

Original Article

Thoracoabdominal aortic aneurysm repair: A Single center experience

 Unal Aydin¹,  Zihni Mert Duman²,  Emre Yasar¹,  Muhammed Bayram¹,  Sefa Eltutan¹,
 Ersin Kadirogullari¹,  Onur Sen¹

¹Department of Cardiovascular Surgery, İstanbul Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital, İstanbul, Turkey

²Department of Cardiovascular Surgery, Cizre State Hospital, Şırnak, Turkey

Received: June 13, 2022 Accepted: October 04, 2022 Published online: October 25, 2022

© 2022 Turkish National Vascular and Endovascular Surgery Society. All rights reserved.

Copyright@Author[s] - Available online at <http://turkishjournalofvascularsurgery.org/>

Content of this journal is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License



Abstract

Aim: The gold standard repair of thoracoabdominal aortic aneurysm (TAAA) is still open surgery. However, few cardiovascular centers are experienced in TAAA repair. The aim of this study was to examine the methods and four-year outcomes of the open TAAA repair program initiated by a single surgical team.

Material and Methods: In this retrospective cohort, patients who were operated for TAAA between August 2018 and March 2022 were collected. Patients treated with the endovascular approach were excluded. After exclusion, 19 patients were included in our analysis. As postoperative outcomes, in-hospital mortality, spinal cord deficit, major neurologic complications, need for dialysis, and visceral ischemia were collected.

Results: Crawford extent II TAAA repair was performed in 10 (52.6%) patients, Crawford extent III in 5 (26.3%) patients, and Crawford extent IV in 4 (21.1%) patients. In hospital mortality occurred in 6 (31.6%) patients. The causes of mortality were perioperative myocardial infarction in 2 (10.5%) patients, visceral ischemia in 1 (5.3%) patient, multisystem organ failure in 3 (15.8%) patients. The highest mortality rate (50.0%) occurred in Crawford extent II repair. Spinal cord deficit developed in 2 (10.5%) patients.

Conclusion: Thoracoabdominal aortic aneurysm surgery is associated with high mortality rates. Open thoracoabdominal aortic aneurysm repair programs in tertiary vascular centers should be supported, to improve the surgical results of thoracoabdominal aortic aneurysm repair.

Keywords: Thoracoabdominal aortic aneurysm, aortic dissection, outcomes, surgery

INTRODUCTION

Despite advances in endovascular treatments, the gold standard repair of thoracoabdominal aortic aneurysm (TAAA) is still open surgery. TAAA repairs with a long history are still performed with

remain substantial mortality even in experienced centers [1,2]. In addition, feared permanent complications such as kidney failure or paraplegia and paralysis due to spinal cord ischemia are not rare after open surgery. Postoperative mortality and morbidity may be higher than expected in cardiovascular centers that are

CITATION

Aydin U, Duman ZM, Yasar E, Bayram M, Eltutan S, Kadirogullari E, Onur Şen . Thoracoabdominal aortic aneurysm repair: A Single center experience. Turk J Vasc Surg 2022;31:163-9.



Corresponding Author: Unal Aydin, Department of Cardiovascular Surgery, İstanbul Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital, İstanbul, Turkey, Email: unalaydin41@gmail.com

newly started to TAAA repair at the initial stage. The aim of this study was to examine the methods and four-year outcomes of the open TAAA repair program initiated by a single surgical team.

MATERIAL AND METHODS

Study Set Up and Data Collection

In this retrospective cohort study, after obtaining institutional ethics committee approval (2022.24), patients who were operated for TAAA between August 2018 and March 2022 at Istanbul Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital were collected. Patients treated with the endovascular approach were excluded. The patient files were retrospectively screened. Demographic, operative and postoperative data of the patients were evaluated. The primary endpoint of the study was in-hospital mortality. The secondary endpoints of the study were the development of permanent spinal cord deficit, severe acute renal failure, visceral ischemia and major neurologic complication. The study was conducted in accordance with the Declaration of Helsinki.

