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Survival and reinterventions after isolated proximal aortic repair in acute type A aortic dissection

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Key question

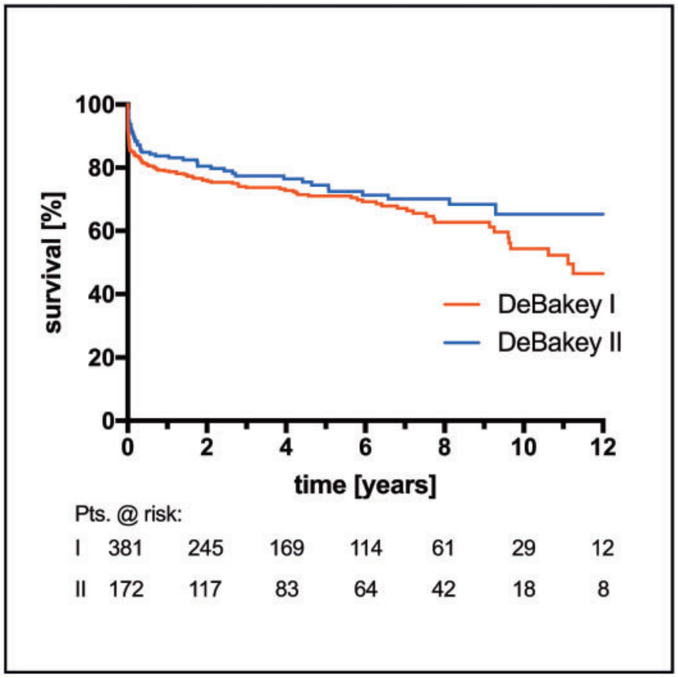
Is isolated proximal repair in acute type A aortic dissection still justified and what are the long-term results?

Key finding

In-hospital mortality was 5.6% in DeBakey type II and 13% in type I. The 5- and 10-year survival rates were 72% and 58%.

Take-home message

Isolated proximal repair with endovascular procedures enables good short- and long-term outcomes in DeBakey type I and II aortic dissections.



Abstract

OBJECTIVES: Conventional treatment for acute type A dissection is the replacement of the ascending aorta. This study demonstrates the results of a conventional approach with isolated proximal repair combined with concomitant endovascular procedures.

METHODS: Replacement of the ascending aorta with or without an open distal anastomosis was defined as isolated proximal repair and was performed in 562/588 patients between January 2004 and June 2017. A total of 68% were DeBakey type I and 32% were DeBakey type II aortic dissections. Concomitant procedures were thoracic endovascular aortic repair (3.6%); visceral, renal and iliac stents (2%); and peripheral bypasses (1.1%). Mean follow-up was 4.6 ± 3.5 years with a 98% follow-up rate. Early and long-term survival, reintervention rates and risk factors were analysed.

RESULTS: Overall, the in-hospital mortality rate was 10.7%, 5.6% in DeBakey type II and 13% in DeBakey type I aortic dissection ($P = 0.008$). Risk factors for in-hospital mortality were age [odds ratio (OR) 1.03], chronic obstructive lung disease (OR 3.98), coronary artery

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disease (OR 2.19), Penn class BC (OR 15.41) and cardiopulmonary bypass time (OR 1.01). The 5- and 10-year survival rates, including in-hospital mortality, were 71% and 54% for type I and 73% and 65% for type II aortic dissection, respectively ($P = 0.14$). Freedom from reintervention after 5 and 10 years was 96% and 94% for DeBakey type II aortic dissection and 86% and 78% for type I ($P < 0.001$).

CONCLUSIONS: Combined with concomitant endovascular procedures, good short- and long-term results can be achieved in DeBakey type I and II aortic dissection. The reintervention rate is higher in DeBakey type I but can be managed open and endovascularly with good results.

Keywords: Aortic dissection • Reintervention

INTRODUCTION

Acute type A aortic dissection is a life-threatening disease with various clinical presentations. Untreated, the mortality rate is 50% after 48 h and 1–2% per h [1]. Despite the tremendous advances in aortic surgery over the past 30 years, operating on a patient with acute type A aortic dissection is still challenging. The primary goal in this emergency is the survival of the patient. The conventional surgical approach is tamponade relief, aortic valve repair and the resection of the primary entry tear by the isolated replacement of the ascending aorta. More aggressive approaches including the replacement of the aortic arch were introduced nearly 3 decades ago. The elephant trunk technique was described in the 1990s by Borst [2] and Svensson [3]. Thoracic endovascular aortic stent grafts evolved simultaneously. The frozen elephant trunk technique, introduced by Jakob *et al*. [4] and Karck *et al*. in 2005 [5], combined both principles. Nevertheless, the long-term benefit for the survival of the patient who has any of these more aggressive approaches is still a matter of debate. In the current era of endovascular arch repair, this debate is further complicated because isolated proximal repair might be sufficient for second stage complete endovascular arch repair, if necessary.

This work presents the short- and long-term results of 562 consecutive patients over a 13-year period treated with isolated proximal repair combined with concomitant endovascular procedures and reinterventions, if necessary. Risk factors for in-hospital and long-term death and reintervention rates are analysed.

