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Hypothermic Circulatory Arrest versus Aortic Clamping in Thoracic and Thoracoabdominal Aortic Aneurysm Repair

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Abstract

Background: To compare perioperative and midterm outcomes in thoracic and thoraco-abdominal aortic aneurysm (TAA and TAAA) repair using hypothermic circulatory arrest (HCA) or aortic clamping with mild hypothermia (AC).

Methods: From 2012–2021 there were 180 open repairs of a TAA or TAAA, of which 90 (50%) were done with HCA and 90 (50%) with aortic clamping with mild hypothermia. The indications for HCA were arch aneurysm, TAA from chronic aortic dissection, and inability to clamp the aorta for proximal anastomosis.

Results: Compared to AC, the HCA group had less prior descending aorta replacement/repair (9.1% vs 32%, p=0.0001). Intraoperatively, the HCA group had more TAAs (70% vs 20%, p<0.0001) while the AC group had more TAAAs (80% vs 30%, p<0.0001). HCA group had longer cardiopulmonary bypass times (242 vs 181 minutes, p<0.0001) but shorter cross-clamp time (39 vs 120 minutes, p<0.0001) and lower temperatures (18 vs 34°C, p<0.0001). Postoperatively, the HCA group had longer intubation times (31 vs 26 hours, p=0.002), but all other postoperative outcomes including paralysis (2.2% vs 8.9%, p=0.08), and operative mortality (4.4% vs 2.2%, p=0.68) were similar between HCA and AC groups. Patient age was an independent risk factor for postoperative paralysis (OR 1.07, p=0.03) while HCA was not significant (OR 0.37, p=0.21). Five-year survival was similar between HCA and AC groups (85% vs 80%, p=0.36).

Conclusions: Postoperative outcomes and midterm survival were acceptable in thoracic and thoracoabdominal aneurysm patients after HCA or AC. Both HCA and AC with mild hypothermia were valid approaches in TAA/A repair.

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Keywords

Thoracoabdominal aneurysm; thoracic aneurysm; hypothermic circulatory arrest; aortic clamping; paralysis

INTRODUCTION

Open thoracic and thoracoabdominal aneurysm (TAA and TAAA) repairs are significantly high-risk procedures with a 4% to 30% risk of paraplegia, renal failure requiring dialysis and death, due to end organ ischemia[1–7]. Various approaches to protect end organ ischemia in the last century has included deep hypothermic circulatory arrest (HCA), total cardiopulmary bypass, aortic clamping (AC i.e., cut and sew technique) with adjuncts such as cerebrospinal fluid drainage, passive moderate hypothermia (33–34C) and distal aortic perfusion[1–7]. However, despite these diverse techniques there is lack of consensus on the optimal management of TAA/TAAA patients due to widely varied reported surgical outcomes in literature[7]. Therefore, this study sought to compare the perioperative and midterm outcomes in thoracic and thoraco-abdominal aortic aneurysm (TAA and TAAA) repair using hypothermic circulatory arrest (HCA) or aortic clamping with mild hypothermia (AC).

MATERIALS AND METHODS

The Institutional Review Board at Michigan Medicine (HUM001118517; 9/26/2016) approved this study, and a waiver of informed consent was obtained.

Study Population

Between 2012–2021, 180 patients underwent open surgical repair of a TAA/TAAA at the University of Michigan, of which 90 (50%) were done with HCA (18°C) and 90 (50%) with aortic clamping (AC) and mild hypothermia (34°C).

Indications and operative techniques for HCA has been extensively discussed in our previous paper[8,9]. HCA was the preferred technique compared to AC in patients with arch aneurysm (>4 cm) that require arch replacement with HCA, TAA/TAAA from chronic aortic dissection, inability to clamp the aorta for proximal anastomosis, and patients with connective tissue disease. AC was used in patients who had no arch or proximal descending thoracic aneurysm, a classic or frozen elephant trunk which did not have endoleak and require a replacement.

