Hemiarch and Total Arch Surgery in Patients With Previous Repair of Acute Type I Aortic Dissection

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Background. **We examined our contemporary experience with hemiarch and total arch replacement in patients with previous acute type I aortic dissection.**

Methods. **Over an 8.5-year period, 137 consecutive patients (median age 58 years, interquartile range, 50 to 67) underwent hemiarch or total transverse aortic arch replacement a median of 7.7 years (range, 67 days to 32 years; interquartile range, 2.8 to 12.3 years) after previous acute type I aortic dissection repair. Interventions involving only the aortic root, aortic valve, descending aorta, or thoracoabdominal aorta were excluded. Multivariate analysis of 20 potential preoperative and intraoperative risk factors was performed to examine early death, neurologic deficit, composite endpoint (operative death, permanent neurologic deficit, or hemodialysis at discharge), and long-term mortality.**

Results. **Total arch replacement was performed in 103 patients (75.2%), hemiarch replacement in 34 (24.8%), and elephant trunk procedures in 77 (56.2%). Thirty-one repairs (22.6%) were emergent or urgent. There were 16 operative deaths (11.7%), 4 permanent strokes (3.6%), and 21 (15.3%) instances of the composite endpoint. In the multivariate analysis, congestive heart failure and cardiopulmonary bypass time independently predicted operative mortality ($p = 0.0027$, $p = 0.018$). Emergency operation approached significance for stroke ($p = 0.088$). Predictors of long-term mortality (during a median follow-up period of 5.1 years, 95% confidence interval: 4.4 to 5.8) were female sex ($p = 0.0036$), congestive heart failure ($p = 0.0045$), and circulatory arrest time ($p = 0.0013$); preoperative pulmonary disease approached significance ($p = 0.074$). Five-year survival was 73.2%.**

Conclusions. **In patients with previous acute type I aortic dissection repair, hemiarch and total arch operations have respectable morbidity and survival rates. Congestive heart failure predicts operative death, long-term mortality, and our adverse event endpoint. Cardiopulmonary bypass time predicts operative mortality, and female sex and circulatory arrest time predict long-term mortality.**

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The widely accepted current operative treatment for acute type I aortic dissection is open distal ascending aortic replacement with hypothermic circulatory arrest with or without cerebral perfusion [1]. Even though recent results from centers of excellence show significant improvement with regard to operative mortality [2, 3], the initial procedure carries substantial morbidity and mortality risk despite advances in surgical techniques and brain protection [4, 5]. The effect of the extent of the initial aortic replacement on operative mortality and long-term outcomes remains an issue of ongoing debate [4, 6–9]. A review by Kirklin and Kouchoukos [10] states that the arch should be included in the initial repair when the intimal tear is in the arch, when the arch is ruptured, when the outer wall of the false lumen of the aneurysmal arch is tenuous, or when the inner wall of the false lumen of the aneurysmal arch is fragmented.

Few data exist with regard to operative morbidity and mortality or disease progression necessitating a second intervention in patients who undergo hemiarch or total arch operations after previous repair of acute type I aortic dissection. Therefore, we analyzed our contemporary experience with hemiarch and total aortic arch replacement in patients with previous aortic repair for acute type I aortic dissection, examining their operative outcomes and long-term survival.

Patients and Methods

Over a recent 8.5-year period, 137 consecutive patients with previous repair of acute type I aortic dissection underwent hemiarch and total arch operation at our institution. Twenty-three of them had pseudoaneurysms, and 2 had impending rupture. Data were collected from a prospectively maintained database, and Institutional

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Review Board approval was obtained. The follow-up data were obtained from clinic visits, telephone conversations with patients, and the Social Security Death Index. Our definitions of cardiopulmonary bypass (CPB) time, cardiac ischemia time, antegrade cerebral perfusion time, and circulatory arrest time are described in previous reports [11], as are our definitions of the preoperative variables (Table 1), operative mortality, stroke, and the composite endpoint (operative mortality or permanent hemodialysis at discharge, or permanent neurologic event) [11, 12].

Table 2 shows the intraoperative variables. The median follow-up period was 5.1 years (95% confidence interval: 4.4 to 5.8). The median time from the initial type I aortic dissection to the current operation was 7.7 years (25% to 75% interquartile range, 2.8 to 12.3).

