Open surgical thoracoabdominal aortic aneurysm repair: The Heidelberg experience

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ABSTRACT

Objective: Open surgical repair of thoracoabdominal aortic aneurysm remains an important treatment option and continues to be challenging. The objective of this study was to investigate the results after open repair of thoracoabdominal aortic aneurysms in a contemporary non-high-volume center collective.

Methods: A total of 38 patients underwent operation for thoracoabdominal aortic aneurysm between August 2007 and April 2017. Patients had aortic aneurysm and chronic aortic dissection. The majority of patients had already undergone previous aortic interventions.

Results: The mean age was 54.4 ± 13.4 years (range, 29-72.5 years), and 22 patients (57.9%) were female. Most commonly, patients (57.9%) presented with Crawford type II aneurysms. The mean cardiopulmonary bypass time was 159 ± 65 minutes. The operative mortality was 10.5% ($n = 4$). The paraplegia rate and the incidence of stroke were 7.9% ($n = 3$). Postoperatively, 4 patients (10.5%) required temporary hemodialysis. In 4 patients (10.5%), reexploration due to bleeding was necessary. Sepsis developed in 4 patients (10.5%). Preoperative renal insufficiency was identified as a predictor of mortality. The patients were discharged from the hospital after a median length of stay of 21.5 days. The 1-year survival was 83%.

Conclusions: Despite the invasiveness of open thoracoabdominal aortic repair and significant risk of major complications, surgical repair can be accomplished in a non-high-volume center with acceptable results. (*J Thorac Cardiovasc Surg* 2018;156:2067-73)

A 64-year-old female patient with Crawford type II aneurysm.

Central Message

In a non-high-volume center of aortic surgery, operative mortality was 10.5% and paraplegia rate was 7.9% with an 83% 1-year survival.

Perspective

We present the results of a contemporary collective of patients with TAAA undergoing open repair. The results are comparable to findings from the literature. Our results suggest that open repair of TAAA has the potential to remain standard of care, but further comparative studies with comparable treatment options (open surgical vs interventional) are needed.

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The first successful thoracoabdominal aortic aneurysm (TAAA) repair was performed by Etheredge and colleagues in 1955.¹ Today, this demanding operation continues to be challenging and remains associated with significant morbidity and mortality. The most feared postoperative

complications are paraplegia and renal failure requiring hemodialysis.² Furthermore, thoracoabdominal aortic repair is associated with remarkable early mortality. This aspect has encouraged the use of less-invasive treatment options, such as endovascular procedures and hybrid techniques.^{2,3} Currently, endovascular treatment is gaining increased popularity and is considered a valid treatment option

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Scanning this QR code will take you to a procedural video.

Abbreviations and Acronyms

IQR = interquartile range

TAAA = thoracoabdominal aortic aneurysm

predominantly in cases of uncomplicated thoracic and abdominal aortic aneurysms.^{3,4} A number of series showed that the obviously less-invasive endovascular therapy has not significantly reduced the incidence of life-threatening events such as paraplegia or early mortality. Furthermore, the rates of reintervention seem to be higher in patients treated endovascularly.^{3,5-9}

In view of the fact that contemporary data about outcomes of open surgical TAAA repair from non-high-volume centers are rare, in this study we analyzed the results of open TAAA repair and survival in a contemporary, high-risk patient collective in a non-high-volume aortic surgery institution.

MATERIALS AND METHODS

Study Population

A total of 38 patients underwent open TAAA repair between August 2007 and April 2017 in our institution. The preoperative demographic characteristics were analyzed, along with the intraoperative and postoperative early and short-term outcomes.

Surgical Techniques

We used the standardized approach for TAAA repair, which has been described in detail.^{2,10} All patients were operated through a left thoracoabdominal incision with a circumferential division of the diaphragm. All operations were performed using femoral-femoral cardiopulmonary bypass at permissive hypothermia. Video 1 shows a thoracoabdominal aortic repair in a 37-year-old patient with Marfan syndrome.

