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Multicentre analysis of current strategies and outcomes in open aortic arch surgery: heterogeneity is still an issue

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Abstract

OBJECTIVES: The study was conducted to evaluate, on the basis of a multicentre analysis, current results of elective open aortic arch surgery performed during the last decade.

METHODS: Data of 1232 consecutive patients who underwent aortic arch repair with reimplantation of at least one supra-aortic artery between 2004 and 2013 were collected from 11 European cardiovascular centres, and retrospective statistical examination was performed using uni- and multi-variable analyses to identify predictors for 30-day mortality. Acute aortic dissections and arch surgeries not involving the supra-aortic arteries were not included.

RESULTS: Arch repair involving all 3 arch arteries (total), 2 arch arteries (subtotal) or 1 arch artery (partial) was performed in 956 (77.6%), 155 (12.6%) and 121 (9.8%) patients, respectively. The patients' characteristics as well as the surgical techniques, including the method of cannulation, perfusion and protection, varied considerably between the clinics participating in the study. The in-hospital and 30-day mortality rates were 11.4 and 8.8% for the entire cohort, respectively, ranging between 1.7 and 19.0% in the surgical centres. Multivariable logistic regression analysis identified surgical centre, patient's age, number of previous surgeries with sternotomy and concomitant surgeries as independent risk factors of 30-day mortality. The follow-up of the study group was 96.5% complete with an overall follow-up duration of 3.3 ± 2.9 years, resulting in 4020 patient-years. After hospital discharge, 176 (14.3%) patients died, yielding an overall mortality rate of 25.6%. The actuarial survival after 5 and 8 years was 72.0 ± 1.5% and 64.0 ± 2.0, respectively.

CONCLUSIONS: The surgical risk in elective aortic arch surgery has remained high during the last decade despite the advance in surgical techniques. However, the patients' characteristics, numbers of surgeries, the techniques and the results varied considerably among the centres. The incompleteness of data gathered retrospectively was not effective enough to determine advantages of particular cannulation, perfusion, protection or surgical techniques; and therefore, we strongly recommend further prospective multicentre studies, preferably registries, in which all relevant data have to be clearly defined and collected.

Keywords: Aortic arch • Aortic surgery • Cerebral protection

INTRODUCTION

Since Griepp and associates first described the use of deep hypothermic circulatory arrest for prosthetic replacement of the aortic arch in 1975, the number of centres performing these procedures has continued to grow and it has become a routine surgery in many units [1]. However, various reports throughout the last decades demonstrate that aneurysms of the arch still remain a

challenging task, requiring thoughtful preoperative and intraoperative planning. Changes in operative techniques and technical progress have led to a substantial improvement in survival and outcomes [2–5]. On the other hand, there is also a rapid growth in alternative techniques and evolving technologies, including debranching of the aortic arch with subsequent thoracic endovascular aortic repair that should be benchmarked adequately [6–10]. With novel perfusion methods, improved neuroprotective strategies, and further technical advances, the success rates should continue to improve in the future. However, the determination of the impact of those advanced techniques on surgical outcomes should be based on the conclusive analysis of data gathered from several aortic referral sites to build a foundation for future recommendations and guidelines. Taking into account that no or very limited multicentre trials exist to date, the aim of this study was to evaluate the operative and clinical outcomes after conventional total or subtotal aortic arch replacement, using current perfusion and surgical techniques at several aortic referral centres in Europe.

PATIENTS AND METHODS

To assess the surgical and mid-term clinical outcomes after a conventional aortic arch surgery performed in several European aortic referral centres during the last 10 years, 18 aortic centres from 5 European countries were asked to report on their respective surgical strategies and postoperative results after elective aortic arch surgery performed between January 2004 and December 2013. Eleven centres (Supplementary material, Table S1) responded to the call and provided their data for a retrospective analysis. To keep an anonymous character of this analysis, the order of the centres as provided in tables and Supplementary tables does not correspond to the alphabetical order in the list of principal investigators and the centre list describing particular perfusion and protection strategies, which are provided in Supplementary material, Tables S1 and S4.