Patients

Nineteen patients who underwent open TAAA repair were included in our analysis. The mean age of the patients was 57.47 ± 10.87 years. Sixteen patients (84.7%) were male and only 3 (15.8) were female. Nine of these patients (47.4%) had DeBakey type III aortic dissection. The remaining 10 patients (52.6%) were treated with diagnosis of idiopathic TAAA. Two patients (10.5%) previously diagnosed with Marfan syndrome; no patients had a bicuspid aortic valve disease. There was a history of proximal aortic surgery in 3 patients, including concomitant Bentall operation plus conventional elephant trunk procedure in 1 patient, and isolated Bentall procedure in 2 patients

Emergency TAAA repair was performed in 2 patients, one due to aortic dissection causing malperfusion syndrome and the other to aortic rupture. According to anatomical classification, 10 (52.6%) patients were diagnosed with Crawford extent II TAAA, 5 (26.3%) patients with Crawford extent III TAAA, and 4 (21.1%) patients with Crawford extent IV TAAA (Figure 1). The preoperative characteristics of the patients were detailed in Table 1.

Table 1. Preoperative characteristics (n=19)		
	N (%)	Mean ± SD & Median (Q1-Q3)
Age		57.47 ± 10.87
Female	3 (15.8)	
Hypertension	15 (78.9)	
Diabetes	1 (5.3)	
Ischemic Heart Disease	6 (31.6)	
Chronic obstructive pulmonary disease	7 (36.8)	
Smoker	16 (84.2)	
Peripheral vascular occlusive disease	2 (10.5)	
Serum creatinine level, mg/dL		1.13 ± 0.43
Ejection fraction, %		56.53 ± 10.65
Connective tissue disease	2 (10.5)	
Aneurysm with dissection	9 (47.4)	
Aneurysm without dissection	10 (52.6)	
Previous proximal aortic surgery	3 (15.8)	
Emergency surgery	2 (10.5)	
Crawford extent II	10 (52.6)	
Crawford extent III	5 (26.3)	
Crawford extent IV	4 (21.1)	