Surgical Technique

The patients included in this report all had either their ascending aorta alone or their ascending aorta and proximal arch replaced during the previous repair of the acute type I aortic dissection (Table 2). A computed tomography scan was obtained to determine the proximity of the cardiac structures to the posterior aspect of the sternum. The axillary, innominate, and femoral arteries were variously used as the cannulation site for arterial inflow; the choice of site depended on the situation. Near-infrared spectroscopy monitoring was used throughout the procedure, as described previously [12].

The target nasopharyngeal temperature for initiation of antegrade cerebral perfusion (ACP) was 21°C to 24°C. The flow rate with ACP on initiation of circulatory arrest was 10 to 15 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, which was adjusted according to the near-infrared spectroscopic findings. If these findings indicated that the patient's regional cerebral oxygen saturation was more than 10% above baseline, we increased the flow. For complex arch reconstructions, it is our preference to perform bilateral ACP through the left and right common carotid arteries.

A variety of reconstruction techniques were used for the replacement of the total transverse arch: Y-graft, double Y-graft (trifurcated), island anastomosis, a combination of a single graft and island configuration, and four-branch configuration. All of these techniques were used with or without elephant trunk (ET), frozen ET, or both.

The steps we use in performing these procedures have been described in detail in previous reports [12, 13]. Briefly, when we use the Y-graft, we expose the brachiocephalic vessels during cooling. The subclavian artery is reconstructed first, followed by the left common carotid artery. The main trunk of the innominate artery is anastomosed to the main trunk of the bifurcated or trifurcated graft. We administer ACP through the branches of the Y-graft. After reconstruction of the head vessels is completed, a clamp is applied at the proximal aspect of the graft, and rewarming starts. Commonly, in chronic type I aortic dissection, the pathology extends beyond the left subclavian artery, and an ET repair using a skirted ET graft (Vascutek Terumo, Inchinnan, UK) is required. A frozen ET technique was used in patients in whom we considered it feasible to perform the second stage of the distal aortic reconstruction as an endovascular procedure [14].

Statistical Analysis

In univariate analysis, the χ^2 test or the Fisher exact test was used to test for between-groups differences in

Table 1. Preoperative Characteristics and Demographics

Characteristics	Values
Age, years	58.0 (50–67)
Age ≥ 70 years	28 (20.4)
Male	105 (76.6)
Hypertension	116 (84.7)
Genetic disease	44 (32.1)
Preoperative cardiac disease[a]	35 (25.6)
Congestive heart failure	46 (33.6)
Preoperative pulmonary disease[b]	42 (30.7)
Cerebrovascular accident	26 (19.0)
Preoperative renal disease[c]	4 (2.9)
Urgent/emergent	31 (22.6)
Previous operations	
Aortic root repair or replacement	54 (39.4)
Aortic valve replacement	24 (17.5)

[a] Preoperative cardiac disease was defined as nonocclusive coronary artery disease or any history of coronary artery bypass grafting or percutaneous coronary intervention. [b] Preoperative pulmonary disease was defined as chronic obstructive pulmonary disease or pulmonary restrictive disease. [c] Preoperative renal disease was defined as a history of hemodialysis, a creatinine level of 1.5 mg/dL or greater, or a history of renal insufficiency.

Values are median (25% to 75% interquartile range) for continuous variables and n (%) for categoric variables.

Table 2. Intraoperative Details

Intraoperative Details	Values
Procedure	
Total arch	103 (75.2)
Hemiarch	34 (24.8)
Concomitant procedures	
Coronary artery bypass grafting	13 (9.5)
Mitral valve repair	3 (2.2)
Tricuspid valve repair	1 (0.7)
Aortic valve replacement	15 (11.0)
Aortic valve repair[a]	10 (7.3)
Aortic root repair or replacement	32 (23.4)
Intraoperative times, minutes	
Circulatory arrest time	60.0 (42–82)
Cardiopulmonary bypass time	141.0 (115–178)
Antegrade cerebral perfusion time	59.0 (38–80)
Cardiac ischemia time	97.0 (74–124)

[a] Aortic valve commissuroplasty or resuspension, or both.

