Original Article

Is total arch replacement associated with an increased risk after acute type A dissection?

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Background: The surgical strategy for acute type A aortic dissection (AADA) usually consists of reconstruction of the tear-lesion in the affected part of the ascending aorta. The optimal strategy either to replace the ascending aorta (AAR) or to replace the ascending aorta and the total aortic arch (TAAR) is still under debate. Our study compares the 30-day mortality between AAR and TAAR in AADA surgery.

Methods: In this retrospective observational study, we analysed a total patient cohort of 339 patients who underwent surgery for AADA from January 2001 until December 2016. A propensity score-matched analysis between the AAR- and the TAAR-group with 43 patients for each subgroup was subsequently carried out. A multivariable analysis was performed to identify risk-factors for the 30-d-mortality. The 30-day mortality was defined as the primary end-point and long-term survival was the secondary endpoint.

Results: In 292 (86.1%) patients AAR and in 47 (13.9%) patients TAAR was performed for emergent AADA. Patients were older (P=0.049) in the AAR group. The median log Euro-SCORE was 25.5 % (12.7; 41.7) for AAR and 19.7% (11.7; 32.2) for the TAAR patient cohort (P=0.12). Operative time, cardiopulmonary bypass- (CPB), cross-clamp- and ischemic time were significantly longer in the TAAR group (P<0.001). The overall 30-day mortality-rate was 17.7% (n=60) but was not significantly different between the two groups (P=0.27). Forty-nine (16.8%) patients died in the AAR and 11 patients (23.4%) in the TAAR group. After propensity-score matching, no difference in mortality was seen between the subgroups as well (P=0.44). Multivariable analysis identified the Euro-SCORE, long operation-time, postoperative dialysis and arrhythmia and administration of red blood cell concentrates as risk factors for 30-day mortality, but not for TAAR versus AAR.

Conclusions: The therapeutic goal in AADA surgery should be the complete restoration of the aorta to avoid further long-term complications and re-operations. Though 30-day mortality and postoperative co-morbidity for AAR are comparable to those in TAAR after treatment of AADA in our analysis, decision-making for the surgical strategy should weigh the operative risk of TAAR against the long-term outcome.

Keywords: Acute type A aortic dissection (AADA); total aortic arch replacement (TAAR); ascending aorta replacement (AAR)

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Introduction

According to the German registry of type A aortic dissection (GERAADA) the incidence of acute aortic dissection type A (AADA) ranges from 2 to 4 cases per 100,000 persons/year and correlates to 1,600 to 3,200 cases annually (1). Without emergency treatment AADA is widely known as a life-threatening disease with a high mortality rate of 1% per hour, an expected mortality rate of over 50% during the first 3 days and reaching 80% by the third week (2). The incidence of AADA is increasing due to increasing average population age (3).

The therapy of choice usually consists of replacement of that part of the ascending aorta, which has a tear in the endothelial layer to restore the diseased part of the ascending aorta. In previous studies mortality rates reflect the critical state of the patients and range from 4.2% to 28.6% with variations due to the surgeon's experience and center volume (3). However, recently results have improved due to better surgical techniques and modern intensive care units (4). The German registry, one of the worldwide largest registries, reported an average 30-day mortality of 18.5% in 2017 (1). In approximately half of the AADA patients, the aortic arch is diseased, and many of those patients are postoperatively far from being cured. Regardless of the surgical techniques used, diseased aortic tissue is left in situ, which might be a source of late complications. The most susceptible region with regard to down-streaming postsurgical endothelial tears is the aortic arch, and to a slightly lower extent the descending part of the thoracic aorta. Up to 40% of patients demonstrate persistent dissection in a previously not replaced part of the aorta and in consequence, 10% to 27% of patients experience a late size increase of the false lumen, which may be a reason for late re-operation with again high perioperative mortality and morbidity (5). Therefore, it is still under debate, as whether to perform a standard hemiarch resection, where the patient survives the acute disease or to perform an extended aortic repair, in order to repair the complete aorta and improve long-term patient outcome, even if the aortic arch has no further tear.

The extension of AADA management using total arch replacement in addition to the frozen elephant trunk (FET) procedure in the emergent surgery is on one hand associated with substantial perioperative risk, such as spinal cord and intestinal ischemia but on the other hand with a proven postoperative and long-term benefit in experienced cardiac centres (6). Therefore, our study intended to compare these treatment strategies regarding the primary aspect of postoperative survival and secondarily to the neurological outcome and postoperative morbidity. We present the following article in accordance with the STROBE reporting checklist (available at http://dx.doi.org/10.21037/jtd-20-871).

Methods

Patient population

This retrospective analysis included 339 consecutive patients who underwent surgery for AADA in moderate hypothermic circulatory arrest (MHCA) (21–28 ℃) from January 2001 until December 2016. Patients were divided into two groups: 47 patients underwent total aortic arch replacement (TAAR) (13.9%) *vs*. 292 (86.1%) patients who underwent ascending aorta replacement (AAR). We performed a propensity-score analysis comparing matched TAAR and AAR subgroups with 43 patients for each group.

The primary endpoint was 30-day mortality. Secondary endpoints were long-term survival, intraoperative variables, and postoperative outcomes such as redo-surgery, blood loss, ventilation time, acute renal failure and neurologic complications.

Data were supplied from the institution's database and medical records. Follow up in terms of survival was determined by inquiries at the residents' registration offices. Follow up completeness was 93%, 7% were lost to follow up. The study conformed to the provisions of the Declaration of Helsinki (as revised in 2013). The study protocol was approved by the local Ethics Committee of the medical faculty of the Christian-Albrechts-Universität zu Kiel (D417/17) and informed consent was taken from the patients.

Patient management

Patients with acute type A aortic dissections were operated on an emergency basis and transported directly to the operating room. The diagnosis was confirmed preoperatively by an electrocardiography (ECG) gated contrast enhanced computed tomography (CT) to detect the exact location and extension of the dissection membrane. Patients with confirmed AADA were directly transferred to the operation room and the surgical procedure was performed on an emergency basis. If not intubated, patients were investigated for neurological symptoms and

malperfusion signs preoperatively by physical examination. Any findings were documented on the admission sheet for further use. Transoesophageal echocardiography (TEE) was performed intraoperatively under general anaesthesia.

