from reoperation

After initial surgical TAAA repair, a total of 18 patients (3.3%) required a surgical intervention due to haemothorax, empyema or superficial wound infection. A descending aortic reoperation was performed in 25 patients (4.6% of total), including aneurysmal progression of degenerative aortic disease ($n = 15$), false aneurysm ($n = 7$) or symptoms related to a residual aortic dissection as imminent rupture, renal insufficiency and peripheral arterial disease ($n = 3$). An additional 21 patients (3.9% of total) were reoperated on the proximal aorta (ascending, root and aortic arch) due to progressive aortic dilatation ($n = 16$), or acute type A aortic dissection ($n = 5$).

For reoperation, the adopted strategy was open surgery in 40 patients (87%) and endovascular repair in 6 (13%) patients. In-hospital mortality for all aortic reinterventions was almost double

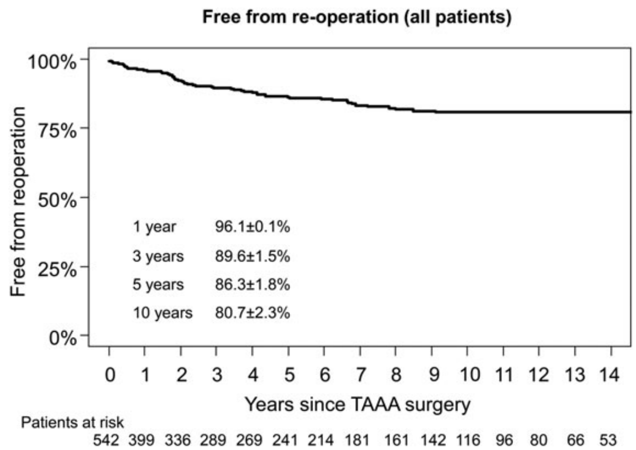

Figure 4: Overall freedom from reoperation. TAAA: thoracoabdominal aortic aneurysm.

compared with the initial TAAA operation (17.4 vs 10.9%). Overall freedom from aortic reintervention at 1-, 3-, 5- and 10 years was 96.1 ± 0.1, 89.6 ± 1.5, 86.3 ± 1.8 and 80.7 ± 2.3%, respectively (Fig. 4).

DISCUSSION

The introduction of a multi-ADJ approach with time has steadily improved the surgical results of open repair for TAAA [6, 9, 17]. Other factors have also contributed to the observed improvement, including advancements in operative techniques and perioperative critical care. Despite these improvements, open surgical repair of TAAA continues to be a complex surgical intervention accompanied by a considerable rate of perioperative complications as well as mortality [6, 17]. As a result, lesser invasive techniques are being widely explored. Apart from technical feasibility and early in-hospital results, long-term durability (in particular for younger patients) including necessity and success rate of redo aortic interventions and survival are important in evaluating these lesser invasive approaches. We reviewed the outcomes of our large single-centre experience in a 20-year period using contemporary adjunctive strategies in open surgical TAAA repair, to serve as a benchmark. This report includes 542 consecutive patients with a 100% complete follow-up.

The observed 30-day mortality for elective TAAA repair was 7.1% (34/478), including aneurysm extent Type II in >50% of all patients. Other large surgical series from experienced American and European centres have shown similar results, like LeMaire *et al*. [9], Safi *et al*. [6] and Greenberg *et al*. [1] reporting 30-day mortality rates of 4.7% in 823 patients, 14% in 1004 patients and 8.3% in 372 patients, respectively. Including our 8.9% urgent and emergent procedures, in-hospital mortality was 10.9%; this was comparable with the endovascular experience of Verhoeven *et al*. [19], reporting 9% in 166 selected patients (including 9% acute cases). Although being more comorbid, one-fourth of their patients (24.8%) were treated for the less extensive extent Type IV (in contrast to only 8.9% in our experience). Undoubtedly, an endovascular approach offers the benefit of aneurysm exclusion without massive surgical invasiveness. It may therefore not only prove to be an alternative treatment option for a subset of patients, but may also increase the total number of patients being amenable for TAAA repair. Anatomical suitability and long-term results together with observed procedural failures add to the current debate about the use of TEVAR for TAAA [10, 11, 20–22]. Scrutiny in patient selection is crucial for success. Our contemporary early- and long-term data on open surgical repair may assist in defining optimal treatment strategy for a given patient.

Frequent mechanisms of endovascular failure are represented by various types of endoleaks, permanent coverage of intercostal and lumbar arteries with a frequent additional left sub-clavian artery occlusion and dramatic consequences like retrograde type A dissection [20–22]. Usually, the need for secondary surgical intervention after an endovascular approach is low but carries high risks of mortality with reported in-hospital death of up to 19% [11].

Anatomic barriers could also represent another limitation before stent delivery. Those include aortic tortuosity, proximity of the aneurysm to the cerebral or visceral vessels and occlusive disease of the iliac vessels that sometimes make the stent delivery a real challenge [3]. Despite these procedural limitations, in extensive endovascular aortic coverage in selected patients, morbidities and mortality are not negligible. In a large contemporary analysis coming from the Cleveland Clinic [1], the authors compared endovascular and open techniques for TAAA repair in 724 patients. Results showed a similar 30-day mortality of 5.7 and 8.3% after endovascular and surgical repair, respectively, and slightly better results concerning spinal cord ischaemia (4.3 vs 7.5%). The authors showed a strong association between the extent of the aneurysm repair and the development of spinal cord injury [1]. In our experience, 21 of the 32 observations (66%) of paraplegia and/or paraparesis occurred in the most extensive aneurysm extent, Type II TAAA. With regard to the interpretation of spinal cord ischaemia, it is important to report not only paraplegia but also paraparesis.