Inclusion criteria

The analysis includes all scheduled (elective and urgent) aortic arch surgeries performed due to any pathology (also including chronic dissections or re-do surgeries after conventional or thoracic endovascular aortic repair—TEVAR) with at least one circular aortic anastomosis and reimplantation of at least one aortic arch branch, regardless of the proximal or distal extent of the thoracic aorta repair. The extent of arch repair was defined as partial, subtotal or total:

- Arch repair with reimplantation of one arch artery (partial arch repair)
- Arch repair with reimplantation of two arch arteries (subtotal arch repair)
- Arch repair with reimplantation of three arch arteries (total arch repair)

To give an exact overview of the various methods for conventional aortic arch replacement, no exclusions were made with regard to the performed surgical approaches, (which, in addition to median sternotomy included median sternotomy with lateral extension [hemi-clamshell], bilateral thoracotomy [clam shell] and posterolateral thoracotomy), anastomosing techniques (conventional, elephant trunk [ET] or stented elephant trunk [so-called frozen elephant trunk—FET]) or any concomitant cardiac or cardiovascular procedures. For supra-aortic reconstruction, all surgical methods of reimplantation were included (e.g. island technique, singular reimplantation, supra-aortic translocation and extra-anatomic bypass). To analyse the potential impact of neuroprotective strategies, all participating centres were also asked to give detailed information on their arterial cannulation techniques and respective cerebral protection and, if appropriate, cerebral perfusion management. Accordingly, all available techniques were included and comprised all forms of antegrade (bilateral or unilateral) cerebral perfusion (ACP), retrograde cerebral perfusion (RCP) and deep hypothermic circulatory arrest (DHCA).

Table 1: Preoperative patient characteristics

Characteristics	No (%) or mean ± SD
Sex male	778 (63)
Age (years)	64 ± 13
Arch pathology	
Aneurysm	874 (70.9)
Chronic dissection	278 (22.6)
False aneurysm	29 (2.4)
Inflammatory/infection	21 (1.7)
Porcelain aorta	14 (1.1)
Others	16 (1.3)
Aortic valve defect	
Insufficiency	515 (41.8)
Stenosis	75 (10.0)
Mixed	51 (4.1)
Previous cardiac surgery	340 (27.6)
Previous neurological events	113 (9.2)
With residuals	66 (5.4)
Without residuals	47 (3.8)
Previous TEVAR	34 (2.8)
Creatinine (mg%)	1.1 ± 1.6

TEVAR: thoracic endovascular aortic repair.

Exclusion criteria

The only exclusion criteria were:

- open arch anastomosis (hemiarch) without involvement of any arch arteries
- acute aortic dissection
- intraoperative aortic injury necessitating unscheduled repair

Altogether, 1232 patients (mean age 64 ± 13 years) were included in the study group (Table 1). The respective numbers of included patients varied between single centres from 17 to 237. The subcohorts also varied in regard to age, gender, previous neurological event and previous surgery (Supplementary material, Table S2). Aortic aneurysm was the most frequent indication for aortic arch surgery (70.9%), followed by chronic dissection (22.6%) and other pathologies (6.5%); however, the incidences of chronic aneurysm, chronic dissection or aortic valve defect were also significantly different among the centres. Previous open cardiac surgery with sternotomy had been performed in 340 patients (27.6%), whereas 34 (2.8%) patients were initially treated by TEVAR of the thoracic aorta. The detailed preoperative patient characteristics and underlying aortic pathologies are summarized in Table 1 for the entire cohort

Table 2: Operative data

Variables	No (%) or mean ± SD
Arterial cannulation	
AXA right	464 (37.7)
Aorta	306 (24.8)
CCA	169 (13.7)
IA	149 (12.1)
Femoral	131 (10.6)
Others	13 (1.1)
Cerebral protection	
Bilateral CP	777 (63.1)
Unilateral CP	377 (30.6)
DHCA	74 (6.0)
Retrograde CP	1 (0.1)
Others[a]	3 (0.2)
CPB time (min.)	206.4 ± 64.4
CP time (min.)	58.1 ± 28.1
CA time of lower body (min.)	50.1 ± 26.0
CA time of brain (min.)	9.3 ± 11.7
Aortic cross-clamp time (min.)	120.8 ± 44.9
Lowest rectal temp. (°C)	26.1 ± 3.5

AXA: axillary artery; CCA: common carotid artery; IA: innominate artery; CP: cerebral perfusion; DHCA: deep hypothermic circulatory arrest; CPB: cardiopulmonary bypass; CA: circulatory arrest; LSA: left subclavian artery.
[a]beating heart with cross-clamping between left CCA and LSA.

and in Supplementary material, Table S2 for all sub-cohorts; whereas Supplementary material, Table S3 demonstrates that the incidences of chronic-obstructive lung disease (COLD), functional NYHA class, ejection fraction (EF) and aortic aetiology were reported incompletely limiting the evidence of statistical analysis. The complete monitoring of operative data, especially perfusion flow and pressure during cerebral perfusion, was provided by only 2 centres.