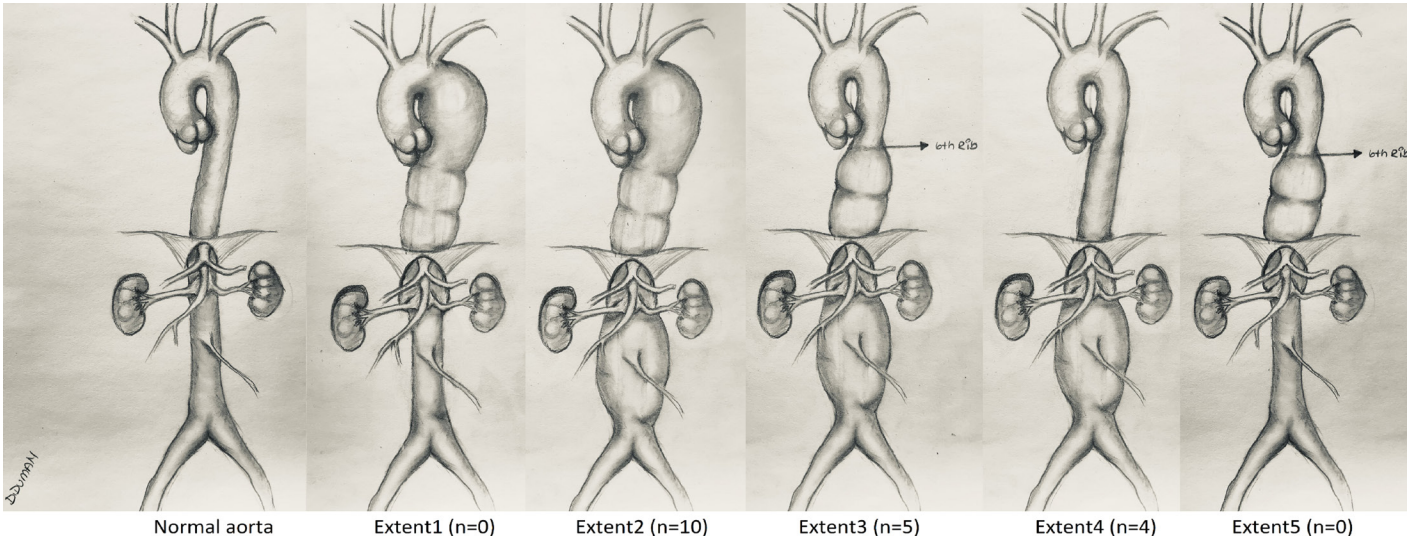


Figure 1. Thoracoabdominal Aortic Aneurysm Classification and Number of Cases

Definitions

In hospital mortality was defined as death occurring before discharge from the hospital or within 30 days postoperatively. Spinal cord deficit (SCD) was defined as the presenting of paraplegia and paraplegia in the lower extremity without any cranial ischemic or hemorrhagic event. The major neurologic complication was defined as brain death, cerebral infarction, intracranial hemorrhage, or seizure occurring within 30 days of thoracoabdominal aortic repair. Severe acute renal failure was defined as the need for dialysis or continuous veno-venous hemodiafiltration at least once in the postoperative period. The need for dialysis was decided by the nephrology and surgery team according to the serum electrolyte imbalance, volume overload and biochemical pathologies of the patients. We defined multisystem organ failure as the acute dysfunction of more than one organ system. Visceral ischemia was defined as intestinal necrosis resulting from hypoperfusion proven by computed tomography angiography (CTA) of the celiac arteries, superior mesenteric arteries, and inferior mesenteric arteries. Prolonged ventilation was defined as mechanical support for more than 48 hours. ICU stay longer than 5 days was defined as prolonged ICU stay.

Surgical Preparation and Technique

Informed consent was obtained from the patients themselves and the first-degree relatives of the patients. Thoracoabdominal (including common femoral arteries) CTA was performed in all patients before the operation. Crawford's extent classification of aneurysms was determined, the localization and calibration of the Adamkiewicz artery were evaluated for surgical planning. On elective patients, transthoracic echocardiography, trans-radial coronary angiography, and carotid artery Doppler ultrasonography were performed.

A cerebrospinal fluid drainage catheter (CSFDC) is routinely inserted into the L4-L5 intervertebral space by the anesthetist prior to induction of anesthesia. The cerebrospinal fluid pressure is monitored and is freely drained when the cerebrospinal fluid pressure exceeds 10 mmHg. After induction of anesthesia, a double-lumen endotracheal tube is placed. The right radial and femoral arteries are cannulated for arterial blood pressure monitoring. Double central venous catheters are placed in the right and left jugular veins. Near-infrared spectroscopy (NIRS) is routinely placed to measure the adequacy of cerebral oxygen balance. Right lateral decubitus position is achieved by oriented shoulders 60° degrees and hips 30° degrees for proper exposure. The left arm is suspended and fixed to the anesthesia frame with a surgical towel.

Autotransfusion systems are established before starting the incision. According to the Crawford extent classification, we perform a 4th (for extent II) and 5th or 6th (for extent III or IV)

intercostal posterolateral thoracotomy. The incision is continued along the costal margin and the paramedian rectus sheath down to the umbilicus. The serratus anterior, the latissimus dorsi, and the partially rhomboid muscles are divided by blunt and sharp dissection for better exposure. Posterolateral thoracotomy is performed up to the paraspinal muscles. We cut the costal margin cartilage with an oscillating sternal saw. At this stage, the terminal branch of the left internal mammary artery is ligated. The inferior pulmonary ligament structures are dissected with electrocautery. The diaphragm is divided circularly and the abdominal aorta is exposed by the retroperitoneal approach.