If aortic crossclamping of the aortic arch distal to the origin of the left carotid artery was not possible, hypothermic circulatory arrest was used. This was necessary in 6 patients. The aneurysm was replaced during sequential clamping. After opening of the abdominal aortic segment, the intestinal and renal arteries were selectively perfused with oxygenated blood. These vessels were reimplanted consecutively, together with a variable number of intercostal and lumbar arteries, in the majority of patients. In 15 patients, no intercostal or lumbar arteries were reattached. All patients received cerebrospinal fluid drainage preoperatively. Intubation was performed with a double-lumen endotracheal tube, thereby enabling collapse of the left lung during the operation. We did not use neuromonitoring with motor-evoked potentials.

Statistical Analysis

Patients were studied retrospectively. Data of the study were analyzed using SPSS, version 24.0 (IBM Corp, New York, NY) and described as continuous and categorical variables subsequently. Continuous variables are presented as mean $\pm$ standard deviation or median (25th quartile; 75th quartile, interquartile range [IQR]). Categorical variables are described in number and percentage forms. Preoperative and intraoperative variables were analyzed with univariate logistic regression models for identifying predictors of 30-day mortality and proportional hazard regression for identifying predictors of mortality with long-term follow-up. The odds ratio and the 95% confidence interval were given in relation to each parameter. The chi-square test was used to describe the relations between categorical variables. Survival was calculated and graphically presented by the Kaplan-Meier method. The Kaplan-Meier estimates of survivor function and corresponding 95% confidence interval were also calculated

VIDEO 1. Thoracoabdominal aortic repair in a 37-year-old patient with Marfan syndrome. Video available at: [https://www.jtcvs.org/article/S0022-5223\(18\)31511-3/fulltext](https://www.jtcvs.org/article/S0022-5223(18)31511-3/fulltext).

and presented. For the survival analysis, we used R 3.4.3 (A Language and Environment for Statistical Computing, The R Foundation for Statistical Computing, Vienna, Austria, 2017, <http://www.R-project.org>), with extension Survminer (Alboukadel Kassambara and Marcin Kosinski (2018). Survminer: Drawing Survival Curves using 'ggplot2'. R package version 0.4.2; <https://CRAN.R-project.org/package=survminer>).

Definitions

All aneurysms were categorized on the basis of Crawford's classification. Operative mortality was defined as death within 30 days after surgery or death during the original hospitalization. Postoperative respiratory failure was defined as reintubation, tracheotomy, or a need for mechanical ventilation for longer than 72 hours. Postoperative stroke, paraparesis, and paraplegia were defined as a new and permanent or temporary neurologic disability or deficit. Postoperative acute renal failure was defined as an increase of the serum creatinine level to twice its baseline value. Postoperative temporary renal failure was defined as a new necessity for dialysis during the hospital stay and as permanent terminal renal failure if dialysis was necessary at the time of discharge. The gastrointestinal complications included gastrointestinal bleeding and visceral ischemia. Redo-operation was defined as surgery on a previously operated aorta. The follow-up data were obtained by clinical visits. This study was approved by the local ethics committee of our university, medical faculty S-266/2017 (June 6, 2017).

RESULTS

Preoperative Data

The patient demographics are summarized in Table 1. Overall, the mean age at the time of TAAA repair was 54.4 ± 13.4 years (range, 29–72.5 years) and female patients were predominantly affected (57.9%, $n = 22$). Crawford extent II aneurysm was the most common type ($n = 22$, 57.9%), followed by extent I ($n = 12$, 31.6%). The mean diameter was 7.0 ± 1.2 cm (range, 5–12 cm). In 25 patients, the procedure was a redo operation, and 24 patients had chronic aortic dissection (12 patients [31.6%] with chronic dissection type A and 12 patients [31.6%] with chronic dissection type B). Five patients (13.2%) had undergone endovascular interventions previously. Nine patients (23.7%) had already experienced chronic renal failure; among them, 1 (2.6%) had dialysis preoperatively. Three patients were preoperatively paraplegic as a consequence of previous open or endovascular repair elsewhere. The cause of the aortic disease was