Surgical techniques, cannulation and perfusion

Surgical access was achieved via full sternotomy, partial sternotomy, bilateral thoracotomy, sternotomy with lateral extension and postero-lateral thoracotomy in 1134 (92.1%), 54 (4.4%), 14 (1.1%), 5 (0.4%) and 25 (2.0%) cases, respectively. Various techniques of arterial cannulation were also used in accordance with the preferences of the respective centre. As presented in Table 2, the right axillary artery (AxA) was the most frequently used arterial cannulation site (37.7%) followed by direct aortic (24.8%), common carotid artery (CCA, 13.7%), innominate artery (IA, 12.1%) and femoral artery (FA, 10.6%); other access routes as double cannulations were documented in only 13 patients (1.1%). The reported cerebral protection strategies comprised mainly bilateral (63.1%) or unilateral (30.6%) ACP, and DHCA (6.0%). In 3 cases (0.2%), the distal arch was performed with beating heart after cross-clamping the arch between the left CCA and left subclavian artery (LSA), and in only 1 case (0.1%) RCP was used (Table 2). However, there were relevant centre-related differences in the execution of these techniques, which could have already been observed in a survey performed by the vascular domain group of the EACTS [11]. A noverview of cannulation sites used in particular centres is demonstrated in Supplementary material, Table S4, whereas a short description of protection and perfusion techniques is provided below. Here, the order of the centres corresponds to the alphabetical list of the principal investigators (Supplementary material, Table S1), which is different from the anonymous order of the sub-cohorts in remaining tables and Supplementary tables.

- In Bologna, the preferred cannulation sites were AxA and IA followed by FA and aorta (Supplementary material, Table S4). Bilateral hypothermic ACP (blood temp. 20–24°C) applied by cannulation graft and/or, if appropriate, by inflatable perfusion catheters in the IA and left CCA with a constant flow of 15 ml per kg of body weight was used for cerebral protection. The LSA was blocked using a Fogarty catheter or, in case of FET, was cannulated with inflatable perfusion catheter and perfused. Near-infrared spectroscopy (NIRS) was used for neuro-monitoring and moderate hypothermia (24–26°C) for organ protection.
- In Bergamo, the preferred cannulation site was IA, followed in very rare cases by aorta, AxA or FA (Supplementary material, Table S4). Unilateral or bilateral moderate hypothermic ACP (blood temp. 24–26°C) applied by cannulation graft and/or, if appropriate, by inflatable perfusion catheters in the IA and left CCA with a pressure-controlled flow (targeting 40 mmHg) was used for cerebral protection. During ACP, the LSA was blocked using a Fogarty catheter. NIRS was used for neuro-monitoring and moderate hypothermia (26°C) was used for organ protection.
- In Leipzig, the preferred cannulation site was right AxA, followed by aorta, IA or FA (Supplementary material, Table S4). Mainly bilateral, or less frequently unilateral, hypothermic ACP (blood temp. 20°C) applied by cannulation graft and/or, if appropriate, by inflatable perfusion catheters in the IA and left CCA, with a flow (within the range of 8–20 ml of flow per minute/kg body weight) and pressure according to the surgeons' preferences. During ACP, the LSA was blocked using a Fogarty catheter. NIRS was used for neuro-monitoring and moderate hypothermia (24–28°C) was used for organ protection.
- In Heidelberg, the preferred cannulation site was the aorta followed by FA (Supplementary material, Table S4). Bilateral, mostly hypothermic ACP (blood temp. about 20°C) applied via 2 inflatable perfusion catheters in the IA and left CCA with a flow and pressure according to the surgeons' preferences was used for cerebral protection. During ACP, the LSA was blocked using a Fogarty catheter. NIRS was used for neuro-monitoring and moderate hypothermia (24–28°C) for organ protection.
- In Munich, until 2011, the preferred cannulation site was an FA combined with DHCA. Since 2012, a preferred cannulation site has been aorta followed by right AxA and IA (Supplementary material, Table S4). Hypothermic ACP (blood temp. 18°C) applied by cannulation graft and/or, if appropriate, by inflatable perfusion catheters in the IA and left CCA with a pressure-controlled flow (60 mmHg) was used for cerebral protection. During ACP, the LSA was blocked using a Fogarty catheter. NIRS was used for neuro-monitoring and moderate hypothermia (24–28°C) for organ protection.
- In Rome, IA or right AxA was used for arterial cannulation (Supplementary material, Table S4). Unilateral or bilateral hypothermic ACP (blood temp. 24–28°C) applied by cannulation graft and/or, if appropriate, by inflatable perfusion catheters in the IA and left CCA with a pressure-controlled flow (50–80 mmHg), resulting in a flow of about 0.7–1.0 l/min. was used for cerebral protection. During ACP, the LSA was blocked using a clamp or Fogarty catheter. NIRS and bilateral RR measurement in radial arteries were used for neuro-monitoring and moderate hypothermia (24–28°C) for organ protection.