Surgical procedure

All patients underwent surgery by a senior surgeon. A standard median sternotomy followed by longitudinal pericardiotomy was performed under general anesthesia. Femoral retrograde and direct aortic antegrade access sites were used to establish cardiopulmonary bypass (CPB). Since 2010, CPB was established using transatrial left ventricular antegrade pulmonary vein cannulation as an alternative for arterial cannulation under moderate hypothermic circulatory arrest (MHCA) with a core temperature between 22–24 ℃ (7). Venous drainage was performed either through direct cannulation of the right atrium or through the femoral vein with a cannula that extends to the right atrium. The extent of femoral vein cannula was controlled with TEE. After cross-clamping of the aorta, a standard retrograde injection of cold Buckberg's blood cardioplegic solution for myocardial protection was performed in all cases in combination with antegrade administration through the ostia. The ascending aorta was opened and antegrade cerebral perfusion with cold oxygenated blood (22–28 ℃) was introduced through a balloon catheter inserted into the arch vessels with flow pressure control of about 50–60 mmHg. Following our center's standard operating procedures, the distal extent of aortic repair was dependent on the extent of the dissected intimal tear. The aortic reconstruction was limited to the ascending aorta just proximal to the innominate artery if the intimal tear did not extend to or originate in the aortic arch.

Otherwise, the aortic repair was extended to a hemiarch or total arch replacement with re-implantation of the head and neck arteries by an island technique. In several cases, a FET was introduced in the proximal descending aorta. Before performing the anastomosis, the intimal tears at the proximal and distal aortic stumps were repaired using Gelatin-resorcinol-formaldehyde biologic glue, and the edges were compressed by flattened so-called Borst clamps circularly for 5 minutes. The stumps were then sharply and circularly cut to achieve a clean edge. Cerebral perfusion was removed shortly before the end of suturing of the distal anastomosis. After insertion of the perfusion cannula directly into the graft, CPB was slowly restarted again after careful de-airing. The proximal aortic repair was performed either through isolated supra-coronary AAR or through a replacement or reconstruction of the aortic root with an isolated aortic valve replacement. In the case of associated isolated aortic valve disease, an additional valve replacement was performed when the aorta was only reconstructed. After removing the aortic clamp, continuous CO_2 insufflation was stopped. Transesophageal echocardiography was performed to control the presence of residual air in the left side of the heart. During rewarming, concomitant procedures, if required, were performed.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows (Version 18.0). Normality of continuous variables was assessed by the Kolmogorow-Smirnov test. Normally distributed data are presented as mean ± standard deviation and compared by unpaired *t*-test, whereas not-normally distributed continuous data are presented as medians with ranges or interquartile ranges as appropriate, and compared by the Mann-Whitney U test. Categorical variables are displayed as frequency distributions (n) and simple percentages (%). Univariate comparison between the groups for categorical variables was made using the Chi2-test and the Fisher's exact test. Missing data were excluded pairwise. Statistical significance was considered when $P \leq 0.05$. Variables associated with 30-day mortality were selected due to clinical relevance and included into multivariable logistic regression analysis with backward elimination to determine their relative impact (adjusted odds ratio, OR) on 30-day mortality. Included variables were age >75 years, Euro-SCORE II, coronary heart disease, TAAR *vs*. AAR, length of surgery (min), CPB time (min), number of red blood cell concentrates intraoperatively, postoperative new-onset of hemodialysis, postoperative TIA or stroke.

Since preoperative findings were not homogeneous between the two surgical groups, statistical matching based on the propensity score was conducted to analyze survival of patients operated on by TAAR and AAR with comparable baseline characteristics. Propensity scores were calculated using multivariable logistic regression analysis with TAAR *vs*. AAR as a dependent variable and age (y), sex, arterial hypertension, chronic obstructive pulmonary disease, coronary heart disease, atrial fibrillation, previous thoracic surgery, diameter of ascending aorta prostheses (mm), urgent or emergency admission, smoking and aortic valve vitium as independent variables. Matching was conducted pairwise

with a maximum caliper width of 0.2 of the pooled standard deviation of the logit of the propensity score according to Austin 2011 (8). Finally, 43 patients operated on by TAAR and 43 patients by AAR were matched and their main pre-, intra and postoperative findings were summarized in *Tables 1-3*. Survival during postoperative follow-up was estimated by Kaplan-Meier curves for the matched and unmatched groups and compared by log-rank test (9).

Results

By comparing demographic data between both groups, it was found that patients were significantly older in the AAR group than in the TAAR group [66.0 (55.9;73.5 y) *vs.* 57.9 (53.6;68.3 y); P=0.049)]. Females underwent AAR more frequently than TAAR (37.3 % *vs.* 23.4 %, P=0.064). The EuroSCORE II was similar between both groups. 72.6% of the study population presented with arterial hypertension, followed by the presence of aortic valve insufficiency in 39.7% of patients, which occurred significantly more frequent in the AAR group than in the TAAR group (43.2% *vs.* 17.5%; P=0.002). Patients with a prior aortic aneurysm represented 29.6% of the study population. Marfan-syndrome was present in 2.1% of patients. 9.0% of patients were cardiopulmonary resuscitated. Cardiogenic shock was diagnosed in 7.5% of patients, and 10.1% were intubated before admission to the operating room.

Presence of coronary heart disease as well as risk factors for AADA such as arterial hypertension and aneurysms showed no significant difference between both groups. Patients who underwent TAAR were more often smokers compared to AAR (P=0.025). Presence of previous thoracic surgery was significantly higher in the TAAR group than in the AAR group [12 (25.5%) *vs.* 24 (8.4%); P<0.001] (*Table 4*).

Intraoperatively, duration of surgery was significantly longer in the TAAR group than in the AAR group [363 (280;432) *vs.* 266 (220;317); P<0.001]. Consequently, patients who underwent TAAR had significantly longer CPB times [250 (181;304) *vs.* 157 (130;196); P<0.001] as well as significantly longer hypothermic circulatory arrest time [81 (49;115) *vs.* 31 (25;41); P<0.001]. The number of transfused red blood cells was higher in the TAAR-group than in the AAR-group [6 (0;9) *vs.* 3 (0;6); P=0.070], but however in failed significance. The surgical procedure was extended to include aortic valve replacement more frequently in the TAAR group than in the AAR group (21.3% *vs.* 8.9%; P=0.011). Aortic root replacement was performed in 27.7% in the TAAR *vs.* 10.3% in the AAR population (P=0.001). David reconstruction was performed in 2.1% in the TAAR *vs.* 4.5% in the AAR group. The FET implantation was performed in 14.9% of patients within the TAAR group (*Table 5*).