Operative Technique

As discussed in our previous paper, a left posterior lateral incision was made during TAA repair and extended to the abdomen as a paramedian incision for TAAA repair[9]. In most TAAs, in order to repair the distal aortic arch or descending thoracic aorta, one skin incision was used with two separate thoracotomies either in the 4th and 7th intercostal space or 8th intercostal. A right thoracotomy was performed for descending thoracic aortic aneurysm. TAAA repair was approached either through a single skin incision with two thoracotomies at the 4th and 8th intercostal space and extension of the 8th thoracotomy to the abdomen incision or via a single thoracotomy at the 5th intercostal space with division of the coastal margin. Thoracoabdominal aortic aneurysms were replaced with a multi-branch Dacron graft (Hemashield, Maquet; Gelweave, Terumo) and visceral branch vessels reimplanted. Intercostal arteries in diseased aortic segment were mobilized for either external ligation or reimplantation. Iliac arteries were replaced if they were also dissected. Majority of patients had a lumbar drain prior to thoracotomy. Finally, in patients who underwent open repair with proximal aorta clamping, distal perfusion was attained through cannulation of the distal non-aneurysm aorta, iliac artery or left femoral artery. Left heart bypass (12%), as well as cardiopulmonary bypass (88%) were used in AC patients based on surgeon's preference. In hypothermic circulatory arrest (HCA), patients were cooled to 18°C[9]. Left ventricle venting was performed in HCA patients with mild or moderate aortic insufficiency.

Data Collection

The Society of Thoracic Surgeons (STS) Michigan Medicine Cardiac Surgery Data Warehouse was queried for patients who underwent open thoracic or thoracoabdominal aortic aneurysm repair in addition to preoperative, intraoperative, and postoperative characteristics of the cohort. Data collection was supplemented with medical record review. Survival data were collected through the National Death Index database (December 12, 2021)[10]. Postoperative paralysis was defined as inability to move lower extremities after aneurysm repair.

Statistical Analysis

Data were presented as n (%) for categorical data and median (25th, and 75th percentile) for continuous data. Univariate characteristics were compared using chi-square tests for categorical data and Wilcoxon rank-sum tests for continuous data. Subgroup analysis of HCA vs AC in TAA and TAAA patients was also performed. The Kaplan-Meier method with log-rank testing was used to describe survival over time. Statistical calculations were performed using SAS 9.4 (SAS Institute, Cary, NC). Logistic regression models were used to calculate the hazard ratio of significant factors for postoperative paralysis adjusting for age, HCA, TAA, TAAA extent, intercostal artery reimplantation and prior descending aorta replacement. These variables were chosen based on literature report[2]. Cox proportional hazard regression models were used to calculate the hazard ratio of risk factors for mid-term mortality adjusting for age, sex, HCA, dialysis, chronic lung diseases, and TAAA extent. Paralysis was set as strata due to its violation of the proportional hazard assumption.

RESULTS

Perioperative Demographics

The average age of the entire cohort was 56 years and was similar between groups. The HCA group had higher preoperative BMI (29.3 vs 26.9, p=0.04) and had less previous descending aorta replacement/repair (9.1% vs 32%, p=0.0001). Other preoperative characteristics, including sex, smoking history, Marfan syndrome, hypertension, diabetes, myocardial infarction, and aortic insufficiency, were similar between groups (Table 1).

Intraoperative and Perioperative Outcomes

Intraoperatively, the HCA group had more thoracic aortic aneurysm (TAA) (70% vs 20%) and less thoracoabdominal aortic aneurysm (TAAA) (30% vs 80%) ($p<0.0001$) compared to AC group. Forty-one percent of patients in the HCA group had chronic dissection and 59% of patients had TAA/TAAA without chronic aortic dissection. In the AC group, 27% of patients had chronic dissection and 69% had TAA/TAAA without chronic aortic dissection. The HCA group had more Extent I TAAA repair (41% vs 9.7%) but fewer Extent III (0% vs 17%), Extent IV (0% vs 15%) and Extent V (0% vs 16%) TAAA repair. Extent II TAAA repair was similar between HCA and AC groups (59% vs 42%). Also, the maximum aortic diameter at time of aortic repair was similar between HCA and AC groups (6.1cm vs 6.1 cm, $p=0.72$). Eighty-four percent of patients in the HCA group and 78% of patients in the AC group had elective repair. The HCA group had longer cardiopulmonary bypass times (242 vs 181 minutes) but shorter cross-clamp times (39 vs 120 minutes) and lower temperatures (18 vs 34°C). Intercostal artery reimplantation, intercostal nerve cryoablation, and intraoperative blood product transfusion was similar between groups. Also, the proportion of patients in the HCA versus AC group that had lumbar drain for cerebrospinal fluid (CSF) drainage were similar (94% vs 93%), (Table 2).