PATIENTS AND METHODS

Patient population

Isolated proximal aortic repair was defined as replacement of the ascending aorta up to the innominate artery with an open or clamped distal anastomosis. The International Classification of Diseases codes, 10th Revision (ICD-10), was used to identify patients in our institutional database who were operated on for acute aortic dissection. Approval from our institutional ethics committee was obtained for this retrospective data analysis (2018-13574-Epidemiologie). Between January 2004 and June 2017, a total of 588 adult patients were operated on for acute type A aortic dissection. Isolated proximal aortic repair was performed in 562/588 patients. Of the 26 (4.4%) patients not treated with isolated replacement of the ascending aorta, 13 were treated with subtotal or total arch replacement primarily for DeBakey type I dissection (85%), depending on the surgeon's preference. Thirteen patients (70% DeBakey type II dissection) were treated unconventionally with partial replacement or wrapping of the ascending aorta, including 1 patient with stent grafting of the ascending aorta. Demographics, comorbidities, clinical status at the time of presentation, operative details, postoperative course and reinterventions after isolated proximal repair were analysed. Mean follow-up was 4.6 ± 3.5 years with a 98% follow-up rate.

Patient demographics and cardiovascular risk factors

Acute type A aortic dissection was diagnosed by computed tomography (86%), echocardiography (11%) or angiography (3%). According to the modified DeBakey classification of Tsagakis *et al.* [6] or Philip *et al.* [7], DeBakey type I aortic dissection was diagnosed in 68% with an entry in the ascending and dissection of the descending aorta, DeBakey type II in 32% of the patients with the dissection ending at the level of the innominate artery or in the arch. The mean age was 63.6 ± 13.8 years; 62% were men. Relevant comorbidities are shown in Table 1.

Patient preoperative status

At the time of presentation, 13% of the patients were ventilated. Pericardial tamponade was found in 16% of the patients; 28% of the patients were in shock; 6% were urgently operated on under resuscitation; and 21% of the patients were diagnosed with true lumen collapse. Cerebral malperfusion was found in 12%, any other or combined malperfusion sites in 31%. No preoperative neurological disease was found in 83% of the patients; 3% arrived with a pathological neurological status; and neurological status was not assessable in 14%. Aortic valve insufficiency II° was diagnosed in 75% of the patients (Table 2). The Penn classification [8] was used to summarize the preoperative status for further analysis as follows: Penn class A (51%): no localized malperfusion or shock; Penn class B (23%): localized malperfusion; Penn class C (13%): shock or circulatory collapse; and Penn class BC (13%): localized malperfusion and shock (Table 2).

Procedural details

Although some procedural details varied over the 13-year period, the common standards are described. All patients diagnosed with aortic dissection were directly admitted to the operating room. At least 2 arterial pressure lines, a central venous line and a Sheldon catheter were established. Cerebral perfusion was routinely monitored by cerebral oximetry (INVOS Somanetics, Troy, MI, USA). Body core temperature was measured vesically or rectally. Transoesophageal echocardiography was performed routinely. After a median sternotomy, the pericardium was opened and heparin was administered. Different cannulation strategies were used (Table 3). After the institution of cardiopulmonary

Table 1: Patient demographics

	Total (n = 562)	In-hospital deaths (n = 60)	Hospital survivors (n = 502)	*P*-value
DeBakey				
Type I	384 (68)	50 (83)	334 (67)	**0.008**
Type II	178 (32)	10 (17)	168 (33)	
Demographics				
Age (years)	63.6 ± 13.8	67.33 ± 14.0	63.10 ± 13.7	**0.024**
Male	351 (63)	39 (11)	312 (89)	0.67
Female	211 (37)	21 (10)	190 (90)	
BMI (kg/m^2)	27.4 ± 5.1	28.8 ± 5.7	27.2 ± 5.0	**0.017**
Comorbidities				
COPD	42 (8)	9 (15)	33 (7)	**0.019**
Systemic hypertension	409 (73)	45 (75)	364 (73)	0.68
Diabetes	57 (10)	5 (8.3)	52 (10)	0.62
Nicotine addiction	115 (20)	10 (17)	105 (21)	0.44
CAD	100 (18)	19 (32)	81 (16)	**0.003**
Marfan syndrome	17 (3)	2 (3)	15 (3)	0.88

Values are expressed as *N* (%) or mean ± SD.
The bold *P*-values are statistically significant. All statistical tests were 2-sided with the alpha level set at 0.05 for statistical significance.
BMI: body mass index; CAD: coronary artery disease; COPD: chronic obstructive pulmonary disease; SD: standard deviation.