Postoperatively, the incidence of acute kidney injury (AKI) and the new onset of dialysis did not differ between AAR and TAAR. The difference between clinically proven and CT-Scan controlled postoperative neurologic damage was not significantly different between both groups (P=0.522). The overall 30-day mortality-rate was 17.7% (n=60) but did not reach significance between the two groups. 49 (16.8%) patients died in the AAR group and 11 patients (23.4%) in the TAAR group (P=0.270) (*Table 6*).

After propensity score matching, preoperative details were comparable without statistically significant differences (*Table 1*). However, some preoperative findings showed disparities, e.g., neurological deficits (30.2% in the AAR group *vs.* 18.6% in the TAAR group, P=0.209), but failed significance.

Intraoperatively, duration of surgery was significantly longer in the matched TAAR subgroup compared to the AAR group (365±101.9 *vs.* 261±86.6; P<0.001), as well as CPB times (258±87.6 *vs.* 148±47.2; P<0.001) and hypothermic circulatory arrest time [86 (55;128) *vs.* 28 (22;36); P<0.001]. The surgical procedure of TAAR includes aortic valve replacement (20.9%). Aortic root replacement was performed in 27.9% in the matched TAAR *vs.* 7.0% in the AAR population (P=0.011). David reconstruction was performed in 2.3% of patients in the matched TAAR *vs.* 4.7% in the AAR group. Within the TAAR group 14% of patients received FET implantation (*Table 2*).

Postoperatively, similar to the unmatched groups, the incidence of AKI and the new onset of dialysis (P=0.955 and 0.750, respectively) showed no difference between AAR ad TAAR. Moreover, postoperative neurologic damage occurred with a similar frequency in both groups (P=0.323). However, 34.9% of TAAR-patients were reintubated in comparison to 4.7% of AAR-patients (P<0.001). The 30-day-mortality showed no statistically significant difference between the matched AAR and TAAR group (P=0.436) (*Table 3*). *Figure 1* shows the 30-day-mortality of patients treated by AAR compared to TAAR for the original groups and the matched subgroups.

The survival curves are presented in *Figures 2* and *3* and showed no statistical difference between the unmatched TAAR and the AAR groups (P=0.436) as well as between the matched subgroups (P=0.503).

In the univariate analysis the DeBakey Classification

Table 1 Demographic and clinical characteristics of propensity-matched patient subgroups

Variable	Total [n (%) or median (quartiles)]	AAR [n (%) or median (quartiles)]	TAAR [n (%) or median (quartiles)]	P value
No. of patients	86 (100%)	43 (50%)	43 (50%)	
Age, years	59.9±12.2, 58.8 (53.5; 67.9)	58.9±13.3, 59.0 (53.0;67.5)	60.9±11.0, 58.5 (523.7;69.1)	0.440
Female	26 (30.2%)	15 (34.9%)	11 (25.6%)	0.348
Logistic EuroSCORE (%)	20.9 (11.7; 38.6)	22.0 (11.5; 40.1)	19.7 (11.7; 32.2)	0.635
EuroSCORE II (%)	5.47 (2.79; 12.98)	5.49 (2.64; 10.23)	5.3 (2.9; 13.0)	0.672
Body mass index, kg/m^2	26.2 (23.9; 29.4)	26.2 (24.1; 29.4)	26.1 (23.8; 29.4)	0.870
Arterial hypertension	60 (69.8%)	30 (69.8%)	30 (69.8%)	1.000
Type 2 diabetes mellitus	3 (3.6%)	2 (4.7%)	1 (2.5%)	1.000
Diabetic neuropathy	1 (1.2%)	0 (0.0%)	1 (2.5%)	0.482
Hyperlipoproteinaemia	14 (16.7%)	8 (18.6%)	6 (14.6%)	0.625
Chronic renal failure/insufficiency	11 (13.1%)	4 (9.3%)	7 (17.1%)	0.291
Decompensated renal insufficiency	2 (2.4%)	1 (2.3%)	1 (2.4%)	1.000
Renal replacement therapy	2 (2.4%)	2 (4.7%)	0 (0.0%)	0.494
COPD	2 (2.3%)	1 (2.3%)	1 (2.3%)	1.000
Smoking (7% m)	29 (37.7%)	17 (42.5%)	12 (32.4%)	0.362
Coronary heart disease	17 (20.5%)	7 (16.3%)	10 (25.0%)	0.325
Previous PCI (+/– DES)	6 (7.0%)	2 (4.7%)	4 (9.3%)	0.676
Previous thoracic surgery	18 (20.9%)	9 (20.9%)	9 (20.9%)	1.000
Previous CABG	5 (5.8%)	4 (9.3%)	1 (2.3%)	0.360
Peripheral vascular disease	4 (4.7%)	2 (4.7%)	2 (4.7%)	1.000
Marfan syndrome	3 (3.5%)	1 (2.3%)	2 (4.8%)	0.616
DeBakey type 1 (*vs.* type 2)	68 (90.7%)	30 (83.3%)	38 (97.4%)	0.050
Aortic aneurysm	26 (30.6%)	11 (26.2%)	15 (34.9%)	0.384
Calcific aortic disease	2 (2.4%)	2 (4.8%)	0 (0.0%)	0.241
Diameter of ascending aorta prostheses, mm	28 (26; 30)	28 (26; 30)	25 (23; 26)	0.867
Bicuspid aortic valve	1 (1.2%)	0 (0.0%)	1 (2.3%)	1.000
Neurological deficits	21 (24.4%)	13 (30.2%)	8 (18.6%)	0.209
Clinical presentation				
Acute myocardial infarction (48 h)	4 (4.7%)	3 (7.0%)	1 (2.3%)	0.616
Cardiogenic shock	6 (7.0%)	4 (9.3%)	2 (4.7%)	0.676
CPR (48 h preoperative)	8 (9.3%)	6 (14.0%)	2 (4.7%)	0.265
Intubated	10 (11.6%)	5 (11.6%)	5 (11.6%)	1.000

EuroSCORE, European System for Cardiac Operative Risk Evaluation; COPD, chronic obstructive pulmonary disease; PCI, percutaneous coronary intervention; DES, drug eluting stent; CABG, coronary artery bypass grafting; CPR, cardiopulmonary resuscitation; m, missing values >5%.