Values are median (25% to 75% interquartile range) for continuous variables and n (%) for categoric variables.

categorical variables. Significance was defined as p less than 0.05. Multivariate analysis involved both nominal and exact logistic regression. Twenty preoperative and intraoperative variables were included in the logistic regression analysis: age, sex, genetic disease, coronary artery disease (including nonocclusive disease and any previous coronary artery bypass grafting or preoperative percutaneous balloon angioplasty), congestive heart failure (CHF [defined as New York Heart Association functional class III or IV]), pulmonary disease, cerebrovascular accident (CVA), renal disease, previous aortic root replacement, previous aortic valve replacement, urgent/emergent status, circulatory arrest time, CPB time, ischemia time, full aortic arch replacement, concomitant coronary artery bypass graft surgery, concomitant aortic valve replacement, concomitant aortic valve repair, and concomitant root replacement or repair.

A logistic regression was performed that included all 20 of these variables. The variables that were significant at a p value of 0.1 were then included in an exact logistic regression to add rigor to the results, thereby compensating for the relatively low frequency of the outcomes of interest. Computer memory issues prevented the exact logistic regression for long-term mortality from executing. However, for the operative death, stroke, and composite-outcome models, the exact logistic regression was run successfully. Univariate logistic regressions were done for the intraoperative times to determine whether they were significant predictors of the outcomes when considered in isolation.

The Kaplan-Meier method was used to estimate survival for patients who survived the operative period. An overall survival curve was created, as were curves for the variables that the multivariate logistic regression model determined to be significant predictors of an outcome of interest. The time to death from the date of surgery was computed for patients who died before December 31, 2014. All statistical analyses were conducted with SAS version 9.1 (SAS Institute, Cary, NC).

Results

Operative Mortality

Sixteen patients (11.7%) died within 30 days or in hospital (Table 3). In 4 of these patients, the procedure was done urgently or emergently. Nine patients required extracorporeal membrane oxygenator or ventricular assist device support at some point during their postoperative course. Five patients died of multiorgan failure, and 5 patients could not be separated from extracorporeal membrane oxygenator or ventricular assist device support. Two patients had fatal stroke. One patient had been admitted with symptomatic pseudoaneurysm of the ascending aorta and simultaneous extent II thoracoabdominal aortic aneurysm; this patient underwent ascending and total arch replacement with ET stage I repair and had postoperative paraplegia. While the patient was recovering (not in the intensive care unit), the thoracoabdominal aortic aneurysm ruptured, and the patient died. Another patient died on postoperative day 19 while recovering at home. The last 2 patients underwent unsuccessful cardiopulmonary resuscitation for hypotension and unresponsiveness on postoperative days 12 and 44.

Table 3. Short-Term Complications

Complication	Value
Operative mortality	16 (11.7)
Long-term mortality	39 (28.5)
Any neurologic deficit at discharge[a]	9 (6.6)
Any permanent neurologic deficit at discharge	6 (4.4)
Postoperative stroke	8 (5.8)
Postoperative spinal cord deficit	2 (1.5)
Reoperation for bleeding	19 (13.9)
Postoperative cardiac events	17 (12.4)
Myocardial infarction	4 (2.9)
Ventricular arrhythmia	10 (7.3)
Arrhythmia requiring pacemaker	5 (3.7)
Postoperative pulmonary[b]	62 (45.3)
Tracheostomy	20 (14.6)
Postoperative renal insufficiency	23 (16.8)
Vocal cord paralysis	17 (12.4)
Renal dysfunction[c]	2 (1.5)
Composite adverse endpoint[d]	21 (15.3)
Length of hospital stay, days	14.0 (10–25)

[a] One patient had both spinal cord deficit (permanent) and stroke (full recovery). [b] Ventilator support more than 48 hours. [c] Requiring hemodialysis at discharge. [d] Operative mortality, permanent neurologic deficit, or permanent renal failure.

Values are median (25% to 75% interquartile range) for continuous variables and n (%) for categoric variables.

Univariate analysis showed that CPB time and cardiac ischemia time were significant predictors of early mortality (ie, 30-day or inhospital mortality; $p = 0.0063$ and 0.0068, respectively), and circulatory arrest time approached significance ($p = 0.068$). In the multivariate analysis, CPB time ($p = 0.018$) and CHF ($p = 0.0027$) independently predicted operative mortality (Table 4).