- In Freiburg, the preferred cannulation site was the right AxA followed by an FA (Supplementary material, Table S4). Unilateral or bilateral hypothermic ACP (blood temp. 18–23°C) applied by cannulation graft and/or, if appropriate, by inflatable perfusion catheters in the IA and left CCA with a flow of 0.5–1.2 l/min., targeting a pressure of 40–50 mmHg was used for cerebral protection. During ACP, the LSA was blocked using a Fogarty catheter. NIRS was used for neuro-monitoring and deep to moderate hypothermia (about 20–22°C) for organ protection.
- In Hannover, the aorta was used for cannulation exclusively (Supplementary material, Table S4). Bilateral moderate hypothermic ACP (blood temp. 27°C) applied via 2 inflatable catheters in the IA and left CCA with a pressure-controlled flow (about 50 mmHg), targeting a flow rate of at least 500 ml/min. During ACP, the LSA was blocked using either a Fogarty catheter or a clamp. NIRS was used for neuro-monitoring and moderate hypothermia (25°C) for organ protection during ACP.
- In Essen, the preferred cannulation site was the right AxA followed by the aorta (Supplementary material, Table S4). Bilateral hypothermic ACP (blood temp. 18°C) applied by cannulation graft and/or, if appropriate, by inflatable perfusion catheters in the IA and left CCA with a pressure-controlled flow (targeting 50 mm of Hg) was used for cerebral protection. During ACP, the LSA was blocked using a Fogarty catheter. NIRS was used for neuro-monitoring and moderate hypothermia (24–26°C) for organ protection.
- In Bad Neustadt, the preferred cannulation site was the right CCA, followed by the left CCA and IA (Supplementary material, Table S4). Unilateral mild hypothermic ACP (blood temp. above 28°C) applied via cannulation graft with a pressure-controlled flow (about 80 mmHg), resulting in a flow of about 1.2 l/min. was used. All arch branches were cross-clamped with soft clamps exclusively. NIRS and bilateral RR measurement in radial arteries were used for neuro-monitoring and mild hypothermia (about 30°C) for organ protection.
- In Frankfurt, the preferred cannulation site was the right AxA, followed in very rare cases by the IA or FA (Supplementary material, Table S4). Mainly unilateral or bilateral mild hypothermic ACP (blood temp. above 28°C) applied by cannulation graft in the right AxA and/or, if appropriate, by inflatable perfusion catheters in the IA and left CCA, with a pressure-controlled flow (about 75 mmHg), resulting in a flow of about 1.1–1.4 l/min., was used. During ACP, the LSA was blocked, mainly using Fogarty catheter and NIRS was used for neuro-monitoring. Mild hypothermia (about 30°C) was used for organ protection.

Definitions and statistical analysis

The Ethics Committee of the Cardiovascular Clinic Bad Neustadt granted approval for the study. Principal investigators of each particular clinic (Supplementary material, Table S1) confirmed the validation of their respective dataset, especially that all consecutive patients who underwent arch surgery according to the study definition had been included.