Table 2 Operative data of matched patient subgroups

Variable	Total [n (%) or median (quartiles)]	AAR [n (%) or median (quartiles)]	TAAR [n (%) or median (quartiles)]	P value
Length of surgery, min	313±107.6	261±86.6	365±101.9	<0.001
Cardiopulmonary bypass time, min	203±89.2	148±47.2	258±87.6	<0.001
Cross-clamp time, min	96 (70; 153)	73 (52; 96)	139 (100; 209)	<0.001
Circulatory arrest, min	43 (28; 88)	28 (22; 36)	86 (55; 128)	<0.001
Number of packed red blood cells	4 (0; 8)	4 (0; 6)	6 (0; 9)	0.394
Number of fresh frozen plasma cells	0 (0; 6)	0 (0; 6)	0 (0; 5)	0.760
Number of platelets concentrate	2 (1; 2)	2 (1; 2)	2 (2; 2)	0.248
Surgical procedure				
Conduit/Bentall operation	15 (17.4%)	3 (7.0%)	12 (27.9%)	0.011
David operation	3 (3.5%)	2 (4.7%)	1 (2.3%)	1.000
Elephant-trunk	6 (7.0%)	0 (0.0%)	6 (14.0%)	0.026
CABG	7 (8.1%)	4 (9.3%)	3 (7.0%)	1.000
Aortic valve replacement	9 (10.5%)	0 (0.0%)	9 (20.9%)	0.002
Mitral valve reconstruction/replacement	1 (1.2%)	0 (0.0%)	1 (2.3%)	1.000
TEVAR (EVAR)	7 (8.1%)	1 (2.3%)	6 (14.0%)	0.110
Arterial cannulation (14%m)				
Femoral artery	10 (13.2%)	9 (24.3%)	1 (2.6%)	
Ascending aorta	20 (26.3%)	9 (24.3%)	11 (28.2%)	
Aortic arch	2 (2.6%)	0 (0.0%)	2 (5.1%)	
Subclavian artery	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Apex	2 (2.6%)	0 (0.0%)	2 (5.1%)	
Pulmonary vein	42 (55.3%)	19 (51.4%)	23 (59.0%)	
Venous cannulation (14% m)				
Right atrium	71 (93.4%)	34 (91.9%)	37 (94.9%)	
Bicaval	3 (3.9%)	2 (5.4%)	1 (2.6%)	
Femoral vein	2 (2.6%)	1 (2.7%)	1 (2.6%)	

CABG, coronary artery bypass grafting; TEVAR, thoracic endovascular aortic repair; EVAR, endovascular aortic repair; m, missing values >5%.

Type I and II was not associated with 30-day (P=0.78) and long-term (P=0.76) mortality in both groups. Multivariable analysis identified the EuroSCORE II, long operation time, the number of intraoperatively administered red blood cell concentrates, postoperative dialysis and postoperative TIA or stroke as independent risk factors for 30-day mortality. However, TAAR and AAR itself were no predictors for 30-d-mortality in this study (*Table* 7).

Discussion

In this retrospective study we demonstrate that the overall postoperative 30-day mortality-rate for all patients suffering from acute Type A dissection was 17.7% (n=60/339 patients). No significant difference (P=0.27) was seen between the AAR (16.8%) and the TAAR group (23.4%). In contrast, the operative time, CPB, cross-clamp and ischemic time were significantly longer in the TAAR group (P<0.001)

Table 3 Postoperative data and outcomes of matched patient subgroups

Variable	Total [n (%) or median (quartiles)]	AAR [n (%) or median (quartiles)]	TAAR [n (%) or median (quartiles)]	P value
AKI KDIGO	18 (21.2%)	9 (21.4%)	9 (20.9%)	0.955
New-onset of Hemodialysis	18 (21.2%)	9 (21.4%)	9 (20.9%)	0.955
48 h-drainage loss, mL (7% m)	730 (475; 1,200)	700 (350; 1,113)	825 (550; 1,258)	0.204
Postoperative blood transfusion (n)	53 (63.9%)	24 (57.1%)	29 (70.7%)	0.198
24 h-number of packed red blood cells	0 (0;2)	0 (0;2)	0 (0;2)	0.936
24 h-number of fresh frozen plasma, (7% m)	0 (0;4)	0 (0;4)	0 (0;4)	0.646
24 h-number of platelets concentrate	0 (0; 0), max 4	0 (0; 0.5)	0 (0; 0), max 4	0.770
Total number of packed red blood cells	2 (0; 7)	2 (0; 6)	2 (0; 8)	0.225
Total number of fresh frozen plasma cells	0 (0; 4)	0 (0; 4)	0 (0; 5)	0.288
Total number of platelets concentrate	0 (0; 2)	0 (0; 2)	1 (0; 2)	0.221
Reintubation	17 (19.8%)	2 (4.7%)	15 (34.9%)	<0.001
Tracheotomy	20 (23.3%)	5 (11.6%)	15 (34.9%)	0.011
Re-admission to the ICU	6 (7.0%)	2 (4.7%)	4 (9.3%)	0.676
Postoperative delirium	18 (21.2%)	7 (16.7%)	11 (25.6%)	0.315
Postoperative myocardial infarction	2 (2.3%)	1 (2.3%)	1 (2.3%)	1.000
TIA/stroke	22 (25.6%)	9 (20.9%)	13 (30.2%)	0.323
Electrical cardioversion	5 (5.8%)	0 (0.0%)	5 (11.6%)	0.055
CPR	7 (8.1%)	2 (4.7%)	5 (11.6%)	0.433
Bronchopulmonary infection	17 (19.8%)	6 (14.0%)	11 (25.6%)	0.176
Bacteriaemia/sepsis	2 (2.3%)	0 (0.0%)	2 (4.7%)	0.494
Rethoracotomy	12 (14.0%)	7 (16.3%)	5 (11.6%)	0.534
Sinus rhythm	62 (75.6%)	36 (85.7%)	26 (65.0%)	0.029
Atrial fibrillation	7 (8.5%)	2 (4.8%)	5 (12.5%)	0.259
Other rhythm	6 (7.3%)	2 (4.8%)	4 (10.0%)	0.427
Pacemaker patient	5 (5.8%)	3 (7.0%)	2 (4.7%)	1.000
Ventilation time, h	39 (18; 189)	32 (16; 98)	97 (24; 287)	0.014
ICU time, d	4 (2; 11)	4 (2; 7)	8 (2; 14)	0.015
Postoperative days	9 (7; 16)	8 (7; 14)	10 (8; 22)	0.081
7 d-mortality	12 (14.0%)	4 (9.3%)	8 (18.6%)	0.213
30 d-mortality	19 (22.1%)	8 (18.6%)	11 (25.6%)	0.436
Hospital mortality	18 (21.2%)	7 (16.7%)	11 (25.6%)	0.315
Cardiac death	13 (65.0%)	6 (75.0%)	7 (58.3%)	–
Cerebral death	1 (5.0%)	0 (0.0%)	1 (8.3%)	–
Sepsis	1 (5.0%)	0 (0.0%)	1 (8.3%)	–
MOF	5 (25.0%)	2 (25.0%)	3 (25.0%)	–

AKI, acute kidney insufficiency; KDIGO, Kidney Disease, Improving Global Outcomes; IABP, intraaortic balloon pump; ECLS, extracorporeal live support; TIA, transient ischemic attack; CPR, cardiopulmonary resuscitation; VAC, vacuum assisted closure-therapy; ICU, intensive care unit; POD, postoperative days; MOF, multiorgan failure; m, missing values >5%.