Neurologic Events

Nine patients (6.6%) had stroke, spinal cord deficit, or (in 1 patient) both (Table 3). In 6 (4.4%) of these patients,

Table 4. Multivariate Analysis Using Logistic Regression Model

Outcome	Model Variable	p Value
Operative death	Congestive heart failure	0.0027
	Cardiopulmonary bypass time	0.018
Long-term mortality	Female	0.0036
	Congestive heart failure	0.0045
	Circulatory arrest time	0.0013
	Preoperative pulmonary disease	…
Stroke	Cerebrovascular accident	0.35
	Urgent/emergent	0.088
Composite endpoint	Congestive heart failure	0.018
	Cardiopulmonary bypass time	0.063

the neurologic deficits were permanent. Eight patients (5.8%) had CVA, 3 of whom fully recovered. All but 2 of these patients underwent full arch reconstruction with prolonged circulatory arrest (ie, longer than 60 min) and bilateral ACP. Among the 5 patients who had permanent stroke, 3 had a history of CVA, and in 2, the operation was performed emergently.

A spinal cord deficit was encountered in 2 patients (1.5%). One recovered completely after total arch and simultaneous extent I thoracoabdominal aortic aneurysm repair; this patient had preoperative cerebrospinal fluid drainage. The other became paraplegic; this patient had permanent spinal cord injury and temporary right-side weakness and slurred speech after undergoing total arch and stage I ET repair. Multivariate analysis showed that urgency of the operation and previous CVA approached significance as predictors of stroke ($p = 0.088$ and 0.35, respectively). None of the intraoperative times was a significant predictor of stroke (Table 4).

Composite Endpoint

Twenty-one patients (15.3%) died or had a permanent neurologic deficit or renal dysfunction during the operative period. Among these patients, 3 had more than one of the events that constituted the composite endpoint. Univariate analysis showed that CPB time, cardiac ischemia time, and circulatory arrest time were predictive of the composite endpoint ($p = 0.022$, 0.034, and 0.052, respectively). In the multivariate analysis, CHF was a predictor of the composite endpoint ($p = 0.018$), and CPB approached significance as a predictor of this endpoint ($p = 0.063$; Table 4). The other short-term complications are listed in Table 3.

Long-Term Survival and Mortality

Figure 1 shows the Kaplan-Meier survival curve during the follow-up period for 121 patients who were discharged from the hospital. Ninety-eight patients (81%) survived until the end of the study (December 31, 2014). Table 4 and Figures 2 and 3 show the predictors of long-term mortality. Five-year survival was 73.2%.

Comment

Proximal aortic dissection is a surgical emergency that necessities replacement of the ascending aorta and that nonetheless carries significant morbidity and mortality. The operator's main concern during such procedures is the patient's survival. The distal extent of the aortic transection during the initial operation has been a matter of debate among different groups [4, 6, 8, 9, 15–17]. The morbidity incurred by a subsequent open aortic operation exclusively in the hemiarch and total arch has not been extensively documented.

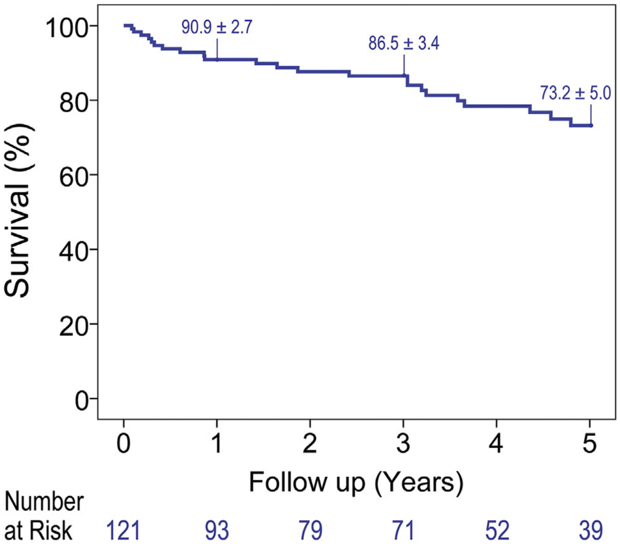

Fig 1. Kaplan-Meier survival curve for 121 patients who survived the operative period. Ninety-eight patients (81.0%) survived until the end of the study (December 31, 2014). Median follow-up time was 5.1 years (95% confidence interval: 4.4 to 5.8).