The clamping and suturing technique was used only in a patient with Crawford extent IV, which we thought would have a short aortic occlusion time in the preoperative period. All remaining patients were operated on under cardiopulmonary bypass via femoral artery and vein. In addition to femoral artery cannulation, the left axillary artery in 3 patients, the right subclavian artery in 1 patient, and the aortic arch in 3 patients were cannulated in a total of 7 Crawford extent II repair. Left heart bypass was never used in our cohort. We do not prefer deep hypothermic circulatory arrest. Cardiopulmonary bypass was continued in mild (28.1 C- 32 C) or moderate hypothermia (20.1 C- 28 C) to protect the spinal cord, brain and visceral organs. We do not use cardioplegia for cardiac protection, but we place a left ventricular apical venting cannula to prevent ventricular overdistension and disruption of subendocardial perfusion during cardiopulmonary bypass (CPB). If there is a 20% decrease from baseline in cerebral oxygen balance measured by NIRS, we take action with perfusion strategies to maintain the adequate cerebral blood flow.

Visceral and renal arteries were perfused via catheters connected to the cardiopulmonary bypass circuit. However, in cases managed with a simple clamp technique, renal and visceral vessels were perfused with cold Custodiol solution before preparing for anastomosis.

We use a sequential aortic clamping technique starting from the proximal healthy anastomotic line according to Crawford's extent classification. We routinely use Dacron graft for the reconstruction of visceral arteries, but we prefer ringed PTFE grafts in areas with high kinking probability. According to the intercostal arteries' backflow during the operation and CTA evaluations, we perform side by side and tube graft anastomosis for the intercostal arteries, (T8 - T12) to the main aortic graft (Figure 2). All 19 patients were operated on a single surgical team.

Postoperative Follow

In the intensive care unit (ICU), cerebrospinal fluid pressure is also followed in addition to the arterial blood pressure and central venous pressure monitoring of the patients. The cerebrospinal fluid is freely drained when the pressure exceeds 10 mmHg.

Low molecular weight heparin (LMWH) and 100 mg aspirin are administered as medication (Figure 3).