Postoperatively, the HCA group had longer intubation times (31 vs 26 hours, $p=0.002$). However, other postoperative outcomes including paralysis (2.2% vs 8.9%), stroke (3.3% vs 4.4%), renal failure (11% vs 10%) and operative mortality (4.4% vs 2.2%) were similar between groups (Table 3). Age was a significant risk factor for postoperative paralysis (OR=1.07, [95% CI: 1.01, 1.14], $p=0.03$). The odds ratio of HCA for postoperative paralysis was 0.37, [95% CI: 0.08, 1.78], $p=0.21$ (Table 4). Five-year survival was similar between HCA and AC groups (85% vs 80%, $p=0.36$); Figure 1. HCA did not significantly impact mid-term mortality (HR=0.99, $p=0.99$) (Table 5).

Subgroup Analysis

HCA vs AC in Descending TAA Repair—There was no significant difference in preoperative data among descending TAA patients who underwent repair with HCA versus AC (Supplementary Table 1). Intraoperatively, compared to AC group, the TAA HCA group had more intercostal artery reimplantation (54% vs 28%) and longer cardiopulmonary bypass time (231 vs 67 minutes) but shorter cross-clamp time (36 vs 58 minutes) and lower temperatures (18 vs 34°C); Supplementary Table 2. Postoperatively, compared to AC group, the TAA HCA group had more prolonged ventilation (33% vs 5.6%), hours intubated (30 vs 15 hours), higher postoperative creatinine (1.3 vs 1.0 mg/dL), longer total intensive care unit stay (112 vs 73 hours). Otherwise, the intra-operative and postoperative outcomes were similar between groups (Supplementary Table 3).

HCA vs AC in TAAA Repair—Compared to AC group, the TAAA HCA group had lower proportions of patients with preoperative congestive heart failure (0% vs 18%), arrythmia (7.4% vs 26%) and previous descending aorta replacement/repair (0% vs 38%). All other preoperative data were similar between groups (Supplementary Table 1). Intraoperatively, compared to the AC group, the HCA group had lower proportion of re-operative cardiac surgery (59% vs 81%), Extent III TAAA (0% vs 17%), Extent IV TAAA (0% vs 15%), Extent V TAAA (0% vs 17%) but higher proportion of Extent I TAAA (41% vs 9.7%). Furthermore, compared to the AC group, the TAAA HCA group had more intercoastal artery reimplantation (100% vs 60%), longer cardiopulmonary bypass time (315 vs 196 minutes) but shorter cross-clamp time (69 vs 138 minutes) and lower temperatures (18 vs 34°C); Supplementary table 2. Postoperatively, compared to the AC group, the TAAA HCA group had more pneumonia (30% vs 11%) and hours intubated (53 vs 28 hours). Otherwise, postoperative outcomes were similar between groups (Supplementary Table 3).

CONCLUSIONS

In this study, the perioperative outcomes and midterm survival of patients with descending thoracic and thoracoabdominal aortic aneurysms (TAA/TAAA) who underwent open repair using either hypothermic circulatory arrest or aortic clamping with mild hypothermia were similar. Postoperative paralysis was low in both groups, but patient' age was an independent risk factor for paralysis. The odds ratio of HCA for paralysis was 0.37, p=0.21. These findings were summarized in the graphical abstract (Figure 2).

There is lack of consensus on the optimal surgical management of TAA/TAAA patients due to significantly high operative mortality (up to 28%) associated with aneurysm repair and lack of optimal end organ protection strategy[1–6]. Occasionally, patients suffer spinal cord ischemia resulting in paraplegia (2–8%) after deep hypothermic circulatory arrest or aortic clamping repair strategy[2,6,13]. Adjuncts such as cerebrospinal fluid drainage, passive moderate hypothermia (33–34C) and distal aortic perfusion have yielded varied outcomes in literature[1–7]. Advocates for HCA report neuroprotection with low rate of paraplegia, elimination of aortic clamping, limited aortic dissection, and bloodless surgical field,[5,6]. However, deep hypothermia results in prolonged cardiopulmonary bypass time, coagulopathy, increased risk of bleeding, and stroke[4,8].