Table 2: Patient status at time of presentation

Patient characteristics	Total (n = 562)	In-hospital deaths (n = 60)	Hospital survivors (n = 502)	*P*-value
Haemodynamics				
Shock	122 (22)	29 (48)	93 (19)	**<0.001**
Tamponade	92 (16)	22 (37)	70 (14)	**<0.001**
CPR	33 (6)	17 (28)	16 (3)	**<0.001**
Ventilated	74 (13)	22 (37)	52 (10)	**<0.001**
AVR ≥II°	421 (75)	42 (70)	379 (76)	0.35
Malperfusion				
Cerebral	68 (12)	14 (23)	54 (11)	**0.005**
Other	172 (31)	34 (57)	138 (28)	**<0.001**
Neurological diseases				
None	465 (83)	42 (70)	423 (84)	**0.019**
Any	17 (3)	13 (22)	63 (13)	
Unknown	80 (14)	5 (8)	67 (13)	
Penn classification				
A	289 (51)	14 (23)	275 (55)	**<0.001**
B	131 (23)	11 (18)	120 (24)	
C	70 (13)	6 (10)	64 (13)	
BC	72 (13)	29 (49)	43 (9)	

Values are expressed as *N* (%).
The bold *P*-values are statistically significant. All statistical tests were 2-sided with the alpha level set at 0.05 for statistical significance.
AVR: aortic valve regurgitation; CPR: cardiopulmonary resuscitation.

bypass (CPB), patients were cooled to a designated temperature. After cross-clamping, the ascending aorta was resected, and the cardioplegic solution was administered selectively into the coronary ostia. The aortic root was replaced or reconstructed by reinforcement with a Teflon felt strip (polytetrafluoroethylene felt, Impra, Tempe, AZ, USA). If necessary, the aortic valve was replaced or reconstructed using commissural resuspension. The proximal anastomosis of the supracoronary graft replacement (tubular Dacron graft, Braun Aesculap, Tuttlingen, Germany) was done during cooling. After the target temperature was reached, circulatory arrest was initiated (mean temperature, 18.9 ± 3.7°C; mean hypothermic circulatory arrest time, 23.3 ± 8.9 min; no cerebral perfusion, 78%; antegrade cerebral perfusion, 8.7%; and retrograde cerebral perfusion, 13.3%). The distal anastomosis was performed at the level of the innominate artery including the inner curvature of the arch (hemiarch procedure, 59%). In 41% of the patients, the distal anastomosis was performed at the tangentially clamped aorta (mean temperature, 28 ± 5.5°C) and reinforced with Teflon felt. Thereafter, the aortic cannula was placed directly into the tube graft, and antegrade perfusion was restored after deairing. After rewarming, the patient was weaned from CPB. In the case of an ongoing true lumen collapse of the descending aorta diagnosed by transoesophageal echocardiography or computed tomography angiography, the descending

Table 3: Procedural details (others: axillary or innominate artery and ascending aorta)

Procedural details	Total (*n* = 562)	In-hospital deaths (*n* = 60)	Hospital survivors (*n* = 502)	*P*-value
Cannulation strategy				
Femoral	127 (23)	13 (22)	114 (22)	0.83
DTLC	310 (55)	31 (52)	279 (56)	
Arch	75 (13)	8 (13)	67 (13)	
Others	50 (9)	8 (13)	42 (9)	
Perfusion details				
CPB time (min)	168.1 ± 82.5	168.1 ± 135.9	160.3 ± 69.8	**<0.001**
Cross-clamp time (min)	87.9 ± 39.8	105.4 ± 58.4	85.9 ± 36.5	**<0.001**
Temperature (°C)	22.7 ± 6.3	21.3 ± 5.9	22.8 ± 6.4	0.077
HCA time (min)	23.3 ± 8.9	26.5 ± 12.3	22.8 ± 8.4	**<0.001**
Aortic replacement				
Ascending	230 (41)	20 (33)	210 (42)	0.21
Ascending + hemiarch	332 (49)	40 (67)	292 (58)	
Concomitant cardiac procedures				
CABG	72 (13)	19 (32)	53 (11)	**<0.001**
Root replacement	20 (3.6)	4 (6.6)	16 (3.2)	**0.009**
AV replacement[a]	23 (4.1)	3 (5.0)	20 (4.0)	0.10
Concomitant aortic procedures				
TEVAR	20 (3.6)	5 (8.3)	15 (3.0)	**0.035**
SMA stents	5 (0.9)	0 (0)	5 (1)	0.44
CT stents	3 (0.5)	0 (0)	3 (0.6)	0.55
Renal stents	8 (1.4)	0 (0)	8 (1.6)	0.33
Iliac stents	1 (0.2)	0 (0)	1 (0.2)	0.78
Peripheral bypasses	6 (1.1)	0 (0)	6 (1.2)	0.40

Values are expressed as *N* (%) or mean ± SD.
The bold *P*-values are statistically significant. All statistical tests were 2-sided with the alpha level set at 0.05 for statistical significance.
[a]Includes biological and mechanical valve replacements; root replacements include the David, the Yacoub and the Bentall procedures.
AV: aortic valve; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; CT: coeliac trunk; DTLC: direct true lumen cannulation; HCA: hypothermic circulatory arrest, only patients with an open distal anastomosis included; SD: standard deviation; SMA: superior mesenteric artery; TEVAR: thoracic endovascular aortic repair.

aorta was immediately treated by thoracic endovascular aortic repair (TEVAR, 3.6%). Ongoing visceral, renal or peripheral malperfusion was immediately treated by a stent inserted into the coeliac trunk (0.5%), superior mesenteric artery (0.9%), renal arteries (1.4%), iliac arteries (0.2%) or peripheral bypasses (1.1%) (Table 3).