In this study, we examined our experience with reoperations involving hemiarch and full arch replacement in patients with previous repair of acute type I aortic dissection, and we analyzed these patients' long-term survival. In one of the largest series reported to date, Malvindi and associates [18] described the outcomes of 104 patients who underwent procedures for proximal dissection. Sixty-seven of these patients had surgery in the proximal aorta, and among them, only 31 patients underwent arch replacement. Their inhospital mortality was 7.7%, and their long-term survival rate over 5 years was 82%. Our 5-year survival rate was slightly lower (73.2%), but our patient population was slightly different, and our operative mortality rate was higher, probably because of the larger number of full arch procedures performed (n = 103).

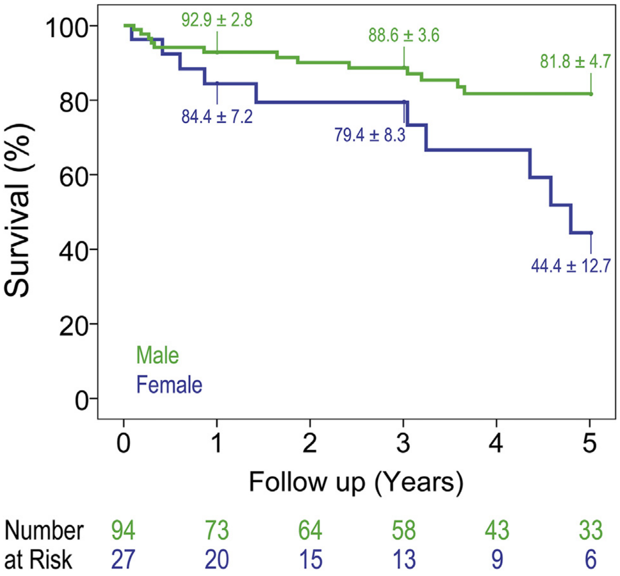

Fig 2. Kaplan-Meier long-term survival curves for males (green line) and females (blue line). Female sex was a predictor of long-term mortality.

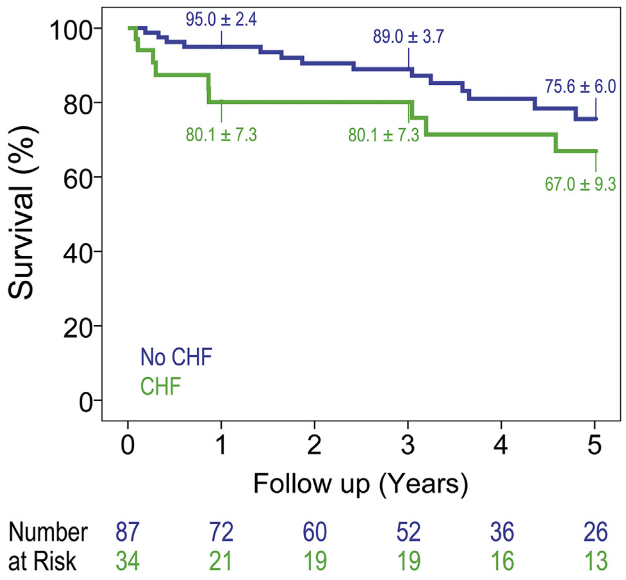

Fig 3. Kaplan-Meier long-term survival curves by congestive heart failure (CHF [green line]) and no CHF (blue line). Congestive heart failure was a predictor of long-term mortality.

In a report from Bologna, Italy, by Bartolomeo and colleagues [19], among 174 patients who had previous proximal aortic operations (not exclusively for dissection), overall hospital mortality was 12.6%, which was slightly higher than ours (11.7%). In their multivariate analysis, the investigators showed that New York Heart Association class III to IV and CPB time were independent predictors of hospital mortality. We drew the same conclusion from our series; CPB time and CHF were independent predictors of operative mortality ($p = 0.018$ and 0.0027, respectively). Likewise, CHF was an independent predictor of the composite endpoint ($p = 0.018$), and CPB time approached significance as a predictor ($p = 0.063$). In the series by Bartolomeo and colleagues [19], age and CPB time emerged as risk factors for late mortality, a finding not encountered in our series ($p = 0.24$). This difference may be a consequence of fewer of our patients being aged 70 years or more; the median age in our series was 58 years (interquartile range, 50 to 67). With the understanding that CPB is a risk factor for operative mortality, we have in recent years used slightly higher temperatures for faster rewarming and shorter CPB times as part of our cerebral protection strategy.