In our study, intraoperative blood transfusion and the proportion of patients with postoperative bleeding, was low and similar in both HCA and AC groups. This could be because we harvested autologous blood before cardiopulmonary bypass, and transfused patients with packed red blood cell when their hematocrit was <25%. This strategy decreased our blood transfusion significantly. Furthermore, the proportion of patients with paralysis was four times lower in the HCA group compared to AC group, though not statistically significant due to low sample size. However, a larger study by Carrel et.al confirms a lower proportion of paraplegia (2.6% vs 8.8%) in TAA/TAAA patients who underwent HCA versus AC[11]. They posit that the risk of paraplegia is related to neuronal metabolism, degree of spinal cord ischemia, and postischemic spinal cord reperfusion injury[11]. Furthermore, we identified that patient's age was an independent risk factors for postoperative paralysis, whereas hypothermic circulatory arrest, intercostal artery re-implantation, descending TAA, Extent II TAAA, and prior descending aortic replacement were not significant risk factors. In line with our study, Safi et al (2005) show that increasing age is a risk factor for post-operative paralysis[2]. Also, Acher et al (2010) argue that older patients (>60years) could be at higher risk of postoperative paralysis because cardiac index decreases with increasing age[12].

Furthermore, in this study, the time to completion of TAA/TAAA repair (OR time) in HCA group was three hours prolonged compared to AC group. Also, postoperatively, patients who underwent TAA repair using HCA had six times prolonged mechanical ventilation, slightly higher postoperative creatinine (1.3mg/dl vs 1.0mg/dl) and required additional intensive care unit (ICU) stay of 39 days compared to AC patients. Likewise, TAAA repair with HCA had more than twice the proportion of patients with pneumonia compared to patients that had aortic clamping (AC). Taken together, aortic clamping with mild hypothermia reduces duration of mechanical ventilation, proportion of lung complications, intensive care unit admission and associated hospital costs. However, HCA should be considered for select patients because it facilitates easy access to the distal ascending aorta and proximal transverse arch, as well as neuroprotection.

In addition, in this study, about a third of patients in the aortic clamping group had prior descending thoracic aorta (DTA) replacement/repair compared to the HCA group (<10%). However, prior DTA replacement/ repair did not significantly impact postoperative paralysis. This could be because we were able to clamp the previous graft during TAA/TAAA repair and prior DTA repair created collaterals for spinal cord perfusion. Covering intercostal arteries prevented paraplegia after TAAA repair.

Finally, we identified that the operative mortality was low and similar (4.4% vs 2.2%) between the HCA and AC group and midterm survival outcomes were favorable. Our midterm mortality after TAA/TAAA repair was unaffected by patient's age, gender, hypothermic circulatory arrest, Extent II TAAA, postoperative dialysis, and chronic lung disease. In contrast to our study, Carrel et al (2000), reported a significant difference in operative mortality between TAA/TAAA patients who underwent HCA versus AC (5.2% vs 16.6%)[11]. Also, Acher et al (2010) showed that younger patients (<60years old) have a lesser risk of mortality (0.7% vs 8.9%) after TAAA repair, though age is less important than cardiac index after a multivariable analysis[12].

Our study is a single center retrospective study and limited due to it heterogenous patient population, varied surgeon expertise and small size. There is a possibility of selection bias in patients who underwent HCA compared to AC. We understand that our results could be limited to our sample population and choice of HCA vs AC should be patient dependent and comfort/skill level of the surgeon should be considered. A longer term and randomized study may be required to better assess surgical outcomes in this patient population.

In conclusion, our study showed that patients who underwent thoracic and thoracoabdominal aneurysm repair using either hypothermic circulatory arrest or aortic clamping with mild hypothermia had similar perioperative outcomes, low postoperative paralysis, and favorable midterm survival outcomes. Both techniques are valid and could be utilized in select patient populations to improve survival outcomes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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REFERENCES