When compared with TEVAR, open surgery is usually associated with increased risks of renal dysfunction, and respiratory complications [22, 23]. These observations are confirmed again by our results, demonstrating a temporary necessity for haemodialysis in 4.2% of our patients, and prolonged ventilation requiring tracheostomy in 7.7%.

Not surprisingly, an urgent or emergent procedure strongly influenced hospital outcome as demonstrated by the substantial higher mortality and morbidity. Once more, this emphasizes the importance of timely elective surgery in order to achieve success. Other known risk factors for in-hospital mortality identified on multivariable analysis were older age and female gender. Surprisingly, we did not observe relevant differences in postoperative outcomes after Type II repair compared with the other less extensive types, apart from total symptomatic spinal cord ischaemia rates. The reason may be found in our strict, systematic approach and use of all proven ADJs during all procedures. Continued blood perfusion is crucial for a proper visceral protection. Additionally, only a small subset of our surgical, anaesthetic and perfusionist group is responsible for all thoracoabdominal surgery and performs this type of surgery on a weekly basis. In support of this theory, the nationwide inpatient sample in the USA demonstrated that both hospital and surgeon volume were significant predictors of mortality for intact TAAA repair [24].

From our analysis, none of the intraoperative variables taken into account showed a significant impact on early and long-term mortality. This finding probably correlates with a homogeneous approach in elective as well as urgent situations by a dedicated staff of surgeons, anaesthesiologists, perfusionists and observing neurophysiologists.

Another interesting point of this study is depicted in the long-term results. Overall long-term survival was satisfactory: 74.2% at 5

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years and 61.6% at 10 years. In addition, we have shown the long-term outcome according to the extent of TAAA repair and underlying aortic disease. As seen in the early results, extensive repair (Types I and II) does not impact on late survival. Surprisingly, the aetiology emerged to be a negative prognostic factor. After hospital discharge, the hazard of dying when the aetiology was a degenerative atherosclerotic aneurysm was 1.66 times higher compared with the other causes [HR = 1.66; 95% CI (1.13–2.44); $P = 0.009$]. This statistical evidence is intriguing and a possible explanation that could be found in the relative younger population of the dissected patients at the time of surgery strengthened even more by the strong impact of age on our overall early and late outcomes. In addition, atherosclerosis is a systemic disease, potentially involving more than only the aortic vascular system. Connective tissue disorders mostly consisting of Marfan syndrome ($n = 37$) did not emerge as risk factor for late survival and, importantly, aortic reintervention ($P > 0.1$). This finding may be obscured by the limited number of patients in the series and the relative younger age of the subjects.

The need for late reintervention appears to be a concern after total endovascular TAAA repair.

In a recent series, Verhoeven *et al*. [19] presented one of the largest series to date of TAAA repair with fenestrated and branched stent grafts. The authors provided encouraging mid-term results (survival at 5 years was 66.6%) but also a considerable proportion of reintervention. Estimated freedom from reintervention at 3 years was 78.4 and 17% of the patients required at least one reoperation within 2–3 years of the index procedure. Most of late reinterventions involved correction of the stented visceral vessels either because of endoleak (more common) or, rarely, because of stenosis [19]. In summary, despite the effectiveness of TEVAR, a considerable reintervention rate should be acknowledged after these procedures [11, 19, 25]. Our report strongly confirms that open repair for TAAA remains durable and does not require multiple reinterventions. Overall freedom from aortic redo intervention remains low over the years (86.3 and 80.7%, respectively, at 5 and 10 years). Primary cause of aortic reintervention was aneurysmal progression of an underlying aortic disease especially on the proximal aorta tract (ascending, root and aortic arch). Only half (25/46) of the patients required reoperation on the descending thoracic and abdominal aorta for aortic reasons. Other causes rather than progressive dilatation were false aneurysm (7/46) and symptoms related to a residual aortic dissection as imminent rupture or peripheral malperfusion (3/46). Of course, a second operation on the aorta after a previous TAAA repair appeared to be associated with a higher rate of hospital mortality compared with the first procedure (17.4 vs 10.9%). For this reason, in selected patients, the use of an aggressive aortic resection at primary elective surgery could be sometimes justified.

Our study limitations are related to its retrospective and single-institutional nature. However, while randomized controlled trials are considered to provide the best level of evidence in clinical and surgical practice, the complex clinical and anatomical scenario offered by diffuse aortic pathologies often make their use less pertinent, and observational studies, such as ours, gain interest and significance. The study is noteworthy as it assesses one of the largest series published to date regarding patients undergoing TAAA repair with well-defined, contemporary uniform techniques and standardized protocols. The final consideration of the current analysis clearly proves that surgical TAAA repair intrinsically still has substantial complications and it remains a challenging operation requiring accurate postoperative care. On the other hand, current understanding of the pathophysiology and contemporary operative strategy has dramatically improved outcomes over the years with a 7.1% 30-day mortality rate in elective setting and a 4.2% paraplegia rate in 542 patients undergoing open TAAA repair at our institution in a 20-year period.

CONCLUSION

Outcomes of contemporary open TAAA repair using a multi-ADJ approach are very satisfactory. Long-term survival is largely determined by patient age and preoperative patient condition and not by the extent of the aortic repair. Post-dissection aneurysms are apparently protective for long-term survival compared with degenerative chronic aneurysms. Our contemporary results demonstrate that open surgical TAAA repair is an extremely effective option and is associated with a low need for aortic reinterventions.

Conflict of interest: none declared.

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