Statistical analyses

Statistical computations and Figs. 1–4 were done using GraphPad Prism version 7.0a for the Mac (GraphPad Software, La Jolla, CA, USA), Wizard Pro data analysis version 1.9.7 (Evan Miller, Chicago, IL, USA) and SPSS 22.0 for the MAC (SPSS Inc., Chicago, IL, USA). Normal assumption of continuous variables was validated using the Shapiro–Wilk test. Baseline demographics, patient status at the time of presentation and procedural data of in-hospital survivors and deceased patients were compared using the Student's *t*-test or the Wilcoxon–Mann–Whitney *U*-test for continuous variables and the χ^2 test or the Fisher's exact test for categorical variables, as appropriate. Variables whose values or distributions differed significantly between the 2 groups of survivors and deceased patients and appeared clinically reasonable were identified as possible risk factors for early or late death. The influence of the identified variables on in-hospital mortality was analysed by multivariable logistic regression analysis. Receiver operating characteristic curve analyses were applied to evaluate the model. Survival was assessed with the use of the Kaplan–Meier method and compared with the use of the log-rank test. Risk factors for long-term survival were assessed with the use of a multivariable Cox regression analysis. All statistical tests were 2-sided with the alpha level set at 0.05 for statistical significance. All frequency data are presented as percentages and all continuous data, as the mean ± standard deviation. The confidence interval (CI) is 95%.

RESULTS

Risk factors for in-hospital death

The overall in-hospital mortality rate after isolated proximal repair in acute aortic dissection was 10.7%; the 30-day mortality rate was 12.1%. The in-hospital mortality rate was significantly higher among patients with DeBakey type I aortic dissection than among those with DeBakey type II aortic dissection (13% vs 5.6%; $P = 0.008$).

The mean age and body mass index of patients who died in the hospital were significantly higher compared to those of hospital survivors. The incidences of chronic obstructive pulmonary disease (COPD) and of coronary artery disease (CAD) were significantly higher in the group of patients who died in-hospital (Table 1). At the time of presentation, the incidences of shock, tamponade, cardiopulmonary resuscitation and of the need for ventilation were significantly higher in the group of patients who died in the hospital. Furthermore, significantly more malperfusion syndromes and neurological diseases were found at the time of presentation in patients who died in the hospital during the postoperative course (Table 2). The in-hospital mortality rate,

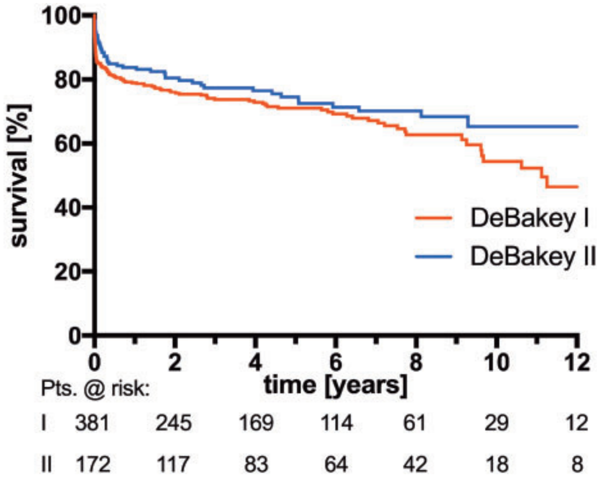

Figure 1: Long-term survival including in-hospital mortality rate ($P = 0.14$). Pts.: patients.

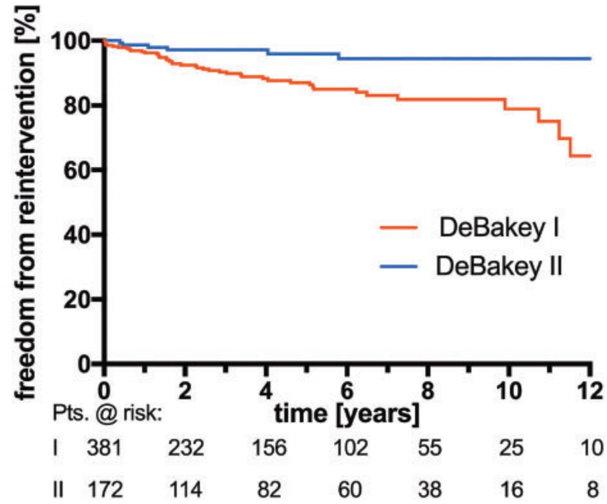

Figure 2: Freedom from any reintervention ($P < 0.001$). Pts.: patients.

according to the Penn classification system, was 4.5% in Penn class A, 8.4% in Penn class B, 8.6% in Penn class C and 40.3% in Penn class BC groups. Concomitant aortic procedures were more frequent in patients with Penn classes B and BC compared to those with Penn classes A and C (14% vs 1%; $P < 0.001$).

No significant differences between hospital survival and mortality rates were found based on the cannulation strategy. CPB, cross-clamp and hypothermic circulatory arrest times were significantly shorter in in-hospital survivors. Whether the distal anastomosis was sewed open or at the clamp did not influence the in-hospital survival rate. Significantly more concomitant root, coronary artery bypass grafting and TEVAR procedures had to be performed in the patients who died in the hospital (Table 3).