TABLE 1. Patient demographics

Variable	Value
Age (y, mean $\pm$ SD)	54.4 $\pm$ 13.4
Male	16 (42.1%)
BMI, kg/m ²	24.6 $\pm$ 4.6
Hypertension	30 (78.9%)
Myocardial infarction	1 (2.6%)
Peripheral arterial disease	4 (10.5%)
Cerebral vascular accident	1 (2.6%)
Paraplegia preoperatively	3 (7.9%)
Diabetes	1 (2.6%)
Cigarette smoking	17 (44.7%)
Chronic renal failure	9 (23.7%)
Chronic renal failure with hemodialysis	1 (2.6%)
Prior type A dissection	12 (31.6%)
Prior type B dissection	12 (31.6%)
Previous aortic surgery	25 (66%)
Prior endovascular repair	5 (13.2%)
Emergency/urgent procedures	8 (21%)/8 (21%)
Aortic disease	
Connective tissue disorder	18 (47.4%)
Degenerative chronic aneurysm	16 (42.1%)
Inflammatory	2 (5.3%)
Infected aortic prosthesis	2 (5.3%)
Aortic diameter (cm, mean $\pm$ SD)	7 $\pm$ 1.2
TAAA extent	
I	12 (31.6%)
II	22 (57.9%)
III	3 (7.9%)
IV	1 (2.6%)
No. of prior aortic surgical procedures	
0	17 (44.7%)
1	16 (42.1%)
2	1 (2.6%)
3	4 (10.5%)

SD, Standard deviation; BMI, body mass index; TAAA, thoracoabdominal aortic aneurysm.

diverse. A total of 18 patients (47.4%) had connective-tissue disorders: Marfan syndrome ($n = 15$), Ehlers–Danlos syndrome ($n = 2$), Loeys–Dietz syndrome ($n = 1$), and atherosclerotic aneurysm ($n = 16$; 42.1%). In 2 patients (5.3%), the cause was most likely of infectious origin (mycotic aneurysm), and in 2 patients (5.3%), inflammatory disease of the aorta was known. The 2 patients with aortic infection had vascular prosthetic infection after open surgical TAAA repair and endovascular treatment. They were paraplegic preoperatively. Twenty-two patients (57.9%) were treated electively, 8 patients (21.1%) were treated urgently, and in 8 patients (21.1%), emergency surgery was necessary.

TABLE 2. Operative data

Variable	Value
Operation time (min, mean $\pm$ SD)	436 $\pm$ 84
Cardiopulmonary bypass time (min, mean $\pm$ SD)	159 $\pm$ 65
Circulatory arrest (min, mean $\pm$ SD)	5 $\pm$ 13.7
Intraoperative temperature, ($^{\circ}$ C, mean $\pm$ SD) excluding hypothermia while circulatory arrest	32.1 $\pm$ 3.9
Reimplantation of intercostal or lumbar artery (patients, %)	23 (60.5%)
No. of reimplanted intercostal or lumbar artery (mean $\pm$ SD)	2 $\pm$ 1.1
Level TH 6	2
Level TH 7	2
Level TH 8	9
Level TH 9	7
Level TH 10	3
Level TH 11	9
Level TH 12	3
Level L 1	9

SD, Standard deviation; TH, thoracic; L, lumbar.

Surgical Data

The operative data are presented in Table 2. The mean operation time was 436 $\pm$ 84 minutes with a mean cardiopulmonary bypass duration of 159 $\pm$ 65 minutes. In 6 patients, deep hypothermic circulatory arrest for 5.0 $\pm$ 13.7 minutes was necessary. In 39.5% ($n = 15$) of patients, there were no intercostal or lumbar arteries suitable for reattachment. The mean number of reimplanted intercostal and lumbar arteries was 2 $\pm$ 1.1. Cerebrospinal fluid drainage was used in all patients. The mean intraoperative body temperature was 32.1 $^{\circ}$ C $\pm$ 3.9 $^{\circ}$ C, excluding the temperature during circulatory arrest. One patient required extracorporeal membrane oxygenation for 8 days.