Table 4 Demographic and clinical characteristics of the study population

Characteristics	Total [n (%) or median (quartiles)]	AAR [n (%) or median (quartiles)]	TAAR [n (%) or median (quartiles)]	P value
No. of patients 339	339 (100%)	292 (86.1%)	47 (13.9%)	
Age, years	63.7±12.1, 65.6 (55.1; 72.8)	64.2±12.2, 66.0 (55.9; 73.5)	60.5±10.7, 57.9 (53.6; 68.3)	0.049
Age ≥70 years	124 (36.6%)	114 (39.0%)	10 (21.3%)	0.019
Female	120 (35.4%)	109 (37.3%)	11 (23.4%)	0.064
Logistic EuroSCORE (%)	23.7 (12.2; 41.5)	25.5 (12.7; 41.7)	19.7 (11.7; 32.2)	0.124
EuroSCORE II (%)	5.46 (2.96; 12.52)	5.45 (2.89; 12.28)	5.8 (2.9; 13.4)	0.851
Body mass index, kg/m^2	26.3 (23.9; 29.1)	26.3 (23.9; 29.1)	26.4 (23.9; 29.3)	0.933
Body mass index >30 (kg/m^2)	69 (20.4%)	60 (20.6%)	9 (19.1%)	0.817
Arterial hypertension	241 (72.6%)	208 (73.0%)	33 (70.2%)	0.693
Pulmonary hypertension	4 (1.2%)	4 (1.4%)	0 (0.0%)	1.000
Type 2 diabetes mellitus	20 (6.2%)	19 (6.8%)	1 (2.3%)	0.495
Diabetic neuropathy	1 (0.3%)	0 (0.0%)	1 (2.3%)	0.136
Hyperlipoproteinemia	47 (14.6%)	39 (14.1%)	8 (17.8%)	0.515
Chronic renal failure/insufficiency	47 (14.5%)	40 (14.3%)	7 (15.6%)	0.822
Decompensated renal insufficiency	9 (2.8%)	8 (2.9%)	1 (2.2%)	1.000
Renal replacement therapy	7 (2.1%)	7 (2.5%)	0 (0.0%)	0.599
COPD	21 (6.4%)	20 (7.1%)	1 (2.1%)	0.332
Smoking	64 (23.0%)	49 (20.7%)	15 (36.6%)	0.025
Coronary heart disease	60 (18.6%)	48 (17.2%)	12 (27.3%)	0.110
Previous PCI (+/– DES)	24 (7.3%)	19 (6.8%)	5 (10.6%)	0.362
Previous thoracic surgery	36 (10.8%)	24 (8.4%)	12 (25.5%)	<0.001
Previous CABG	10 (3.0%)	8 (2.8%)	2 (4.3%)	0.639
Peripheral vascular disease	16 (4.9%)	14 (5.0%)	2 (4.3%)	1.000
Marfan syndrome	7 (2.1%)	5 (1.8%)	2 (4.3%)	0.252
DeBakey type 1 (*vs.* type 2)	240 (79.7%)	199 (76.8%)	41 (97.6%)	0.002
Aortic aneurysm	100 (29.6%)	83 (28.5%)	17 (36.2%)	0.286
Diameter of aneurysm, mm (24% m)	52±10	51±10	57±12	0.092
Calcific aortic disease	8 (2.4%)	8 (2.8%)	0 (0.0%)	0.606
Diameter of ascending aorta prostheses, mm	28 (28; 30)	30 (28; 30)	28 (26; 30)	0.001
Bicuspid aortic valve	7 (2.1%)	6 (2.1%)	1 (2.1%)	1.000
Aortic valve insufficiency	115 (39.7%)	108 (43.2%)	7 (17.5%)	0.002
Neurological deficits	69 (20.8%)	61 (21.5%)	8 (17.0%)	0.486
Clinical presentation				
Acute myocardial infarction (48 h)	14 (4.2%)	12 (4.2%)	2 (4.3%)	1.000

Table 4 (*continued*)

Table 4 (*continued*)

Characteristics	Total [n (%) or median (quartiles)]	AAR [n (%) or median (quartiles)]	TAAR [n (%) or median (quartiles)]	P value
Cardiogenic shock	25 (7.5%)	22 (7.7%)	3 (6.4%)	1.000
CPR (48 h)	30 (9.0%)	28 (9.7%)	2 (4.3%)	0.282
Intubated	34 (10.1%)	28 (9.7%)	6 (12.8%)	0.601

EuroSCORE, European System for Cardiac Operative Risk Evaluation; COPD, chronic obstructive pulmonary disease; PCI, percutaneous coronary intervention; DES, drug eluting stent; CABG, coronary artery bypass grafting; CPR, cardiopulmonary resuscitation; m, missing values >5%.

