

Original Article

Ten-year experience of hybrid arch repair in thoracic aortic diseases from a Vietnamese center

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Abstract

Aim: This study aimed to compare perioperative and long-term outcomes of zone 0 versus zone 1 hybrid aortic arch repair in a Vietnamese cohort.

Material and Methods: The present study is a retrospective–prospective cohort study of 117 patients who underwent hybrid arch repair at a single tertiary centre from 2014 to 2023. Hybrid arch repair was performed in patients with thoracic aortic diseases, including aneurysm, dissection, intramural hematoma, penetrating aortic ulcer, and blunt thoracic aortic injury. Patients were stratified by proximal landing zone 0 or 1. Perioperative outcomes, complications, and long-term survival were analyzed using Kaplan–Meier and Cox regression methods.

Results: Thirty-four patients underwent zone 0 repair and 83 underwent zone 1 repair. The median follow-up duration was 40.7 ± 29.6 months (range 0.2–122.6 months), with a 97.4% follow-up completion rate. The overall 30-day mortality rate was 9.0%, significantly higher in the zone 0 group (26.5%) compared to zone 1 (6.0%; $p = 0.002$). Stroke occurred in 6.0% of patients. The overall survival rates at 1, 3, 5, and 10 years were 96.2%, 89.6%, 86.9%, and 75.0%, respectively. At 10 years, survival in zone 0 was 66.8% versus 82.5% in zone 1 ($p = 0.019$). Retrograde type A dissection was observed in 2.6% of patients, one in zone 0. Late complications, including endoleak type Ia (1.7%) and graft occlusion (0.9%), were infrequent and not statistically different between groups.

Conclusion: Zone 1 hybrid arch repair was associated with better early and long-term outcomes than zone 0. These findings support preferential use of zone 1 landing when anatomically feasible and underscore the importance of proximal landing zone selection in optimizing hybrid TEVAR outcomes in high-risk populations.

Keywords: Hybrid procedure, thoracic aortic diseases, endovascular repair

INTRODUCTION

Thoracic aortic diseases represent a broad and life-threatening spectrum, encompassing thoracic aortic aneurysms (TAA), thoracic aortic dissections (TAD), penetrating atherosclerotic ulcers (PAU), intramural hematoma (IMH), and blunt traumatic aortic injuries (BTAI) [1]. Timely treatment is essential, but surgical repair of the aortic arch remains one of the most technically complex challenges due to the proximity of supra-aortic vessels and the need for cerebral protection [2].

Over recent decades, thoracic endovascular aortic repair

(TEVAR) has transformed the management of thoracic aortic disease, providing a less invasive alternative to open repair with lower perioperative risk. Meta-analyses report 30-day mortality of 6.1–12.1% and stroke rates of 4.8–7.7%, both generally lower than with open surgery, alongside comparable or reduced rates of cerebrovascular events, renal failure, and spinal cord injury [3,4]. However, TEVAR in the aortic arch—especially zones 0 and 1—remains challenging due to difficulties securing a proximal landing zone (PLZ) and risks such as type I endoleak, retrograde type A dissection, and neurologic events [5,6]. Hybrid arch repair, combining supra-

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aortic debranching with zone-specific TEVAR, addresses these issues by creating a favorable PLZ without cardiopulmonary bypass and circulatory arrest. Studies show it yields acceptable perioperative outcomes in high-risk or elderly patients [7,8]. Nonetheless, evidence directly comparing zone 0 and zone 1 strategies is limited. Zone 0 repairs, requiring sternotomy and complete debranching, offer a potentially more secure seal but at the cost of greater invasiveness, operative time, and stroke risk [9,10]. Zone 1 approaches, often using cervical bypasses, may reduce operative complexity and perioperative risk but raise concerns over long-term durability and higher endoleak rates [9].

Although several studies have reported favorable outcomes in Western populations, the evidence remains limited and heterogeneous. Data from Asian populations, especially in Southeast Asia, are still scarce, thereby restricting the generalizability of existing findings to diverse demographic and anatomical settings. To address this gap, we conducted a single-center, combined retrospective and prospective cohort study at Viet Duc University Hospital, one of the largest surgical institutions in Northern Vietnam. The aim of our study was to evaluate the safety, effectiveness, and durability of zone 0 versus zone 1 proximal landing strategies in hybrid arch repair.

MATERIAL AND METHODS

Study Design and Patient Selection

This was a single-center, observational cohort study including both retrospective and prospective components. All patients diagnosed with thoracic aortic diseases, including aneurysm, dissection, intramural hematoma, penetrating aortic ulcer, and blunt thoracic aortic injury, and treated with hybrid aortic arch repair at Viet Duc University Hospital, Vietnam, between January 2014 and September 2023 were considered for inclusion. The retrospective cohort included 75 patients who underwent hybrid treatment for thoracic aortic disease between January 1, 2014 and December 31, 2021. The prospective cohort included 42 patients who were consecutively enrolled between January 1, 2022 and September 30, 2023. The hybrid repair was defined as supra-aortic debranching followed by thoracic endovascular aortic repair (TEVAR). Patients were classified into two groups according to the PLZ of the stent graft, based on the Ishimaru classification: zone 0 and zone 1. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Viet Duc University Hospital. This study was approved by the Institutional Review Board of Hanoi Medical University (HMU IRB; approval code IRB-VN01.001/IRB00003121/FWA00004148; Study code: T2404; approval period: January 1, 2022 – December 31, 2023). All study procedures adhered to the ethical principles for biomedical

research, and written informed consent was obtained from all participants prior to enrollment.