Estrera and colleagues [20], in a cohort of 63 patients, reported 12.7% hospital mortality—slightly higher than ours. They encountered no strokes, whereas some of our patients had strokes, including 3.6% whose strokes were permanent. One possible explanation is that urgent and emergent operations were three times more common in our series than in theirs (22.6% versus 8%), and we had twice as many patients with previous CVA (19% versus 10%). In our multivariate analysis, urgent and emergent status came close to significantly predicting stroke ($p = 0.088$), as did previous CVA ($p = 0.35$). As in the series by Estrera and colleagues [20], 1 patient had a permanent spinal cord deficit after full arch replacement with ET procedure. Renal dysfunction, CPB time, and previous coronary artery bypass graft surgery were predictors of late mortality in their series [20].

With regard to long-term mortality, we found that the risk factors were CHF ($p = 0.0045$), circulatory arrest time ($p = 0.0013$), and female sex ($p = 0.0036$). In contrast, Kimura and colleagues [21] found that male sex was a predictor of late mortality ($p = 0.002$). With regard to preoperative pulmonary dysfunction, we found in our series that it approached significance as a predictor of long-term mortality ($p = 0.074$), as others have found [20]. We speculate that if our sample size had been larger, this association might have reached significance.

Zero percent to 14% hospital mortality and 8% to 21% long-term mortality have been reported in other series [22–25], but these series had very small patient cohorts ($n = 24$, 21, 19, and 17) and even smaller numbers of patients who underwent procedures involving replacement of the entire arch. Of interest, in our series, full arch replacement versus hemiarch replacement was not significantly associated with either operative or long-term mortality ($p = 0.54$ and 0.28, respectively).

None of the analyses discussed used the composite endpoint of mortality, permanent renal dysfunction, and permanent neurologic deficit. It is very important, when we evaluate patients for major proximal reoperation, to be able to estimate not only their mortality risk but also their overall risk of permanent neurologic or renal deficit, which can affect their quality of life. We have previously studied this composite endpoint only in patients who have undergone total arch reoperations [12]. The current study differs from our previous ones in that it is focused solely on hemiarch and total arch repair in patients with previous type I aortic dissection. The literature on this specific aspect of aortic pathology and its surgical treatment (hemiarch or full arch replacement) almost always includes this group as an indistinguishable part of a much larger cohort of patients whose disease represents the entire spectrum of aortic pathology. We strongly believe that the fate of the aortic arch and progression of this disease after previous repair of acute type I aortic dissection warrants its own specific focus, because it is encountered regularly in the practice of cardiothoracic surgeons around the world.

The limitations of our study include its retrospective design and the inherent biases thereof. In our initial therapy for patients with acute type I aortic dissection, we take an aggressive position with regard to performing the initial hemiarch procedure so as to eliminate the need for reoperation. Despite the advent of totally endovascular aortic repair, hybrid techniques, and debranching, these treatments are appropriate for only certain patients with prior repair of type I aortic dissection. That may change in the future when industry develops specifically designed endografts for the aortic arch.

It is important to note that most of the hemiarch and full arch patients in this series were initially operated on at outside institutions and were referred to our center for reoperation. Nonetheless, to our knowledge, this is one of the largest studies to focus only on hemiarch and total arch operations in patients who had previous repair of type I aortic dissection.

In conclusion, among patients who have previously undergone operations for type I aortic dissection, the overall mortality and morbidity associated with hemiarch and total arch repair is respectable. Our data do not support total arch replacement as an initial operation for acute type I aortic dissection; rather, this procedure offers respectable morbidity and mortality as a second operation after a more limited, life-saving initial procedure. Congestive heart failure predicts short-term and long-term mortality and our composite endpoint. Cardiopulmonary bypass predicts short-term mortality and approaches significance for long-term mortality. Female sex and circulatory arrest time are predictors of long-term mortality. Continuous and lifelong surveillance of the dissected aortic segment in these patients is very important.

Stephen N. Palmer, PhD, ELS, contributed to the editing of the manuscript.

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INVITED COMMENTARY

Preventza and colleagues [1] present their outcome and long-term survival on hemiarch and total aortic arch replacement in patients with previous repair for acute type I aortic dissection. The authors report an operative mortality rate of 11.7% and neurologic events in 6.6% of all patients.

All patients underwent either ascending replacement or ascending and proximal arch replacement in primary

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