In a multivariable logistic regression model, age (years) [odds ratio (OR) 1.03, CI 1.004–1.055; $P = 0.021$], COPD (OR 3.5, CI 1.4–9.3; $P = 0.01$), CAD (OR 2.3, CI 1.2–4.7; $P = 0.016$), Penn class BC (OR 15.4, CI 6.9–34.1; $P < 0.001$) and CPB time in min (OR 1.009, CI 1.005–1.012; $P < 0.001$) were the relevant risk factors for in-hospital death. The receiver operating characteristic analysis showed a good fitting of this model (AUC = 0.85). Based on this model, the predicted in-hospital mortality rate for a 40-year-old patient without COPD or CAD, without shock or malperfusion and a CPB time of 170 min is only 2%. The predicted in-hospital mortality rate for an 80-year-old patient with COPD, CAD, shock and malperfusion and 170 min CPB time is 86%.

Postoperative morbidity and neurological outcome

The overall rethoracotomy rate was 11.6% and was significantly higher in the group who died in the hospital (25% vs 10%; $P < 0.001$). Temporary renal replacement therapy was necessary for 14.6%, which was significantly lower in the hospital survivor group (11.6% vs 40%; $P < 0.001$). The average duration of the intensive care stay of the entire group was 5.8 ± 7.3 days, the mean duration of ventilation was 75.2 ± 145.4 h and the mean duration of hospitalization was 13.2 ± 14.6 days. New neurological diseases were diagnosed in 7.7% of the patients. The rate of new neurological events was higher in the DeBakey type I dissection group compared to the DeBakey type II dissection group (8.3% vs 6.2%; $P = 0.37$). An existing preoperative condition resolved in 50% of these patients.

Long-term survival

The long-term survival rate including in-hospital mortality was 71% after 5 years and 54% after 10 years in patients with DeBakey type I aortic dissection. In DeBakey type II aortic dissection, the 5- and 10-year survival rates were 73% and 65%, respectively. No statistically significant differences were found between the Kaplan–Meier survival curves of DeBakey type I and II aortic dissections (Fig. 1; $P = 0.14$).

In the group of hospital survivors, age (HR 1.05, CI 1.05–1.08; $P < 0.001$), hypertension (HR 1.88, CI 1.16–3.04; $P = 0.01$), CAD (HR 1.85, CI 1.22–2.81; $P = 0.004$) and COPD (HR 2.43, CI 1.45–4.06; $P < 0.001$) were significant risk factors for long-term survival in multivariable Cox regression analyses. Postoperatively, the relevant risk factors were rethoracotomy (HR 1.66, CI 1.01–2.72; $P = 0.046$), temporary and continuous haemodialysis (HR 3.45, CI 2.30–5.16; $P < 0.001$) and tracheotomy with prolonged ventilation (HR 4.09, CI 2.57–6.53; $P < 0.001$).

Reinterventions

Rates of freedom from any reintervention in DeBakey type II aortic dissection were significantly lower than those from a DeBakey type I aortic dissection after 5 (96% vs 86%) and 10 years (94% vs 78%; $P < 0.001$, Fig. 2). In total, 52 patients needed reinterventions. The mean age of these patients at the time of reintervention was 59 ± 13 years, and 73% were men.

Proximal reinterventions included aortic valve replacement ($n = 6$), root replacement ($n = 7$) or repair ($n = 6$) for symptomatic aortic valve insufficiency or root dilatation >55 mm. Distal reinterventions were a conventional arch repair with an elephant trunk or frozen elephant trunk procedure ($n = 9$), TEVAR ($n = 22$) or false lumen closure with a candy plug device ($n = 3$) for a false lumen aneurysm. One patient had root replacement and arch repair.

Significantly higher distal and proximal reintervention rates were found in patients with DeBakey type I aortic dissection compared to those with DeBakey type II aortic dissection. Freedom from proximal reintervention in those with DeBakey type II aortic dissection was 99% after 5 and 98% after 10 years, but 96% and 91% after 5 and 10 years in those with DeBakey type I aortic dissection ($P = 0.02$, Fig. 3). The freedom from distal reintervention in

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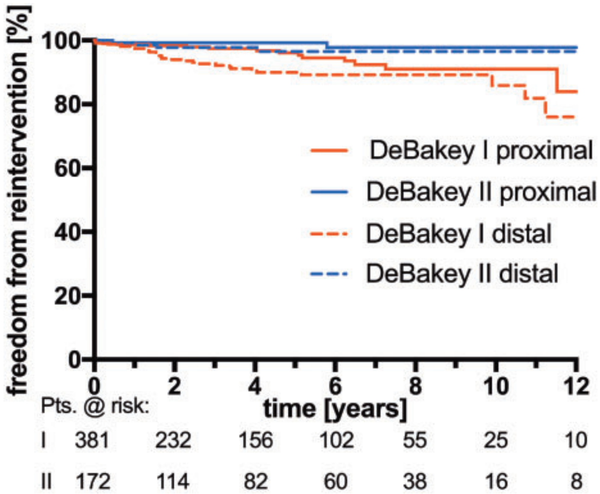

Figure 3: Freedom from proximal reintervention (DeBakey I versus DeBakey II: $P = 0.02$) and distal reintervention (DeBakey I versus DeBakey II: $P = 0.01$). Pts.: patients.