The clinical charts of all patients were retrospectively reviewed if no prospectively collected data were available (depending on the respective centre). Follow-up consisted of a telephone interview with patients and/or their physicians and especially included the following variables: survival, neurological morbidity (permanent), aortic events and a need for aortic reinterventions. The primary end-points were set as: early (30 days) and late mortality for any reason, postoperative permanent neurological deficit (within 7 days after surgery or after gaining consciousness if longer ventilation was necessary). The secondary end-points included postoperative early (30 days) transient neurological deficit, late permanent neurological morbidity and all aortic events including aortic reinterventions.

Categorical variables were reported using the number and percentage of occurrences. Continuous variables were expressed as mean ± standard deviation. The impact of the available variables on the early (30-day) mortality was analysed using univariable and multivariable analyses. For the latter, several logistic regression models were built to determine the independent predictors for early (30-day) mortality. Actuarial survival was estimated by the Kaplan–Meier method. The statistical analysis was performed with the SPSS statistical software package (version 22.0; IBM, Ehningen, Germany).

Table 3: Extent of surgery

Variables	No (%) or mean ± SD
Extension of arch repair	
Repair 3 arch arteries	956 (77.6)
Repair 2 arch arteries	155 (12.6)
Repair 1 arch artery	121 (9.8)
Ascending aorta replacement	1033 (83.8)
Descending aorta replacement	44 (3.6)
Aortic valve sparing	247 (20.0)
VSRR	190 (15.4)
Aortic valve replacement	327 (26.6)
Valve conduit	218 (17.7)
Mitral valve surgery	33 (2.7)
CABG	205 (16.6)

VSRR: valve-sparing root repair; CABG: coronary artery bypass grafting.

RESULTS

Operative data

The extent of surgery depended on the extent of aortic arch disease and the coexistence of other cardiac pathologies (Table 3). Arch repair involving all 3 arch arteries (total), 2 arch arteries (subtotal) or 1 arch artery (partial) was performed in 956 (77.6%), 155 (12.6%) and 121 (9.8%) patients, respectively. The extent of aortic pathology required additional replacement of the ascending aorta in 1033 (83.8%) and descending aorta in 44 (3.6%) patients. Concomitant procedures included aortic valve and/or aortic root surgery in 574 (46.6%), coronary artery bypass grafting in 205 (16.6%) and mitral valve surgery in 33 (2.7%) patients (Table 3). There were, however, considerable differences with regard to the extent of surgery between the sub-cohorts. In some centres, the ET technique was the preferred method of arch replacement with more than 70% occurrence (Supplementary material, Table S5). Beginning in 2012, even a rate of 100% was documented in 1 centre. In contrast, only 2 centres reported about combined conventional arch and descending aorta replacement (Supplementary material, Table S5), and the rate of descending aorta replacements combined with at least partial arch replacement was only 3.6% altogether (Table 3). Also, the incidences of valve-sparing root repair, complete root replacement with valve composite graft, concomitant mitral valve surgery and coronary

Table 4: Outcome and follow-up

Variables	No (%) or mean ± SD
30-day mortality	108 (8.8)
In-hospital mortality	143 (11.6)
Re-sternotomy	150 (12.2)
Dialysis	160 (13.0)
Permanent	52 (4.2)
Transient	108 (8.8)
Myocardial infarction	18 (1.5)
Neurological defect	
Focal permanent	70 (5.7)
Focal transient	40 (3.3)
Paraplegia	13 (1.1)
Transient neuro-psychological deficit	97 (7.9)
Lost to follow-up	43 (3.5)
Follow-up duration (years)	3.3 ± (2.9)
Overall mortality	317 (25.8)

bypass grafting (CABG) were remarkably different between the sub-cohorts (Supplementary material, Table S5). Accordingly, operative data such as ischaemic time, perfusion time and temperature; which are provided in Table 2 for the entire cohort, varied considerably between particular sub-cohorts (Supplementary material, Table S6). Especially, the brain ischaemia time (9.3 ± 11.7) occurred only in patients undergoing DHCA or those patients with ACP, in whom a femoral artery or the aorta was cannulated and in whom the perfusion had to be completely interrupted during the placement of perfusion cannulas in the arch branches. Some cerebral perfusion data, especially, the flow, pressure and blood temperature during ACP, were reported incompletely, and therefore, had to be excluded from the multivariable statistical analysis (see below).