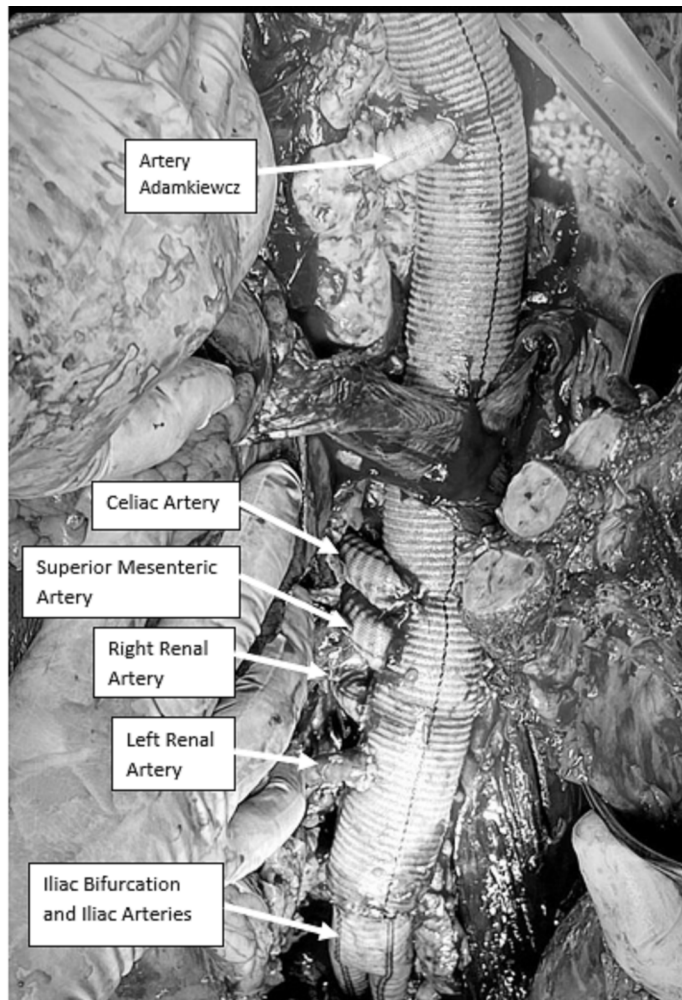


Figure 2. Intra operative Image of Thoracoabdominal Aortic Reconstruction

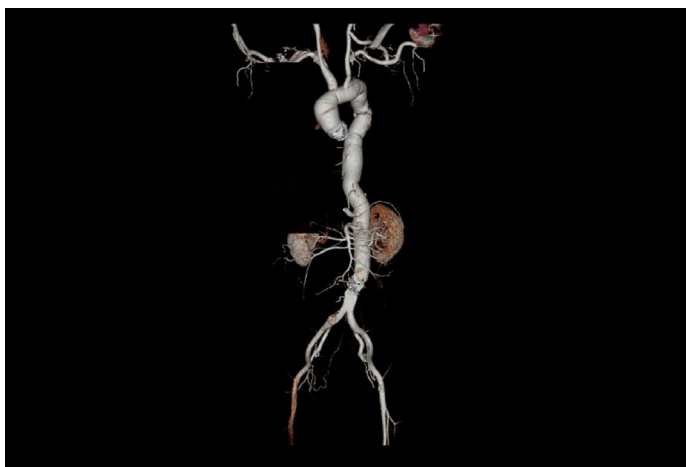


Figure 3. CT Image of Thoracoabdominal Aortic Reconstruction

Statistical Analysis

Statistical analyzes were performed using R version 4.0.3(R Foundation for Statistical Computing). Kolmogorov-Smirnov test was used to determine the abnormal distribution. Normally distributed continuous data were presented as mean and standard deviation (SD) and compared by Student's t-test. Non-normally distributed continuous data were presented as median, first and third interquartile range (Q1–Q3) and compared by the Mann Whitney U test. Categorical data were presented as number of patients with ratio and compared by the Fisher exact test.

RESULTS

CPB was used in 18 patients. The mean CPB time was 189 ± 77 min. CPB was continued in 13 (68.4%) patients with moderate hypothermia and 5 (26.3%) patients with mild hypothermia. Operative data of the repairs were detailed in Table 2.

Table 2. Operative data

	N (%)	Mean $\pm$ SD
CPB time (min)		189 ± 77
Descending aortic clamp time (min)		107 ± 51
Moderate hypothermia	5 (26.3)	
Mild hypothermia	13 (68.4)	
Reattachment of T8-12 intercostal arteries	7 (36.8)	
Visceral perfusion with cold Custodiol solution	2 (10.5)	

CPB, cardiopulmonary bypass

Permanent SCD developed in two patients. In one of these patients, T8 - T12 intercostal ligation was performed. Severe acute renal failure occurred in 6 (31.6%) patients. Among them, 3 patients died due to multi-organ failure. One of the survivors became dialysis-dependent patient.

In our cohort, in-hospital mortality occurred in 6 (31.6%) patients. The causes of mortality were perioperative myocardial infarction in 2 patients, visceral ischemia in 1 patient, and multisystem organ failure in 3 patients. Of the hospital deaths, five occurred in Crawford extent II repair and one in Crawford extent III repair. The highest mortality rate (50.0%) occurred in Crawford extent II repair. Preoperative, operative and postoperative data of patients with and without in-hospital mortality was compared (Table 3). Chronic obstructive pulmonary disease was statistically significantly higher in patients with mortality (2 patients & 5 patients; $p:0.004$). CPB time was statistically significantly longer in patients with mortality (164 ± 65 & 247 ± 74 ; $p:0.025$). Ventilation time and intensive care unit stay (days) were statistically significantly longer in patients with hospital mortality. (3.2 ± 2.6 & 10.7 ± 7.7 ; $p:0.02$ - 5.1 ± 3.6 & 12.5 ± 7.0 ; $p:0.01$, respectively).