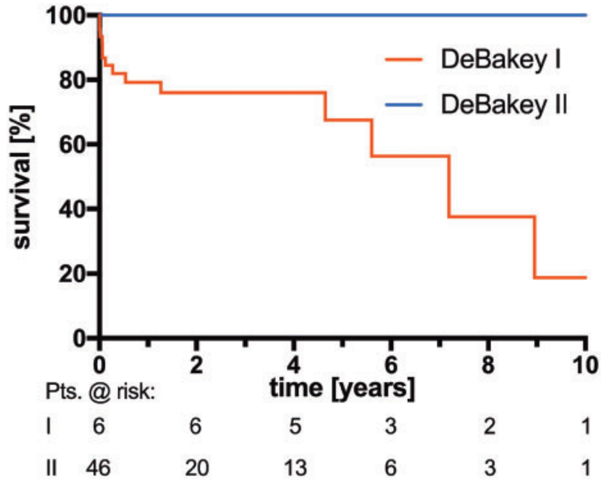

Figure 4: Long-term survival including in-hospital mortality rate after reintervention. Pts.: patients.

patients with DeBakey type II aortic dissection was 97% after 5 and 10 years and 90% and 86% after 5 and 10 years in those with DeBakey type I aortic dissection ($P = 0.01$, Fig. 3).

The in-hospital mortality rate was 15.8% after proximal and 14.7% after distal reintervention. The long-term survival rate including in-hospital mortality was 100% in patients with DeBakey type II and 68% in those with DeBakey type I after 5 years (Fig. 4; $P = 0.067$). No differences in long-term survival were found in patients with or without reintervention ($P = 0.58$).

Aortic re-reinterventions were necessary for 12 patients. One (5.2%) patient who had a mechanical valve replacement had to be re-reoperated on for endocarditis after 4.6 years. Eleven patients (29.4%) received distal re-reinterventions after 1.9 ± 2.0 years. These included TEVAR elongation for distal endoleaks ($n = 5$), debranching and type II hybrid repair ($n = 1$) or branched arch stenting ($n = 1$) for arch aneurysms >60 mm, candy plugs for growing false lumen aneurysms ($n = 2$) and abdominal branched grafts with endovascular aneurysm sealing (EVAS) ($n = 2$) for abdominal aortic aneurysm growth. Three patients received a third reintervention with arch debranching and type II hybrid repair for continuous arch dissection with aneurysm growth.

In a multivariable logistic regression model, DeBakey type I or II (OR 0.24, CI 0.01–0.59; $P = 0.002$), age in years (OR 0.96, CI 0.94–9.8; $P < 0.001$) and Marfan syndrome (OR 4.68, CI 1.6–13.7; $P = 0.005$) were the relevant risk factors for any reintervention during the follow-up period. The receiver operating characteristic analysis showed the good fit of this model (area under the curve (AUC) = 0.72). Based on this model, the predicted chance for any reintervention after isolated proximal repair in DeBakey type I dissection is 13% for a 55-year-old patient, but only 6.5% for a 75-year-old patient. In the case of Marfan syndrome, the 55-year-old patient has a 41.8% chance and the 75-year-old patient, a 24.5% chance of any reintervention.

DISCUSSION

We present our experience with 562 patients treated with an isolated proximal repair in acute DeBakey type I and II aortic dissections. Our patient demographics, with a mean age of about 60 years and 2 out of 3 male patients, are typical, as demonstrated in large registries like the German Registry for Acute Aortic Dissection Type A [9], the International Registry of Acute Aortic Dissections (IRAD) [10] or the Nordic consortium registry [11].

Patients comorbidities and clinical status at the time of presentation are known risk factors for in-hospital mortality. The distribution of the Penn classification in our group (A 51%, B 23%, C 13%, BC 13%) was similar to the distribution first described by the Penn group (A 58%, B 18%, C 15%, BC 9%) [12] and others [13, 14].

Our overall in-hospital mortality after isolated proximal repair was 10.7% and slightly lower compared to results reported by the IRAD (14.2%) [15], the German Registry for Acute Aortic Dissection Type A (16.9%) [9] or larger single-centre series with isolated proximal repair like Kim *et al.* (9.7%) [16] or Geirsson *et al.* (12.7%) [17]. The lowest in-hospital mortality rate was found among patients with Penn class A (4.5), a higher mortality rate in those with Penn classes B and C (8.5%) and the highest mortality rate among those with Penn class BC (40.3%). These results are consistent with those of previous reports [13, 14] and further validate the Penn classification. In our multivariable logistic regression model, shock and malperfusion (Penn class BC) had the biggest impact on in-hospital mortality followed by the presence of COPD and CAD, the patient's age and the CPB time, which is the only variable that can be influenced by the surgeon. Isolated proximal repair enables short CBP times of about 170 min and cross-clamp times of about 90 min, which are significantly less compared to CPB and cross-clamp times for extensive repairs with total arch replacement reported in a large meta-analysis of frozen elephant trunk procedures where CPB time was strongly correlated with mortality [18].