Postoperative Outcome

The postoperative data are summarized in Table 3. There were no intraoperative deaths, the 30-day mortality was 7.9% ($n = 3$), and the overall operative mortality was 10.5% ($n = 4$). The causes of death were septic multiple-organ failure, bowel ischemia, and hypoxic brain injury in 1 patient each. Permanent paraplegia occurred in 3 patients (7.9%) postoperatively, and no paraparesis was observed. The incidence of stroke was 7.9% ($n = 3$); 2 patients experienced complete regression of neurologic deficit before discharge. One of them experienced a stroke due to a heparin-induced thrombocytopenia. Nine patients (23.7%) developed acute renal failure, of whom 4 (10.5%) required temporary dialysis. Two patients required permanent hemodialysis at hospital discharge. One of them had already been dialyzed preoperatively.

Early postoperative complications included bleeding requiring reexploration in 2 patients (5.3%) due to hemothorax and 2 patients (5.3%) due to retroperitoneal

TABLE 3. In-hospital outcome

Variable	Value
Operative mortality	4 (10.5%)
30-d mortality	3 (7.9%)
Paraplegia	3 (7.9%)
Paraparesis	0
Stroke	3 (7.9%)
Renal failure	9 (23.7%)
Requiring temporary dialysis	4 (10.5%)
Dialysis at discharge	1 (2.6%)
Bleeding requiring re-thoracotomy	2 (5.3%)
Bleeding requiring laparotomy	2 (5.3%)
Pneumonia	4 (10.5%)
Mechanical ventilation >72 h	5 (13.2%)
Tracheotomy	4 (10.5%)
Reintubation	1 (2.6%)
Sepsis	4 (10.5%)
Wound infection requiring revision	3 (7.9%)
Intensive care duration (d, median, IQR)	3.5 (2.3-21.5)
Duration of intubation (h, median, IQR)	38 (13-303.5)
Hospital length of stay (d, median, IQR)	21.5 (16-38)

IQR, Interquartile range.

hematoma and intra-abdominal bleeding. Bowel ischemia was encountered in 1 patient (2.6%), who then received laparotomy and intestinal resection. Wound infection requiring surgical revision was observed in 3 patients (7.9%). Vocal cord paralysis occurred in 1 patient (2.6%). The median intensive care unit length of stay was 3.5 days (IQR, 2.3-21.5 days), and median hospital length of stay was 21.5 days (IQR, 16-38 days). The median duration of ventilation was 38 hours (IQR, 13.0-303.5 hours). Four patients developed pneumonia, and 4 others (10.5%) required tracheotomy.

Emergency and urgent procedures did not significantly increase the incidence of spinal cord ischemia ($P = .369$), stroke ($P = .748$), or the 30-day mortality rates ($P = .369$). Furthermore, chronic dissection (A and B) did not significantly influence the 30-day mortality and the occurrence of stroke and spinal cord ischemia. Connective-tissue disorders (Marfan syndrome, Ehlers-Danlos syndrome, Loeys-Dietz syndrome) had no bearing on early mortality and the incidence of neurologic deficits. More details about predictors of 30-day mortality are summarized in Table 4.

Follow-up Data

The mean follow-up time was 1.6 ± 2 years. At 1, 3, and 5 years after operation, the survival rates were 83%, 77%, and 62%, respectively (Figure 1). Age, gender,

cardiopulmonary bypass time, diameter of aneurysm, extents I and II, and chronic aortic dissection were not predictors of mortality during the follow-up time. Likewise, intubation time, emergency procedures, the numbers of previous aortic procedures, and redo surgery could not be identified as predictors of overall mortality. Only preoperative renal insufficiency and prolonged postoperative noradrenalin support were identified as such (Table 5).