1. Svensson LG, Crawford ES, Hess KR, Coselli JS, Safi HJ. (1993). Experience with 1509 patients undergoing thoracoabdominal aortic operations. J Vasc Surg 17:357–68 [PubMed: 8433431]
2. Safi HJ, Estrera AL, Miller CC, et al. (2005). Evolution of risk for neurologic deficit after descending and thoracoabdominal aortic repair. Ann Thorac Surg, 80:2173–2179. [PubMed: 16305866]
3. Fehrenbacher JW, Hart DW, Huddleston E, et al. (2007). Optimal end organ protection for thoracic and thoracoabdominal aortic aneurysm repair using deep hypothermic circulatory arrest. Ann Thorac Surg, 83:1041–1046. [PubMed: 17307456]
4. Coselli JS, Bozinovski J, Cheung C. (2008). Hypothermic circulatory arrest: safety and efficacy in the operative treatment of descending and thoracoabdominal aortic aneurysms. Ann Thorac Surg, 85:956–963. [PubMed: 18291178]
5. Kulik A, Castner C, & Kouchoukos N (2011). Outcomes after thoracoabdominal aortic aneurysm repair with hypothermic circulatory arrest. The Journal of Thoracic and Cardiovascular Surgery, 141(4), 953–960. [PubMed: 20621310]
6. Kouchoukos NT, Masetti P, Rokkas CK, Murphy SF. (2002). Hypothermic cardiopulmonary bypass and circulatory arrest for operations on the descending thoracic and thoracoabdominal aorta. Ann Thorac Surg, 74:1885–7.
7. Sundt T, Flemming M, Oderich G, Torres N, Li Z, Lenoch J, & Kalra M (2011). Spinal Cord Protection During Open Repair of Thoracic and Thoracoabdominal Aortic Aneurysms Using Profound Hypothermia and Circulatory Arrest. Journal of The American College of Surgeons, 212(4), 678–683 [PubMed: 21463811]
8. Patel HJ, Shillingford MS, Mihalik S, Proctor MC, Deeb GM. (2006). Resection of the descending thoracic aorta: outcomes after use of hypothermic circulatory arrest. Ann Thorac Surg, 82:90–5 [PubMed: 16798196]
9. Clemence J, Malik A, Farhat L, Wu X, Kim K, Patel H, & Yang B (2020). Cryoablation of Intercostal Nerves Decreased Narcotic Usage After Thoracic or Thoracoabdominal Aortic Aneurysm Repair. Seminars In Thoracic and Cardiovascular Surgery, 32(3), 404–412. [PubMed: 31972300]
10. Centers for Disease Control and Prevention; National Center for Health Statistics. National Death Index. n.d.
11. Carrel TP, Berdat PA, Robe J, et al. (2000). Outcome of thoracoabdominal aortic operations using deep hypothermia and distal exsanguination. Ann Thorac Surg 69:692–5. [PubMed: 10750745]
12. Acher C and Wynn M (2010). It is not just assisted circulation, hypothermic arrest, or clamp and sew. The Journal of Thoracic and Cardiovascular Surgery, 140(6), S136–S141. [PubMed: 21092780]