Early mortality and morbidity

Four foreign patients, who went to their countries after discharge, were lost to follow-up before the end of the 30-day postoperative period. The in-hospital and 30-day mortality rates for the remaining cohort of 1228 patients were 11.4% (140 patients) and 8.8% (108 patients) (Table 4).

Postoperative complications comprised the incidence of resternotomy for haemorrhage, reintubation, tracheostomy, renal failure (by means of temporary or permanent dialysis), myocardial infarction and transient or permanent neurological deficits. An occurrence of tracheostomy was reported incompletely and therefore was excluded from statistical analysis.

Resternotomy for haemorrhage was required in 150 (12.2%) cases. Postoperative respiratory failure occurred in 262 patients (21.3%), among whom 77 (6.3%) required prolonged ventilation primarily and 185 (15.0%) after reintubation. Renal failure with transient or permanent dialysis was required in 108 (8.8%) and 52 (4.2%) cases. The incidence of perioperative myocardial infarction was low (1.5%) despite the relatively high rate of concomitant coronary heart disease, requiring simultaneous CABG in 205 patients (16.6%), (Table 3). Focal permanent and transient defects or transient neuro-psychological deficits were noted in 70 (5.7%), 40 (3.3%) and 97 (7.9%) patients. Postoperative paraplegia occurred in 13 patients (1.1%).

Statistical analysis revealed significant differences between the surgical outcomes in particular sub-cohorts (Supplementary material, Table S7). The 30-day mortality ranged between 1.7 and 19.0%, the rate of permanent neurological deficit from 0 to 12.0% and the paraplegia rate from 0 to 3.6%. In the univariable analysis, the surgical centre, age, EF, previous CABG, number of previous surgeries means sternotomy, concomitant surgeries, cardiopulmonary bypass (CPB) time and cardiac cross-clamp time were revealed as predictors of increased 30-day mortality (Table 5). In the multivariable analysis, several models were built in which a few variables had to be excluded. For example, CCA cannulation was performed in only one centre, and the brain ischaemia occurred only in patients undergoing DHCA or those patients with ACP in whom a femoral artery or the aorta was cannulated; consequently, it was also limited to only a few centres. Lastly, as mentioned above, several preoperative and operative data were not complete and were even missing entirely in some centres. For example, 2 centres did not provide EF at all and would have been excluded completely from the analysis. Nonetheless, it has to be emphasized that in all models, the surgical centre could be revealed as the most important predictor of early mortality. Eventually, a model, adjusting the 30-day mortality with a particular centre, patient age, number of previous surgeries with sternotomy and concomitant surgeries (Table 6) revealed to be very suitable in regard to the number of observations (1129 cases equalling 88% of the study group) and in regard to the conformity between occurrences and estimated probabilities as shown in the goodness-of-fit test.

Table 5: Univariable analysis to identify risk factors for 30-day mortality

Variables	Odds Ratio	95% CI		*P*-value
		Low	High	
Centre B	3.09[a]	0.61	15.72	0.18
Centre C	6.61[a]	1.96	22.31	0.002
Centre D	7.40[a]	2.06	26.60	0.002
Centre E	2.58[a]	0.66	10.16	0.174
Centre F	12.57[a]	2.32	68.15	0.003
Centre G	8.26[a]	2.39	28.48	0.001
Centre H	5.33[a]	1.15	24.70	0.032
Centre I	7.48[a]	2.17	25.78	0.001
Centre K	13.73[a]	3.68	51.22	0.000
Centre L	5.10[a]	0.81	32.16	0.083
Age	1.03	1.01	1.05	0.001
EF	0.97	0.95	0.99	0.001
Pervious CABG	1.58	1.03	2.42	0.035
No of previous surgeries[b]	2.64	1.40	4.95	0.003
Concomitant CABG	1.71	1.05	2.79	0.030
Concomitant MVR	1.70	0.58	4.99	0.332
CPB time	1.01	1.01	1.01	0.000
Cardiac cross-clamp time	1.01	1.00	1.01	0.000

CI: confidence interval; EF: ejection fraction; CABG: coronary artery bypass grafting; MVR: mitral valve repair/replacement; CPB: cardiopulmonary bypass.
[a]in relation to centre A.
[b]cardiovascular surgeries performed through sternotomy.