Table 3. Comparison of demographic, preoperative, operative and postoperative data of patients with mortality and patients without mortality

	Patients without mortality (n=13)	Patients with mortality (n=6)	p Value
	N (%) & Mean $\pm$ SD	N (%) & Mean $\pm$ SD	
Age	56.85 $\pm$ 11.01	58.85 $\pm$ 11.46	0.72
Female	3 (23.1)	0	0.54
Hypertension	6 (69.2)	5 (83.3)	0.13
Diabetes	1 (7.7)	0	0.99
Ischemic Heart Disease	4 (30.8)	2 (33.4)	0.91
Chronic obstructive pulmonary disease	2 (15.4)	5 (83.3)	0.004
Smoker	10 (76.9)	6 (100)	0.54
Peripheral vascular occlusive disease	1 (7.7)	1 (16.7)	0.55
Serum creatinine level, mg/dL	1.19 $\pm$ 0.50	1.03 $\pm$ 0.23	0.46
Ejection fraction, %	55.3 $\pm$ 12.4	59.2 $\pm$ 4.9	0.48
Connective tissue disease	2 (15.4)	0	0.83
Aneurysm with dissection	6 (46.2)	3 (50.0)	0.88
Aneurysm without dissection	7 (53.8)	3 (50.0)	0.88
Previous proximal aortic surgery	3 (23.1)	0	0.54
Emergency surgery	1 (7.7)	1 (16.7)	0.55
CPB time (min)	164 $\pm$ 65	247 $\pm$ 74	0.025
Descending aortic clamp time (min)	96 $\pm$ 48	131 $\pm$ 59	0.36
Moderate hypothermia	4 (30.8)	1 (16.7)	0.85
Mild hypothermia	8 (61.5)	5 (83.3)	0.85
Reattachment of T8-12 intercostal arteries	4 (30.8)	3 (50.0)	0.77
Visceral perfusion with cold Custodiol solution	1 (7.7)	1 (16.7)	0.55
Permanent spinal cord deficit	1 (7.7)	1 (16.7)	0.55
Severe acute renal failure	3 (23.1)	3 (50.0)	0.52
Visceral ischemia	0	1 (16.7)	0.68
Major neurologic complication	1 (7.7)	0	0.99
Ventilation, day	3.2 $\pm$ 2.6	10.7 $\pm$ 7.7	0.02
ICU stay, day	5.1 $\pm$ 3.6	12.5 $\pm$ 7.0	0.01
Hospital stay, day	15.1 $\pm$ 6.2	12.5 $\pm$ 7.0	0.44

ICU, intensive care unit

DISCUSSION

TAAA repair is a challenging surgery for both surgeons and patients. TAAA reconstruction is performed on patients which are at high risk of aortic rupture or have complicated pathologies. However, TAAA repair operations are performed with higher mortality and morbidity rates than standard cardiac surgeries, even in the highest volume centers. In a meta-analysis conducted in 2018, Moulakakis et al. [2] had compiled a total of 9963 TAAA repair results. Pooled mortality was found to be 11.26%.

This is the one of the most comprehensive study showing the results of TAAA repair in Turkey. Surgical centers experienced in the repair of TAAA are few, due to the relatively low

incidence, complex surgical protocol, and high mortality risk of thoracoabdominal aortic aneurysm. To improve surgical outcomes of TAAA repair, it is necessary to reduce blood loss and protect vital organs well in the operation.

Our hospital mortality outcomes are higher compared to the experienced centers [1-3]. However, our 19-patient series is considerably smaller than 3309 TAAA repair series by Coselli et al. [1] and other series [3]. It has been proven that there is a statistically significant inverse relationship between the mortality rate of the centers and the volume of TAAA repair cases [2]. Also, Crawford extend II that requiring the longest segment aortic replacement comprised more than half of our study population, which may be the reason for the higher mortality rate.

As expected, CPB durations were higher in patients with mortality in our study. Prolonged CPB is the result of complicated case which defines extended aneurysm, degenerated tissues and challenging reconstruction. Prolonged ventilation and ICU stay are the results of operation processes, as a surgical idiom mentions : ICU is the mirror of surgery.