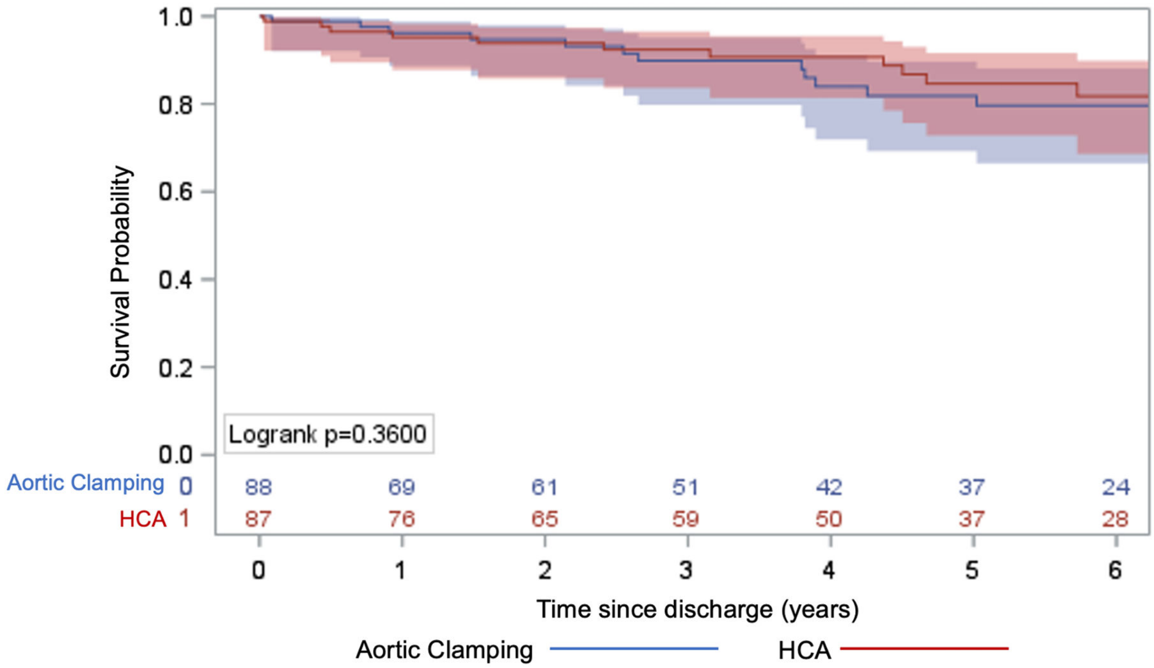

Figure 1:

Kaplan-Meier analysis showed that midterm-term survival was not significantly different between TAA/TAAA patients who underwent hypothermic circulatory arrest versus aortic clamping with mild hypothermia; 5-year: 84.6%, (95% confidence interval (CI): 72.8%, 91.6%) vs. 79.6% (95% CI: 66.5%, 88.1%); p=0.36.

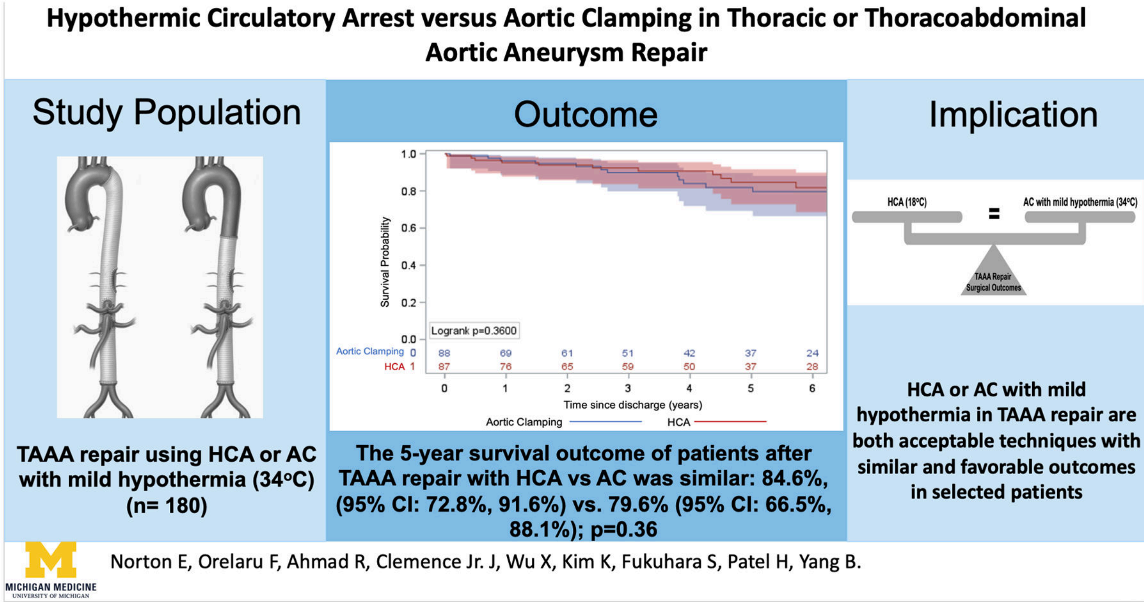

Figure 2 (Graphical Abstract):

Summary of the study showing that midterm survival of patients with thoracic and thoracoabdominal aneurysm who underwent hypothermic circulatory arrest versus aortic clamping with mild hypothermia were similar; 5-year: 84.6%, (95% confidence interval (CI): 72.8%, 91.6%) vs. 79.6% (95% CI: 66.5%, 88.1%); p=0.36.

Table 1.