The number of patients with DeBakey type II aortic dissection in our cohort was similar to that in the Nordic consortium cohort (26%) [11], but higher compared to that in the IRAD cohort, which reported 10% with DeBakey type II aortic dissection [10]. The modified classification we used might cause this result [6]. To our knowledge, ours is the most extensive series demonstrating significant differences for in-hospital mortality in DeBakey type I and II aortic dissections. Based on our current knowledge, we would expect more distal reinterventions in DeBakey type I aortic dissection and similar rates of proximal reinterventions in DeBakey type I and II aortic dissections. Interestingly, the rate of distal and proximal reinterventions was significantly higher in DeBakey type I aortic dissection. This finding could indicate that the differences between DeBakey type I and II dissections do not exist only in the longitudinal extent of the dissection but rather that the different extent of the dissection can be attributed to tissue-specific differences. Despite the differences in the rates of reintervention, there were no significant differences in long-term outcome between type I and II dissections. Longer follow-up times might have resulted in significant differences.

In similar series with >95% isolated proximal aortic repair, the rates of freedom from proximal or distal reinterventions in DeBakey I and II dissections after 10 years were between 70% and 74% [17, 19, 20]. In our series the freedom from reintervention after 10 years in DeBakey type I was 78%. This result could be explained by the use of TEVAR as a concomitant procedure in 3.6% of cases in the event of a persistent collapse of the true lumen. The 15% in-hospital mortality rate of reinterventions that we described is similar to the 19.6% mortality described by Dell'Aquila *et al.* [21] in 117 type A dissection reoperations.

Nevertheless, the 5- and 10-year survival rates of 71% and 54% for DeBakey type I aortic dissection and 73% and 65% for DeBakey type II aortic dissection after isolated proximal repair are good. In the literature, a 5-year survival rate of 65% to 68% and a 10-year survival rate of 53% and 55% is reported from groups and registries that predominantly performed an isolated proximal repair in acute type A dissections [22–25]. Although the distal reintervention rates after a more extensive arch replacement with the frozen elephant trunk technique are slightly lower, the 5-year survival rate is not superior. In an international registry with 138 acute dissections treated with the frozen elephant trunk technique, freedom from distal reintervention and 5-year survival were 90% and 63% [26].

In addition to age, the risk factors we identified for long-term survival were early postoperative factors such as long-term ventilation, rethoracotomy and dialysis, as well as chronic secondary diseases such as CAD, hypertension and COPD. Of the early postoperative factors, dialysis and long-term ventilation are mostly unaffectable and closely associated with the preoperative clinical condition of the patient. The importance of a rethoracotomy for the outcome has already been discussed by Martens *et al.* [27] and stresses the importance of haemostasis and coagulation management in these complex interventions. The optimization and treatment of chronic secondary diseases such as CAD, COPD and hypertension are important factors for long-term survival and must not be neglected in the context of regular follow-up examinations.

Limitations

A relevant limitation of this study is the missing morphological CTA analyses. It is therefore not possible to determine the frequency of persisting entries in the arch or even new entries at the distal anastomosis. Nor can we quantify their effect on aortic remodelling and potentially necessary reinterventions, which is the task of a future research project.

CONCLUSION

In conclusion, this study demonstrates excellent results for isolated proximal repair in patients with DeBakey type II aortic dissection. Combined with concomitant endovascular procedures, proper short and long-term results can be achieved in patients with DeBakey type I aortic dissection. Although the reintervention rate is higher in those with DeBakey type I aortic dissection, reinterventions can be managed both open and endovascularly with good results. Nevertheless, in younger patients without malperfusion or shock, and primarily if any signs of connective tissue disease exist, more aggressive repair strategies concerning the root and the arch should be applied. Close and regular follow-up examinations with the focus on aortic imaging and secondary diseases by an integrated team of cardioaortic and vascular specialists are mandatory for good long-term results.

Conflict of interest: none declared.