Unlike most large volume centers, we do not use left heart bypass for TAAA repair [4,5]. We prefer femoro - femoral CPB because of its advantages such as keeping cannulas away from the surgical field and using cardiectomy aspirator and cardioplegia circuits [6]. In our series femoral artery cannulation was used routinely for artery cannulation. However, patients who had poor pulmonary and/or heart performance we used double artery cannulation. In addition to femoral artery, left axillary artery, right subclavian artery and distal arcus aorta was preferred. We used distal arcus aorta cannulation at the patients who had inadequate axillary artery diameter and degenerative formation with poor pulmonary and heart functions. Furthermore, right subclavian artery bypass was used at the patient who had left subclavian artery occlusion and aneurysmatic distal arcus aorta.

We did not prefer hypothermic circulatory arrest during aortic repair to avoid coagulopathy [7]. In moderate hypothermia, we prefer additional cannulation of the axillary artery, subclavian artery or proximal aorta to the femoro-femoral bypass to perfuse the brain and heart. A recent meta-analysis reviewed studies comparing hypothermic circulatory arrest and left heart bypass in TAAA repair and found no superiority over each other [8]. However, there is no study in the literature comparing proximal aortic - femoral or axillo - femoral perfusion in moderate hypothermia with hypothermic circulatory arrest.

Two popular trends occurred about 3 decades ago for the exclusion of aortic pathologies. These trends were endovascular aortic replacement of abdominal and thoracic aorta (EVAR and TEVAR) [9]. These methods were extremely used all over the world [10]. However, failure of these grafts occurred during follow-up [11]. Consequently, surgical conversion of these stents became an indication of aneurysm management or obligation for life-saving. In this series 3 (15 %) TEVAR stents and 1 (5 %) thoracoabdominal multilayer stent was excluded and surgical aortic reconstructions were performed. Distal partial resection of TEVAR stent was performed in 1 patient. At the rest of the stent excluded patients, total exclusion was performed. The main reasons for stent failure were Type 1 endoleak and stent-graft migration.

Compared with in-hospital mortality, spinal cord ischemia in our cohort is closer to studies in experienced centers (2,4). We routinely use several improved strategies to reduce spinal cord ischemia. We try to keep the body temperature at maximum 32 degrees under CPB, as studies have shown that cooling

between 3°C or 5°C degrees increases the ischemia tolerance of the spinal cord by 2 times [12,13]. The use of a CSFDC is controversial because of some serious complications that may develop during the insertion procedure. However, we did not see any complications related to the insertion of a CSFDC [14,15], and we think that one of the reasons for our low spinal cord ischemia rate is our routine use of implantation and continuous monitoring of CSFDC. Wongkornrat et al. [16] have not found a statistically significant relationship between reimplantation of intercostal arteries and spinal cord ischemia. However, as suggested by Tanaka et al. [17], the decision to anastomose based on the identification of the Adamkiewicz artery in preoperative CTA may also have had an impact on the results.

The study has several limitations. The main limitation of this study is the small number of patients included. The study was designed retrospectively. Another limitation is that all repairs are performed by a single surgical team.

In conclusion, thoracoabdominal aortic aneurysm surgery is associated with high mortality rates. To improve the surgical results of thoracoabdominal aortic aneurysm repair, open thoracoabdominal aortic aneurysm repair programs in tertiary vascular centers should be supported.