Table 5 Operative data

Variable	Total [n (%) or median (quartiles)]	AAR [n (%) or median (quartiles)]	TAAR [n (%) or median (quartiles)]	P value
Length of surgery, min	275 (225; 340)	266 (220; 317)	363 (280; 432)	<0.001
Cardiopulmonary bypass time, min	164 (134; 210)	157 (130; 196)	250 (181; 304)	<0.001
Cross-clamp time, min	85 (67; 120)	81 (65; 108)	129 (96; 209)	<0.001
Circulatory arrest, min	34 (26; 48)	31 (25; 41)	81 (49; 115)	<0.001
Number of packedred blood cells, n (6.2% m)	4 (0; 6)	3 (0; 6)	6 (0; 9)	0.070
Number of fresh frozen plasma, n (6.8% m)	0 (0; 6)	0 (0; 6)	0 (0; 5)	0.847
Number of platelet concentrates, n (6.8% m)	2 (1; 2)	2 (1; 2)	2 (1.5; 2)	0.033
Surgical procedure				
Conduit/Bentall operation	43 (12.7%)	30 (10.3%)	13 (27.7%)	0.001
David operation	14 (4.1%)	13 (4.5%)	1 (2.1%)	0.702
Elephant-trunk	7 (2.1%)	0 (0.0%)	7 (14.9%)	<0.001
CABG	31 (9.3%)	28 (9.7%)	3 (6.4%)	0.595
Aortic valve replacement	36 (10.7%)	26 (8.9%)	10 (21.3%)	0.011
Mitral valve reconstruction/replacement	1 (0.3%)	0 (0.0%)	1 (2.1%)	0.139
TEVAR (EVAR)	22 (6.5%)	15 (5.2%)	7 (14.9%)	0.021
Arterial cannulation (9.7% m)				
Femoral artery	65 (21.2%)	64 (24.3%)	1 (2.3%)	
Ascending aorta	79 (25.8%)	65 (24.7%)	14 (32.6%)	
Aortic arch	11 (3.6%)	9 (3.4%)	2 (4.7%)	
Subclavian artery	1 (0.3%)	1 (0.4%)	0 (0.0%)	
Apex	5 (1.6%)	3 (1.1%)	2 (4.7%)	
Pulmonary vein	145 (47.4%)	121 (46.0%)	24 (55.8%)	
Venous cannulation (9.7% m)				
Right atrium	295 (96.4%)	254 (96.6%)	41 (95.3%)	
Bicaval	4 (1.3%)	3 (1.1%)	1 (2.3%)	
Femoral vein	7 (2.3%)	6 (2.3%)	1 (2.3%)	

CABG, coronary artery bypass grafting; TEVAR, thoracic endovascular aortic repair; EVAR, endovascular aortic repair; m, missing values >5%.

Table 6 Postoperative data and outcomes

Variable	Total [n (%) or median (quartiles)]	AAR [n (%) or median (quartiles)]	TAAR [n (%) or median (quartiles)]	P value
AKI KDIGO	76 (22.7%)	65 (22.6%)	11 (23.4%)	0.899
New-onset of hemodialysis	75 (22.3%)	64 (22.1%)	11 (23.4%)	0.838
Temporary dialysis, d	4 (2; 13)	4 (3; 12)	5 (2; 24)	0.652
48 h-drainage loss, mL (m 12.7%)	800 (450; 1,208)	800 (450; 1,200)	850 (575; 1,305)	0.431
Postoperative blood transfusion	229 (70.5%)	197 (70.1%)	32 (72.7%)	0.723
24 h-Number of packed red blood cells	0 (0; 2)	0 (0; 2)	0 (0; 2)	0.545
24 h-Number of fresh frozen plasma	0 (0; 4)	0 (0; 4)	0 (0; 4)	0.435
24 h-Number of platelets concentrate	0 (0; 0), max 10	0 (0; 0), max 10	0 (0; 0), max 4	0.784
Number of packedred blood cells, n (8.6% m)	3 (0; 8)	3 (0; 7)	2 (0; 8)	0.633
Number of fresh frozen plasma, n (8.8% m)	0 (0; 4)	0 (0; 4)	1.5 (0; 5)	0.267
Number of platelet concentrates, n (8.0% m)	0 (0; 1)	0 (0; 1)	1 (0; 2)	0.032
Postoperative status				
Stable	67 (20.4%)	57 (20.1%)	10 (21.7%)	
Stable with low dose catecholamines	219 (66.6%)	192 (67.8%)	27 (58.7%)	
Stable with high dose catecholamines	34 (10.3%)	27 (9.5%)	7 (15.2%)	
IABP/ECLS with catecholamines	8 (2.4%)	7 (2.5%)	1 (2.2%)	
IABP without catecholamines	1 (0.3%)	0 (0.0%)	1 (2.2%)	
Reintubation	60 (17.7%)	44 (15.1%)	16 (34.0%)	0.002
Tracheotomy	77 (22.7%)	61 (20.9%)	16 (34.0%)	0.046
Re-admission to the ICU	31 (9.2%)	27 (9.3%)	4 (8.5%)	1.000
Re-admission POD	5.6±4.6	6.0±4.7	2.3±1.9	0.128
Postoperative delirium	61 (18.1%)	48 (16.6%)	13 (27.7%)	0.067
Postoperative myocardial infarction	4 (1.2%)	3 (1.0%)	1 (2.1%)	0.452
TIA/Stroke	54 (16.0%)	45 (15.5%)	9 (19.1%)	0.522
Electrical cardioversion	25 (7.4%)	20 (6.9%)	5 (10.6%)	0.367
CPR	25 (7.4%)	20 (6.9%)	5 (10.6%)	0.368
Bronchopulmonary infection	45 (13.3%)	32 (11.0%)	13 (27.7%)	0.002
Bacteremia/sepsis	16 (4.7%)	14 (4.8%)	2 (4.3%)	1.000
Re-thoracotomy	56 (16.5%)	50 (17.1%)	6 (12.8%)	0.455
Sternal wound infection/VAC revision	6 (1.8%)	6 (2.1%)	0 (0.0%)	1.000
Sinus rhythm	250 (76.9%)	220 (78.3%)	30 (68.2%)	0.139
Atrial fibrillation	36 (11.1%)	31 (11.0%)	5 (11.4%)	1.000
Other rhythm	10 (3.1%)	6 (2.1%)	4 (9.1%)	0.033
Pacemaker patient	21 (6.2%)	19 (6.5%)	2 (4.3%)	0.750

Table 6 (*continued*)

Table 6 (*continued*)

Variable	Total [n (%) or median (quartiles)]	AAR [n (%) or median (quartiles)]	TAAR [n (%) or median (quartiles)]	P value
Ventilation time, h	70 (21; 189)	64 (21; 173)	129 (25; 287)	0.087
ICU time, d	5 (2; 11)	5 (2; 10)	9 (2; 14)	0.065
Postoperative days	11 (7; 19)	11 (7; 18)	11 (8; 22)	0.634
7 d-mortality	43 (13.0%)	35 (12.4%)	8 (17.0%)	0.380
30 d-mortality	60 (17.7%)	49 (16.8%)	11 (23.4%)	0.270
Hospital mortality	57 (17.3%)	46 (16.3%)	11 (23.4%)	0.230
Cardiac death	32 (53.3%)	25 (52.1%)	7 (58.3%)	
Cerebral death	4 (6.7%)	3 (6.3%)	1 (8.3%)	
Sepsis	3 (5.0%)	2 (4.2%)	1 (8.3%)	
MOF	21 (35.0%)	18 (37.5%)	3 (25.0%)	

AKI, acute kidney insufficiency; KDIGO, Kidney Disease, Improving Global Outcomes; IABP, intraaortic balloon pump; ECLS, extracorporeal live support; TIA, transient ischemic attack; CPR, cardiopulmonary resuscitation; VAC, vacuum assisted closure-therapy; ICU, intensive care unit; POD, postoperative days; MOF, multiorgan failure; m, missing values >5%.