REFERENCES

[1] Hirst AE, Johns VJ, Kime SW. Dissecting aneurysm of the aorta: a review of 505 cases. Medicine (Baltimore) 1958;37:217–79.
[2] Borst HG. The birth of the elephant trunk technique. J Thorac Cardiovasc Surg 2013;145:44.
[3] Svensson LG. Rationale and technique for replacement of the ascending aorta, arch, and distal aorta using a modified elephant trunk procedure. J Card Surg 1992;7:301–12.
[4] Jakob H, Tsagakis K, Leyh R, Buck T, Herold U. Development of an integrated stent graft-dacron prosthesis for intended one-stage repair in complex thoracic aortic disease. Herz 2005;30:766.
[5] Karck M, Chavan A, Khaladj N, Friedrich H, Hagl C, Haverich A. The frozen elephant trunk technique for the treatment of extensive thoracic aortic aneurysms: operative results and follow-up. Eur J Cardiothorac Surg 2005;28:286–90; discussion 290.
[6] Tsagakis K, Tossios P, Kamler M, Benedik J, Natour D, Eggebrecht H *et al.* The DeBakey classification exactly reflects late outcome and reintervention probability in acute aortic dissection with a slightly modified type II definition. Eur J Cardiothorac Surg 2011;40:1078–84.
[7] Philip JL, De Oliveira NC, Akhter SA, Rademacher BL, Goodavish CB, DiMusto PD *et al.* Cluster analysis of acute ascending aortic dissection provides novel insight into mechanisms of distal progression. J Thorac Dis 2017;9:2966–73.
[8] Augoustides JGT, Szeto WY, Desai ND, Pochettino A, Cheung AT, Savino JS *et al.* Classification of acute type A dissection: focus on clinical presentation and extent. Eur J Cardiothorac Surg 2011;39:519–22.
[9] Conzelmann LO, Weigang E, Mehlhorn U, Abugameh A, Hoffmann I, Blettner M *et al.* Mortality in patients with acute aortic dissection type A: analysis of pre- and intraoperative risk factors from the German Registry for Acute Aortic Dissection Type A (GERAADA). Eur J Cardiothorac Surg 2016;49:e44–52.
[10] Evangelista A, Isselbacher EM, Bossone E, Gleason TG, Eusanio MD, Sechtem U *et al.* Insights from the International Registry of Acute Aortic Dissection: a 20-year experience of collaborative clinical research. Circulation 2018;137:1846–60.
[11] Pan E, Gudbjartsson T, Ahlsson A, Fuglsang S, Geirsson A, Hansson EC *et al.* Low rate of reoperations after acute type A aortic dissection repair from the Nordic Consortium Registry. J Thorac Cardiovasc Surg 2018;156:939–48.
[12] Augoustides JGT, Geirsson A, Szeto WY, Walsh EK, Cornelius B, Pochettino A *et al.* Observational study of mortality risk stratification by ischemic presentation in patients with acute type A aortic dissection: the Penn classification. Nat Rev Cardiol 2009;6:140–6.
[13] Kimura N, Ohnuma T, Itoh S, Sasabuchi Y, Asaka K, Shiotsuka J *et al.* Utility of the Penn classification in predicting outcomes of surgery for acute type A aortic dissection. Am J Cardiol 2014;113:724–30.

[14] Olsson C, Hillebrant C-G, Liska J, Lockowandt U, Eriksson P, Franco-Cereceda A. Mortality in acute type A aortic dissection: validation of the Penn classification. Ann Thorac Surg 2011;92:1376–82.

[15] Larsen M, Trimarchi S, Patel HJ, Di Eusanio M, Greason KL, Peterson MD *et al*. Extended versus limited arch replacement in acute type A aortic dissection. Eur J Cardiothorac Surg 2017;52:1104–10.

[16] Kim JB, Chung CH, Moon DH, Ha GJ, Lee TY, Jung SH *et al*. Total arch repair versus hemiarch repair in the management of acute DeBakey type I aortic dissection. Eur J Cardiothorac Surg 2011;40:881–7.

[17] Geirsson A, Bavaria JE, Swarr D, Keane MG, Woo YJ, Szeto WY *et al*. Fate of the residual distal and proximal aorta after acute type A dissection repair using a contemporary surgical reconstruction algorithm. Ann Thorac Surg 2007;84:1955–64; discussion 1955–64.

[18] Tian DH, Wan B, Bannon PG, Misfeld M, LeMaire SA, Kazui T *et al*. A meta-analysis of deep hypothermic circulatory arrest versus moderate hypothermic circulatory arrest with selective antegrade cerebral perfusion. Ann Cardiothorac Surg 2013;2:148–58.

[19] Zierer A, Voeller RK, Hill KE, Kouchoukos NT, Damiano RJ, Moon MR. Aortic enlargement and late reoperation after repair of acute type A aortic dissection. Ann Thorac Surg 2007;84:479–86; discussion 486–7.

[20] Kazui T, Washiyama N, Bashar AHM, Terada H, Suzuki T, Ohkura K *et al*. Surgical outcome of acute type A aortic dissection: analysis of risk factors. Ann Thorac Surg 2002;74:75–81; discussion 81–2.

[21] Dell'Aquila AM, Pollari F, Fattouch K, Santarpino G, Hillebrand J, Schneider S *et al*. Early outcomes in re-do operation after acute type A aortic dissection: results from the multicenter REAAD database. Heart Vessels 2016;32:566–73.

[22] Fann JI, Smith JA, Miller DC, Mitchell RS, Moore KA, Grunkemeier G *et al*. Surgical management of aortic dissection during a 30-year period. Circulation 1995;92:II113–21.

[23] Sabik JF, Lytle BW, Blackstone EH, McCarthy PM, Loop FD, Cosgrove DM. Long-term effectiveness of operations for ascending aortic dissections. J Thorac Cardiovasc Surg 2000;119:946–62.

[24] Kohl LP, Isselbacher EM, Majahalme N, Evangelista A, Russo MJ, Hutchison S *et al*. Comparison of outcomes in DeBakey type AI versus AII aortic dissection. Am J Cardiol 2018;122:689–95.

[25] Bekkers JA, Raap GB, Takkenberg JJM, Bogers AJJC. Acute type A aortic dissection: long-term results and reoperations. Eur J Cardiothorac Surg 2013;43:389–96.

[26] Jakob H, Tsagakis K. International E-vita open registry. Ann Cardiothorac Surg 2013;2:296–9.

[27] Martens A, Beckmann E, Kaufeld T, Umminger J, Fleissner F, Koigeldiyev N *et al*. Total aortic arch repair: risk factor analysis and follow-up in 199 patients. Eur J Cardiothorac Surg 2016;50:940–8.