Demographics and Preoperative Outcomes of the sample population

	HCA (n=90)	AC (n=90)	p-value
Patient age (years)	55 (48, 62)	58 (44, 65)	0.23
Sex, male	58 (64)	46 (51)	0.07
BMI (kg/m^2)	29.2 (25.6, 32.1)	26.9 (24.4, 30.8)	**0.04**
Pre-existing comorbidities			
Hypertension	83 (92)	78 (87)	0.23
Diabetes	9 (10)	10 (11)	0.81
Chronic lung disease	21 (23)	34 (38)	0.05
CHF	12 (13)	16 (18)	0.41
Arrhythmia	13 (14)	22 (24)	0.09
Liver disease	4 (4.4)	2 (2.2)	0.68
History of MI	14 (16)	12 (13)	0.67
History of stroke	13 (14)	6 (6.7)	0.09
Renal failure on dialysis	11 (12)	10 (11)	0.82
Marfan syndrome	9 (10)	14 (16)	0.26
Aortic insufficiency			0.44
None	28 (34)	31 (39)	
Trace	24 (29)	23 (29)	
Mild	28 (34)	19 (24)	
Moderate	3 (3.6)	6 (7.6)	
Severe	0 (0)	0 (0)	
Aortic stenosis	5 (5.6)	5 (5.6)	1.0
Ejection fraction	60 (56, 65)	60 (55, 65)	0.86
Smoking history	58 (64)	60 (67)	0.75
Alcohol consumption ≥2 drinks/week	18 (20)	18 (20)	1.0
Preoperative creatinine	1.0 (0.8, 1.2)	0.9 (0.8, 1.1)	0.22
Previous cardiac surgery			
CABG	7 (7.8)	6 (6.7)	1.0
Any valve	31 (34)	37 (41)	0.36
Aortic root replacement/repair	15 (17)	22 (24)	0.20
Ascending aorta replacement/repair	33 (37)	36 (40)	0.76
Aortic arch replacement/repair	25 (28)	36 (40)	0.08
Descending aorta replacement/repair	8 (9.1)	29 (32)	**0.0001**

Data presented as median (25%, 75%) for continuous data and n (%) for categorical data.

Abbreviations: AC=aortic clamping; BMI=body mass index; CABG=coronary artery bypass grafting; CAD=coronary artery disease; CHF=congestive heart failure in the past 2 weeks; HCA=hypothermic circulatory arrest; MI=myocardial infarction. P-value indicates the difference between HCA and AC groups.

Table 2.

Intraoperative Outcomes

	HCA (n=90)	AC (n=90)	p-value
Re-operative cardiovascular surgery	61 (68)	70 (78)	0.13
Indications for operation			
Aortic rupture*	3 (3.3)	8 (8.9)	0.12
Thoracic aortic aneurysm	63 (70)	18 (20)	**<0.0001**
Thoracoabdominal aortic aneurysm	27 (30)	72 (80)	**<0.0001**
Extent I	11 (41)	7 (9.7)	**0.0009**
Extent II	16 (59)	30 (42)	0.12
Extent III	0 (0)	12 (17)	**0.03**
Extent IV	0 (0)	11 (15)	**0.03**
Extent V	0 (0)	12 (16)	**0.03**
Maximum aortic diameter (cm)	6.1 (5.6, 7.0)	6.1 (5.6, 6.9)	0.72
Timing of surgery			
Elective	76 (84)	70 (78)	0.25
Urgent/Emergent	14 (16)	20 (22)	0.25
Thoracotomy incision type			**<0.0001**
Left thoracotomy	67 (74)	30 (33)	
Right thoracotomy	1 (1.1)	2 (2.2)	
Thoracoabdominal	22 (24)	58 (64)	
Number of thoracotomy incisions			0.64
One	32 (36)	35 (39)	
Two	58 (64)	55 (61)	
CPB time (min)	242 (214, 288)	181 (133, 241)	**<0.0001**
Cross-clamp time (min)	39 (26, 121)	120 (62, 178)	**<0.0001**
HCA time (min)	28 (23, 38)	-	-
Lowest temperature (°C)	18 (18, 18)	34 (33, 24)	**<0.0001**
Intercostal artery reimplantation	60 (67)	48 (53)	0.07
Intercostal nerve cryoablation	38 (42)	39 (43)	0.88
Lumbar Drain	85 (94%)	84 (93%)	0.76
Blood transfusion (PRBCs), units	2 (0, 3)	2 (0, 5)	0.31
Platelets, units	0 (0, 2)	1 (0, 3)	0.11
Fresh frozen plasma, units	0 (0, 2)	0 (0, 3)	0.35
Time in OR (hours)	13 (12, 15)	13 (10, 15)	**0.02**

Data presented as median (25%, 75%) for continuous data and n (%) for categorical data.