Ethics Committee Approval: The study was approved by the Istanbul Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital Clinical Research Ethics Committee (date/no: (2022.24). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: Individual informed consent was waived due to retrospective design.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: All authors contributed equally to the article.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

REFERENCES

1. Coselli JS, LeMaire SA, Preventza O, de la Cruz KI, Cooley DA, Price MD, et al. Outcomes of 3309 thoracoabdominal aortic aneurysm repairs. *J Thorac Cardiovasc Surg* 2016;151:1323-37.
2. Moulakakis KG, Karaolanis G, Antonopoulos CN, Kakisis J, Klonaris C, Preventza O, et al. Open repair of thoracoabdominal

- aortic aneurysms in experienced centers. *J Vasc Surg* 2018;68:634-45.e12
3. Khoury MK, Acher C, Wynn MM, Acher CW. Long-term survival after descending thoracic and thoracoabdominal aortic aneurysm repair. *J Vasc Surg* 2021;74:843-50.
4. Estrera AL, Sandhu HK, Charlton-Ouw KM, Afifi RO, Azizzadeh A, Miller CC 3rd, et al. A Quarter Century of Organ Protection in Open Thoracoabdominal Repair. *Ann Surg* 2015;262:660-8.
5. Wong DR, Parenti JL, Green SY, Chowdhary V, Liao JM, Zarda S, et al. Open repair of thoracoabdominal aortic aneurysm in the modern surgical era: contemporary outcomes in 509 patients. *J Am Coll Surg* 2011;212:569-79; discussion 579-81.
6. Coady MA, Mitchell RS. Femoro-femoral partial bypass in the treatment of thoracoabdominal aneurysms. *Semin Thorac Cardiovasc Surg* 2003;15:340-4.
7. Ise H, Kitahara H, Oyama K, Takahashi K, Kanda H, Fujii S, et al. Hypothermic circulatory arrest induced coagulopathy: rotational thromboelastometry analysis. *Gen Thorac Cardiovasc Surg* 2020;68:754-61.
8. Papadimas E, Tan YK, Qi Q, Ng JJ, Kofidis T, Teoh K, et al. Left heart bypass versus circulatory arrest for open repair of thoracoabdominal aortic pathologies. *ANZ J Surg* 2020;90:2434-40.
9. Parodi JC, Palmaz JC, Barone HD. Transfemoral intraluminal graft implantation for abdominal aortic aneurysms. *Ann Vasc Surg* 1991;5:491-9.
10. Dua A, Kuy S, Lee CJ, Upchurch GR Jr, Desai SS. Epidemiology of aortic aneurysm repair in the United States from 2000 to 2010. *J Vasc Surg* 2014;59:1512-7.
11. Dias AP, Farivar BS, Steenberge SP, Brier C, Kuramochi Y, Lyden SP, et al. Management of failed endovascular aortic aneurysm repair with explantation or fenestrated-branched endovascular aortic aneurysm repair. *J Vasc Surg* 2018;68:1676-87.e3.
12. Strauch JT, Lauten A, Spielvogel D, Rinke S, Zhang N, Weisz D, et al. Mild hypothermia protects the spinal cord from ischemic injury in a chronic porcine model. *Eur J Cardiothorac Surg* 2004;25:708-15.
13. Vacanti FX, Ames A 3rd. Mild hypothermia and Mg⁺⁺ protect against irreversible damage during CNS ischemia. *Stroke* 1984;15:695-98.
14. Fedorow CA, Moon MC, Mutch WA, Grocott HP. Lumbar cerebrospinal fluid drainage for thoracoabdominal aortic surgery: rationale and practical considerations for management. *Anesth Analg* 2010;111:46-58.
15. Youngblood SC, Tolpin DA, LeMaire SA, Coselli JS, Lee VV, Cooper JR Jr. Complications of cerebrospinal fluid drainage after thoracic aortic surgery: a review of 504 patients over 5 years. *J Thorac Cardiovasc Surg* 2013;146:166-71.
16. Wongkornrat W, Yamamoto S, Sekine Y, Ono M, Fujikawa T, Oshima S, et al. Predictors of paraplegia with current thoracoabdominal aortic aneurysm repair. *Asian Cardiovasc Thorac Ann* 2015;23:406-11.
17. Tanaka H, Ogino H, Minatoya K, Matsui Y, Higami T, Okabayashi H, et al. The impact of preoperative identification of the Adamkiewicz artery on descending and thoracoabdominal aortic repair. *J Thorac Cardiovasc Surg* 2016;151:122-8.