Table 7 Multivariable analysis on risk factors for 30-d-mortality

Variable	P	Odds ratio	Confidence interval
EuroSCORE II	0.004	1.046	1.014–1.079
Length of surgery, min	0.016	1.005	1.001–1.009
RBC intraoperative, n	0.002	1.156	1.052–1.269
New-onset of hemodialysis	<0.001	5.573	2.522–12.313
Postoperative TIA or stroke	0.016	3.195	1.246–8.194

EuroSCORE, European System for Cardiac Operative Risk Evaluation; RBC, red blood cell concentrates; TIA, transient ischemic attack.

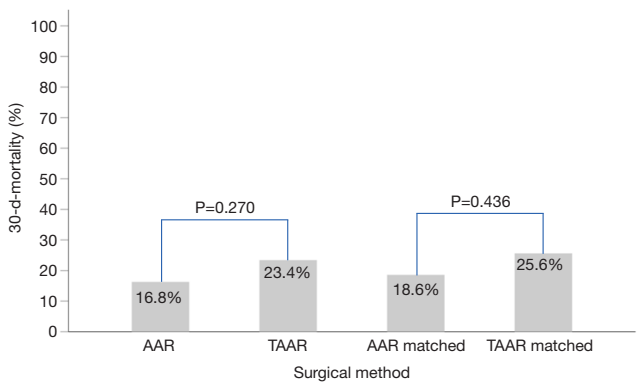

Figure 1 Showing 30-day-mortality in the matched groups and the unmatched subgroups.

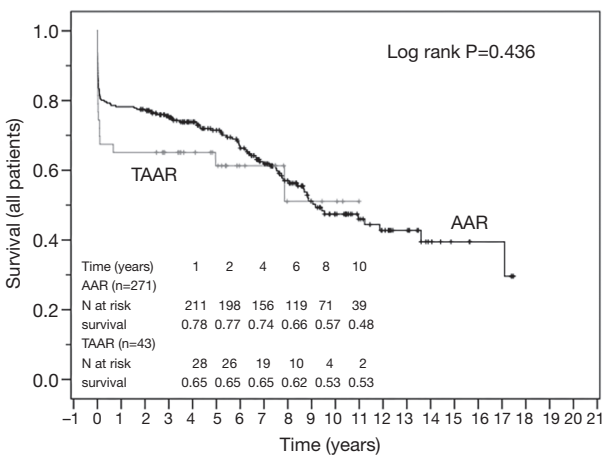

Figure 2 Kaplan-Meier curves of the original groups.

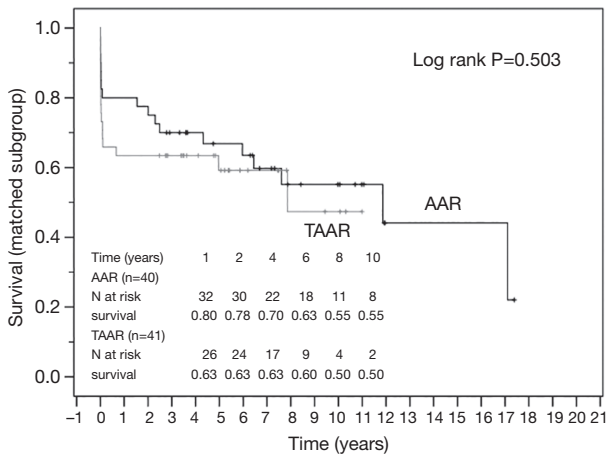

Figure 3 Kaplan-Meier curves of the matched subgroups.

than in the AAR group. However, after propensity-score matching no difference in the 30-day-mortality was seen between the subgroups (P=0.44).

Multivariable analysis in this study identified the EuroSCORE II, long operation time, the number of intraoperatively administered packed red blood cells, postoperative dialysis, and postoperative TIA or stroke as independent risk factors for the 30-day mortality. In the univariate analysis the aortic dissection DeBakey Classification Type I and II was not associated with 30-day (P=0.78) and long-term mortality (P=0.76) in both study groups.

In general, acute aortic dissection is a life-threatening condition that invariably requires emergency surgical intervention. The operative concept of resecting the tear from the ascending aorta is internationally accepted and is daily clinical practice worldwide. Nevertheless, it is still under debate as to whether to leave further tears in the arch, the distal arch and the descending aorta untreated, or to expand the surgical strategy and to treat the arch and the proximal descending aorta for preventive reasons only.

Our study underlines the fact that AAR and TAAR showed no significant difference in postoperative outcome according to 30-day mortality (P=0.27), even though TAAR is associated with longer cross-clamping and operation time (P=0.035), which predicts co-morbidity and worse early outcome after surgery.

The German Registry for Acute Aortic Dissection Type A analyzed the effect of different operative strategies with respect to the treatment of the aortic arch with regard to postoperative mortality and new onset of neurological adverse outcomes, malperfusion as well as mortality: the overall mortality was up to 20.2% and was higher than in our study population. The mortality in their AAR group tended to be lower than in their TAAR-group (18.7% *vs.* 25.7%), although without a significant statistical difference (P=0.07) (10).

The interesting results of the German Registry are confirmed by this study: the extent of the dissection classified by DeBakey had no influence on the short (P=0.76) and long-term outcome (P=0.78). Depending on the extent of the disease, a total resection of all the teared aorta as in this study described. Therefore, a patient-based treatment plan in case of type A dissection depending on preoperative age and patient's risk factors should define whether to replace the ascending aorta alone or to replace the aortic arch for preventive and prognostic reasons.