DISCUSSION

Various studies from high-volume centers for aortic surgery recognize the open surgical approach as the golden standard and set the benchmark for both other institutions and treatment options.^{3,6,11,12} Comparable reports from US or European “less-than-high-volume-centers” are relatively rare.^{7,13,14} Therefore, the aim of this study was to investigate the operative risk and postoperative course of open TAAA repair in a single, non-high-volume center. Open surgical TAAA repair is still associated with significant mortality and morbidity, with spinal cord injury being the most dreaded complication.^{2,15} We were able to show an acceptable rate of paraplegia at 7.9%. Data series from centers with different volumes of aortic surgery reported rates of paraplegia between 2.9% and 12%.^{2,4,6,13,15-17} Others demonstrated that the incidence of spinal cord injury is dependent on Crawford extent II.^{17,18} Extent II is already considered a predictor of early mortality.^{17,19,20} In our cohort among the 3 paraplegic patients, we observed 2 cases with extent II, 1 with previous aortic surgery, and 2 who underwent emergency surgery. Two of the 3 30-day deaths had extent II. In our aneurysm sample collective, extent II, extent I, emergency procedures, and redo surgery could not be identified as predictors of mortality and did not influence the occurrence of paraplegia significantly. In 23 of 38 patients (60.5%), intercostal or lumbar arteries were reattached to the vascular graft. Three patients in our cohort developed paraplegia. Two of them did so despite intercostal or lumbar artery reimplantation. However, these 2 patients underwent emergency surgery and had presented with type II aneurysms. We regard both variables together as an important risk factor for the development of paraplegia despite intercostal or lumbar artery reimplantation. This aspect might have outweighed the beneficial effects of intercostal/lumbar artery reimplantation on spinal cord protection in these patients.^{21,22}

Remarkably, the complex extent II was over-presented in our patient collective. This observation may be due to a shift of treatment allocation toward the endovascular approach in many patients with less complex aortic disease. In our cohort, we conducted 8 emergency procedures with a 30-day mortality of 25% (2 of 3 30-day deaths). Afifi and colleagues¹¹ demonstrated that rupture at presentation was associated with 38.2% early mortality and that an

TABLE 4. Thirty-day mortality, spinal cord ischemia, and stroke according to operation priority and pathology

	No. of patients	30-d mortality	SCI	Stroke
TAAA				
Elective	22	1	1	2
Emergency/urgency	16	2	2	1
Chi-square		$P = .369$	$P = .369$	$P = .748$
Dissection				
None	14	2	2	0
A	12	1	0	1
B	12	0	1	2
Chi-square		$P = .403$	$P = .403$	$P = .29$
Connective tissue disorder				
No	20	3	2	1
Yes	18	0	1	2
Chi-square		$P = .087$	$P = .612$	$P = .485$

SCI, Spinal cord injury; TAAA, thoracoabdominal aortic aneurysm.

emergency operation was associated with early mortality of 53.3% in patients undergoing redo operation. Furthermore, Coselli and colleagues¹⁷ showed that emergency repair of TAAA was associated with a higher incidence of paraplegia and adverse outcome.²³ Surprisingly, although all patients with connective-tissue disorders had undergone multiple surgical interventions previously and had chronic aortic dissections, they showed excellent outcome and no early deaths, and only 1 lethality during follow-up. Our findings were comparable to other studies that analyzed the mortality and outcome of patients with and without Marfan syndrome after TAAA repair.²³⁻²⁷ Therefore, we believe that open repair is preferable to endovascular treatment and remains the gold standard in these mostly young patients. The relatively large subcohort of patients with Marfan syndrome has shifted the mean age of our entire patient cohort to 54 years, which is more than 10 years younger

TABLE 5. Cox proportional hazards regression analysis: Impact of certain risk factors on the overall mortality