Survival

The follow-up of the study group was 96.5% complete with an overall follow-up duration of 3.3 ± 2.9 years, resulting in 4,020 patient-years. Forty-three patients were lost to follow-up, including 4 who were lost after discharge but still during the 30-day

Table 6: Multivariable analysis to identify risk factor for 30-day mortality

Variables	Odds Ratio	95% CI		*P*-value
		Low	High	
Centre B	2.83[a]	0.54	14.73	0.217
Centre C	6.82[a]	1.93	24.13	0.003
Centre D	7.28[a]	1.98	26.82	0.003
Centre E	2.51[a]	0.63	10.04	0.192
Centre F	14.30[a]	2.50	81.68	0.003
Centre G	8.30[a]	2.37	29.04	0.001
Centre H	6.20[a]	1.30	29.57	0.022
Centre I	6.35[a]	1.80	22.56	0.004
Centre K	12.57[a]	3.31	47.70	0.000
Centre L	4.02[a]	0.62	26.20	0.146
Age	1.05	1.02	1.07	0.000
No of previous surgeries[b]	1.21	1.04	1.42	0.016
Concomitant CABG	1.79	1.06	3.04	0.029
Concomitant MVR	2.35	0.75	4.61	0.143

CABG: coronary artery bypass grafting; MVR: mitral valve repair/replacement; CI: confidence interval.
[a]in relation to centre A.
[b]cardiovascular surgeries performed through sternotomy.

Table 7: Cause of death

Variable	In-hospital, No (%)	After discharge, No (%)
Total	140 (11.4)	176 (14.3)
Cardiac	46 (3.7)	20 (1.6)
Non-cardiac	66 (5.4)	62 (5.0)
Aortic	11 (0.9)	17 (1.4)
Neurological	18 (1.5)	4 (0.3)
Sudden/unknown	3 (0.2)	72 (5.8)

postoperative period. After hospital discharge, 176 (14.3%) patients died, resulting in an overall mortality rate of 25.6% (Table 7). The actuarial survival after 5 and 8 years was 72.0 ± 1.5% and 64.0 ± 2.0, respectively (Fig. 1). The respective causes of death were cardiac-related in 20 (1.6%), aortic-related in 17 (1.4%), neurologic-related in 4 (0.3%) and non-cardiac-related in 62 (5.0%) patients. However, in 5.8% (72) of the cases, the causes of death were unknown (Table 7).

Aortic events

In the entire study period, a total of 130 (10.6%) aortic events occurred, including aortic dissection in 3 (0.2%), formation of a false aneurysm in a further 3 (0.2%), aortic rupture in 18 (1.5%) and others (including endoleak development after stented elephant trunk or distal aortic progression) in 106 cases (8.6%).

DISCUSSION

With the data presented, we are confronted with a fact that overall surgical risk in elective aortic arch surgery has remained high during the last decade despite the advancements in surgical techniques. The evaluation of procedural methods additionally

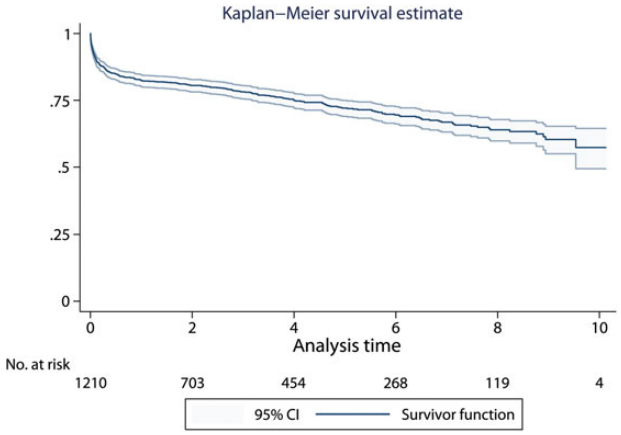

Figure 1: Actuarial survival (Kaplan–Meier) after aortic arch replacement.