The standard surgical treatment of AADA is known to be the emergency replacement of that part of the ascending aorta with the tear in the endothelial layer. Increasingly more extensive procedures including FET have been carried out during the last years, particularly for a more complex dissection of the aortic arch, or if the thoracic aorta is dilated or malperfusion is present in the descending part of the thoracic aorta (11,12). The remaining untreated diseased tissue of the aortic arch and the descending part of the thoracic aorta are responsible for the postsurgical complications (13). The use of FET prostheses in our patient population with first-time aortic arch replacement is rare with only 2.1% (7/47patients) though many advantages are proposed. The current strategy is to implant the FET in zone I or II of the aortic arch and bypass the left subclavian artery or any supraaortal vessel even in experienced aortic centers to reduce longer operation times, which reflects the complexity of FET prosthesis implantation methods to the descending aorta (14,15).

In contrast to the wide use of FET prothesis, Kobuch *et al.* stated that re-operation could be carried out with low mortality rate if necessary with several complications after primary surgery for type A dissection. For those patients, FET had become a favored technique in case of reoperation after initial conventional surgery for Type A dissection to restore the descending part of the aorta, to avoid further re-operation and to enable the implantation of further endovascular stents in the descending aorta if necessary (6). FET was recommended also in a study from Tsagakis *et al.* (14). Additionally, Luehr *et al.* described that 12.6% of patients had adverse events and redo surgery after a median follow-up time of 4 years due to aortic dilatation, rupture of

the aorta and endoleaks in a retrospective multicenter study on elective aortic arch surgery (16).

Bringing all experiences together, Leone *et al.* reviewed 437 patients with different FET prosthesis for a mix of complex aortic diseases and showed acceptable postoperative results with a remarkable low rate of 5% paraplegia rate and 10% neurological deficiencies with overall mortality rate of 14.9% (17).

The current analysis showed an overall 30-day mortality-rate of 17.7% (n=60). The mortality rate in patients with AAR *vs*. TAAR did not reach statistical significance [16.8% (n=49) *vs*. 23.4% (n=11); P=0.270]. Moreover, no significant difference regarding postoperative neurologic adverse outcome between the study groups was detected (P=0.522).

Furthermore, we used Kaplan-Meier estimator to analyze the long-term survival. The analysis showed a satisfactory result without statistical differences between the presented groups.

Czerny *et al.* compared the perioperative death rates which strongly depended on the number of organs affected by malperfusion before and after AADA surgery in patients included in GERAADA. The mortality varied according to the number of organs affected by malperfusion (none, 12.6%; 1 system, 21.3%; 2 systems, 30.9%; 3 systems, 43.4%; P<0.001) (18). Though we couldn't find a significant influence of the extent of the aortic dissection on short and long-term mortality in our patients, organ perfusion might also have an impact on the survival. These findings could play an important role in future decisions regarding the surgical repair strategy of AADA whether to replace only the ascending aorta or to replace the arch in total with the proximal descending aorta. With the capacity to start early distal perfusion as soon as possible, the effect of the extended surgical duration on the mortality and comorbidity in TAAR could be further minimized.

Previous studies showed that increased age in general is associated with increased short- and long-term mortality rates after surgical repair of AADA independent from the extent of the performed surgical repair (19,20). We found that patients were significantly older in the AAR group than in the TAAR group [66.0 *vs*. 57.9 y; P=0.049]. This could be attributed to the tendency of performing the less aggressive surgical repair in elderly patients. A study from Trimarchi *et al.* confirmed that increased age (70 years or more) is an independent predictor of in-hospital mortality [38.2% (>70 y) *vs*. 26.0% (<70 y); P<0.001, odds ratio 1.73] (21). Though in our study the mean age of patients in the AAR group is significantly younger, 1/3 of our patients are older than 70 years in total and therefore associated with higher risk of perioperative mortality. The overall conclusion from those previous findings focused on the role of age in those patients undergoing surgery of AADA. However, the role of the extension of the surgical procedure performed including TAAR on postoperative mortality rate still remains to be clarified.

A large study from the International Registry of Acute Aortic Dissection (IRAD) reported preoperative shock conditions, aortic rupture, neurologic damage, and organ ischemia as major determinants of outcomes after surgical repair of AADA. Unstable patients had almost double the postoperative mortality rate when compared with stable patients (31.4% *vs*. 16.7%). Those findings were independent of the extent of the surgical procedure (22,23). According to the propensity matching in our study including 43 patients in each group of AAR and TAAR who were matched according to preoperative parameters such as age and gender of patients, coronary heart disease and arterial hypertension, we found that the mortality between both groups did not differ significantly (P=0.436).

The overall mortality rate in patients undergoing emergency surgery for AADA is still high. However, we concluded from this study as well as from similar studies that the more aggressive surgical repair including the total arch replacement by itself is not associated with higher mortality rates compared to other more conservative surgeries. We believe that in patients suffering from AADA the surgical decision should be taken on an individual basis according to various parameters: the preoperative condition as well as the age of the patients and the presence of multiorgan malperfusion should be the main determinants as whether to perform a more aggressive surgical repair or not. Various single-centres reported satisfactory results and fewer mortality rates between 2.8% to 9% in comparison to large registries (24,25).

Our results may reflect the improvement of postoperative mortality after AADA in general. With surgeon practice, increasing experience, implementation of precise criteria for surgical decisions, as well as minimising the duration of malperfusion, we believe that the outcomes after AADA will be continuously improved.

Limitations of our study

The main limitation of this study is its retrospective design and the risk of bias due to unknown confounding variables as well as the surgeon and an individual patient depending

decision making in a non-randomized patient population. Therefore, we conducted propensity score matching, however this statistical method cannot fully prevent confounding and the resulting small size of the matched subgroups reduces the statistical power to detect significant differences. Though we are aware of the fact, that many publications focused on the differentiation between the aorta related and non-aorta-related mortality, we believe that the overall mortality reflects additional important aspects like age and co-morbidities which are associated with the aortic disease, therefore providing a more realistic view of the long-term outcome after surgical therapy of the dissected aorta. This study is based on single-centre experience with high experienced surgeons performing the procedure.

Conclusions

Both TAAR and AAR demonstrated a comparable postsurgical outcome regarding their mortality and morbidity after surgical repair of AADA. The decision considering the extent of surgical repair of AADA should be taken on an individual basis according to the preoperative condition, age of the patients and the presence of preoperative extension of the dissection.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study conformed to the provisions of the Declaration of Helsinki (as revised in 2013). The study protocol was approved by the local Ethics Committee of the medical faculty of the Christian-Albrechts-Universität zu Kiel (D417/17) and informed consent was taken from the patients.

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