Abbreviations: AC=aortic clamping; CPB=cardiopulmonary bypass; HCA=hypothermic circulatory arrest; OR=operating room; PRBCs=packed red blood cells. P-value indicates the difference between HCA and AC groups.

Table 3.

Postoperative Outcomes

	HCA (n=90)	AC (n=90)	p-value
Reoperation for bleeding	2 (2.2)	4 (4.4)	0.68
Sepsis	6 (6.7)	3 (3.3)	0.50
Myocardial infarction	4 (4.4)	3 (3.3)	1.0
Stroke	3 (3.3)	4 (4.4)	1.0
TIA	1 (1.1)	1 (1.1)	1.0
Paralysis	2 (2.2)	8 (8.9)	0.10
Permanent	2 (2.2)	6 (6.7)	0.11
Pneumonia	17 (19)	8 (8.9)	0.05
Prolonged ventilation	37 (41)	28 (31)	0.16
Hours intubated	31.3 (26.3, 54.1)	25.6 (17.5, 49.9)	**0.002**
Postoperative creatinine	1.4 (1.1, 2.3)	1.4 (1.0, 1.9)	0.74
New-onset renal failure	10 (11)	9 (10)	0.81
On dialysis	8 (9.1)	8 (8.9)	0.96
Gastrointestinal complications	12 (13)	14 (16)	0.67
Atrial fibrillation	18 (20)	18 (20)	1.0
Permanent pacemaker/ICD	2 (2.2)	0 (0)	0.50
ICU stay, initial (hours)	114 (94, 186)	158 (94, 208)	0.29
ICU readmission	4 (4.4)	3 (3.3)	1.0
ICU stay, total (hours)	115 (95, 187)	159 (94, 214)	0.30
Chest tube (days)	7.6 (5.5, 9.6)	6.4 (4.8, 9.5)	0.22
Postoperative LOS (days)	13 (9, 19)	13 (8, 20)	0.98
Intraoperative mortality	2 (2.2)	2 (2.2)	1.0
In-hospital mortality	3 (3.3)	2 (2.2)	1.0
30-day mortality	4 (4.4)	2 (2.2)	0.37
Operative mortality *	2 (2.2)	2 (2.2)	0.68
Major adverse event **	15 (17)	14 (16)	0.84
Readmission with 30 days of discharge	26 (29)	23 (26)	0.61

Data presented as median (25 %, 75 %) for continuous data and n (%) for categorical data.

Abbreviations: AC=aortic clamping; HCA=hypothermic circulatory arrest; ICD=implantable cardioverter defibrillator; ICU=intensive care unit; LOS=length of stay; MI=myocardial infarction; TIA=transient ischemic attack. P-value indicates the difference between HCA and AC groups.

* Defined as mortality in-hospital or within 30 days after surgery.

** Major adverse event including operative mortality, stroke, permanent paralysis, and new-onset renal failure.

Table 4:

Logistic Regression Model of Risk Factors for Postoperative Paralysis

Variables	Hazard Ratio (95% CI)	p-value
Age	1.07 (1.01, 1.14)	**0.03**
HCA	0.37 (0.08, 1.78)	0.21
Descending TAA	0.56 (0.09, 3.34)	0.52
Extent II TAAA	2.04 (0.41, 10.2)	0.39
Intercostal artery reimplantation	0.42 (0.10, 1.74)	0.23
Prior descending aortic replacement	0.07 (0.004, 1.08)	0.06

CI=confidence interval; HCA=hypothermic circulatory arrest; TAAA=thoracoabdominal aortic aneurysm.

Table 5:

Cox Model of Risk Factors for Mid-term Mortality

	Hazard Ratio (95% CI)	p-value
Age	1.01 (0.98, 1.05)	0.45
Gender, female	1.68 (0.66, 4.26)	0.28
HCA	0.99 (0.39, 2.48)	0.99
Extent II TAAA	1.79 (0.72, 4.46)	0.21
Dialysis	1.95 (0.24, 15.6)	0.52
Chronic Lung Disease	1.09 (0.14, 8.64)	0.93

CI=confidence interval; HCA=hypothermic circulatory arrest; TAAA= Thoracoabdominal aortic aneurysm

** Postoperative paralysis was set as strata due to its violation of the proportional hazard assumption