Variable	OR, 95% CI	P value
Sex		.985
Age		.074
Redo surgery		.41
BMI		.42
Renal insufficiency	6.2 (1.8-21.1)	.003
CPB time		.189
Crossclamp time		.294
Circulatory arrest		.43
Transfusion of packed red cells		.198
Operation time		.174
Noradrenalin – length of support	1.1 (1.03-1.19)	.006
Intubation time		.155
Connective tissue disorder		.257
Urgent surgical indication		.438
Diameter of aneurysm		.98
Crawford I		.98
Crawford II		.561
Type A aortic dissection		.401
Type B aortic dissection		.678
Presence of stent graft		.526
Rethoracotomy		.545

OR, Odds ratio; CI, confidence interval; BMI, body mass index; CPB, cardiopulmonary bypass.

compared with other series.^{3,6,7,9} This aspect may have contributed to a relatively favorable early survival, because age has been identified as a predictor of mortality. Coselli and colleagues⁹ reported that the variable age at 50 years or younger was an independent predictor of reduced adverse events after open repair of TAAA. In accord with this finding, we observed no early deaths among patients with connective tissue disorders. Likewise, we were able to identify preoperative renal insufficiency as a risk factor of mortality.¹⁷ In addition, we found out that the postoperative need for prolonged noradrenalin support was an independent risk factor for overall mortality. To the best of our knowledge, this aspect has not been described before and may be indicative of additional comorbidities influencing the outcome.

There is increasing interest in the use of endovascular techniques as treatment of aortic pathologies. The respective results are acceptable but not significantly superior to open surgical repair of TAAA. The 30-day mortality is reported to be approximately 6.4% to 7.7%, and the perioperative spinal cord ischemia is between 2.6% and 9.2%.^{4,28,29} Ferrer and colleagues⁴ demonstrated in a propensity-matched comparison that the 24- and 42-

FIGURE 1. Survival of the cohort using Kaplan–Meier analysis including 95% confidence intervals and number of patients at risk.

month survival and rates of freedom from reintervention did not differ significantly between endovascular and open treatment of TAAAs. On the other hand, Verhoeven and colleagues²⁸ reported a 5-year survival of approximately 66.6% after endovascular treatment. These results do not appear superior to the outcome after open repairs in high-volume centers.^{3,4,8,12,29} In addition, endovascular techniques have a significant incidence of specific complications, such as primary and secondary endoleaks, which make further interventions necessary.²⁹

Another potential limitation of aortic endovascular therapy relates to anatomic and logistic issues, especially in emergency cases.³⁰ Dias and colleagues³¹ reported a 28.6% rate of 30-day mortality in patients with ruptured TAAA after endovascular TAAA repair. These aspects add to the consideration that open surgery should remain the optimal treatment for ruptured descending thoracic aorta and TAAAs.⁷ In contrast to open repair, long-term follow-up beyond 10 years for the total endovascular repair of TAAA is still not available.¹¹

Upon comparing the mortality and paraplegia rates of less-specialized centers with a high-volume center for aortic repair, we have observed differences that are probably acceptable. Nevertheless, the surgical experience remains an important issue. However, other published series with collectives of between 28 and 41 patients, as in our present study, also indicated comparable early mortality rates and paraplegia rates.^{13,14,32}

Study Limitations

The study is limited by its design as a single-center retrospective review. Failure to demonstrate significant differences between patients who were operated on an elective or emergency basis could be related to the overall small number of patients in this cohort.

CONCLUSIONS

Contemporary, non-high-volume center reports regarding the outcomes of open surgical thoracoabdominal aortic replacement are extremely rare. Our results indicate mortality and complication rates comparable to those of high-volume centers. The finding supports the expectation that this treatment modality will remain the standard of care for the majority of patients including selected subcohorts with connective tissue disorders or other conditions such as endograft infection or adverse aortic anatomy unsuitable for endograft repair.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: early mortality, open repair, outcomes, thoracoabdominal aneurysm

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