supports the results of the observations from the recently published survey from the EACTS vascular domain group on current trends in cannulation and neuroprotection during surgery of the aortic arch in Europe [11]. Only a decade ago, DHCA, RCP and ACP represented three almost equally distributed strategies for cerebral and visceral organ protection [12]. More recently, a clear trend towards ACP is noticeable in the literature, and it was confirmed by our results with only 1/1232 patients (0.1%) receiving RCP and only 74/1232 patients (6.0%) using DHCA for cerebral protection. While the vast majority of patients (93.7%) were operated on employing selective ACP, presented data reveal a substantial diversity regarding the technical details, including cannulation site, ACP flow, ACP pressure and temperature management. However, even similar surgical and cerebral perfusion techniques may yield different outcomes due to the variations in cardiopulmonary bypass perfusion flow and pressure, temperature and glucose management and haematocrit profile [13]. Additionally, most of the perfusion variables vary over the duration of the surgical procedure, so continuous data recording with the advent of electronic perfusion recording systems may be needed to find out the subtle yet important changes.

Actually, we hoped that the study would enable us to identify the procedural aspects impacting the surgical outcomes; yet, the complete intraoperative monitoring data were not continuously recorded in all centres and therefore not available for retrospective analysis. Additionally, the techniques were closely connected with specific centres (mostly at a 1:1 ratio), making a separate analysis nonsensical, especially from the statistical point of view. In other words, it was not possible to differentiate if the results in particular centres were associated with the characteristics of their sub-cohorts or specific procedural methodologies. Consequently, an assessment of the impact of specific technical details on surgical outcomes will be the major task of future studies. The necessity for prospective randomized multicentre trials has been advocated several times before, but its realization seems to be very difficult for many reasons. One of them is a lack of homogenous definitions in the field of aortic arch surgery, especially the fundamental definition of the area of arch surgery. Most series reporting on aortic arch surgery include the results of simple 'hemiarch' replacement, even if it is well recognized that not only the extent of this repair but also the surgical techniques and outcomes differ substantially when compared with total aortic arch replacement [2, 5, 14, 15]. Taking this aspect into account, it is not surprising that the current guidelines do not give evidentiary

recommendations for aortic arch surgery [16, 17]. Such recommendations should not only differentiate between the extents of surgery but also consider acceptable risk, especially in such pathologies like asymptomatic chronic aneurysm (as it has been provided for decades for asymptomatic carotid stenosis [18]). Another key definition concerns the lowest core temperature since substantial differences may occur depending on whether bladder, rectal or nasopharyngeal temperatures are reported. Similarly, perfusion pressure during ACP may be understood as the pressure recorded on the arterial line or, on the right or left radial artery. In addition, the ACP flow may be reported misleadingly high in cases in which an unknown amount of the flow is directed to the right arm. It seems hardly comprehensible why cerebral perfusion in a 120-kg patient should be double that of a 60-kg patient; and therefore, the pressure measurement seems to be indispensable. When compared with a visual evaluation of the backflow from an unclamped supra-aortic artery, the pressure monitoring is objectively gaugeable, efficient and reproducible. Furthermore, it needs to be distinguished between classic clamping of non-perfused arch vessels when compared with endovascular balloon occlusion, which is less controllable and may result in accidental injuries, misplacements and thrombo-embolic events. Nevertheless, there is still a problem in conducting randomized multicentre trials that assess particular surgical methods in aortic arch surgery. There seems to be a creed among particular aortic surgeons who develop a strong attachment to their distinct perfusion and temperature management protocols with which they achieve good clinical outcomes and are not willing to switch their routine for clinical trials. Members of the EACTS vascular domain group recently experienced this renunciation when attempting to initiate a prospective multicentre trial with a random assignment to either unilateral or bilateral ACP.

In summary, the presented data reveal that the surgical risk in elective aortic arch surgery has remained high during the last decade despite the advancements in surgical techniques. Despite the widespread acceptance of ACP, a substantial heterogeneity of technical details in aortic arch surgery is still an issue. Whether the impact of one or more of these details led to the broad range of reported mortality and morbidity rates could not ultimately be delineated; and therefore, the members of the steering committee of the current investigation strongly recommend the need for further multicentre studies, preferably registries, in which all relevant variables have to be thoroughly defined and collected prospectively.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

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Sadly, Robert Bonser, the initiator of this study died unexpectedly, before completion of the data. His fellow co-authors would like to dedicate this paper to his memory.

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