The sample size was estimated using the expected 30-day mortality rate of 8.9%, reported by Benrashid et al. in a previous study on hybrid treatment for thoracic aortic disease. [9]. With a 95% confidence level and a margin of error of 6%, the minimum required sample size was calculated to be 105 participants. A convenience sampling approach was applied, in which all consecutive patients who met the eligibility criteria and underwent hybrid treatment for thoracic aortic disease at Viet Duc University Hospital during the study period were included until the required sample size was achieved.

Inclusion and Exclusion Criteria

Patients with a confirmed diagnosis of thoracic aortic disease who were indicated for and underwent hybrid treatment, either successfully or converted to conventional open surgery, were eligible for inclusion. There were no restrictions regarding age or sex, provided that complete medical records were available. Only patients whose families provided informed consent were included.

Patients were excluded if they underwent surgery with cardiopulmonary bypass, were referred from other hospitals after failed surgery or intervention, or received combined surgical and endovascular treatment during different hospitalizations. Patients and families who declined participation were also excluded.

Procedure

Supra-aortic debranching was performed prior to TEVAR to ensure an adequate PLZ. For zone 0 repairs, median sternotomy was used with total arch debranching utilizing bifurcated Dacron grafts. In zone 1 procedures, carotid-carotid bypass was performed via cervical incisions. The left subclavian artery (LSA) may not be revascularized, or it may be revascularized using one of several techniques, such as a direct bypass from the ascending aortic graft or from the left common carotid artery (LCA) for zone 0, bypass or transposition to LCA for zone 1. The origin of the LSA was either covered by the stent graft alone, ligated, or occluded using an Amplatzer plug. Following the vascular bypass procedure, endovascular repair was performed using stent grafts from one of the following manufacturers: Medtronic, Bolton, Lifetech, Jotec Evita, or Zenith Cook, depending on the availability of materials at the time of intervention. The stent grafts were deployed via femoral or iliac access under general anesthesia. Selective cerebrospinal fluid drainage (CFD) was employed in patients at high risk for spinal cord ischemia. In patients presenting with associated hemothorax, intraoperative chest drainage was applied.

Data Collection and Variables

Clinical data were extracted from hospital electronic medical records, surgical logs, imaging databases, and outpatient or telephone follow-up assessments.

Outcomes

The primary outcomes of the study were 30-day mortality, defined as death from any cause within 30 days after the hybrid procedure. Overall survival was defined as the time from the date of surgery to death from any cause or last follow-up, and long-term survival during the follow-up period. Survival status was evaluated using hospital medical records, outpatient clinic visits, and telephone interviews with patients or their families. Specific causes of early mortality were documented and included aortic rupture, extensive cerebral ischemia, retrograde type A dissection (RTAD), multiple organ failure, and septic shock. Early postoperative and late complications were systematically recorded. Early and late endoleaks (types I, II, III) were assessed via postoperative contrast-enhanced CT scan.

Statistical Analysis

All statistical analyses were performed using Stata version 18.0. Categorical variables were presented as frequencies and percentages, while continuous variables were summarized using median and interquartile range (IQR). Comparisons between zone 0 and zone 1 groups were made using the Chi-square test or Fisher's exact test for categorical variables and the Mann-Whitney U test for continuous variables. Kaplan-Meier survival curves were generated to assess long-term survival and freedom from aortic-related events. Comparisons between survival curves of zone 0 and zone 1 patients were made using the log-rank test. All results were reported with corresponding 95% confidence intervals (CIs).

RESULTS

In total, 117 patients underwent hybrid aortic arch repair during the study period. The indications included thoracic aortic aneurysm (n=45), aortic dissection (n=48), intramural hematoma and penetrating aortic ulcer (n=12), and blunt thoracic aortic injury (n=12). The median age was 63 years (Range: 54–67), with no statistically significant difference between groups ($p = 0.895$). The majority of patients were male (87.2%). Hypertension was the most common comorbidity (80.3%), followed by a history of smoking (41.0%) and chronic obstructive pulmonary disease (5.1%). Baseline characteristics, including body mass index, comorbidity profiles, and aortic dimensions, were comparable between the two groups, except for the aortic arch diameter, which was significantly greater in the zone 0 group (33.4 mm vs. 31.3 mm, $p = 0.029$).

Median operative time was significantly longer for patients in the zone 0 group compared to zone 1 (245 minutes vs. 160 minutes, $p < 0.001$). Likewise, the median stent deployment time was also longer in zone 0 (50 vs. 40 minutes, $p = 0.047$). Patients in the zone 0 group experienced significantly longer postoperative hospital stays (median: 19 vs. 11 days, $p < 0.001$), total hospital stay (24.5 vs. 20.0 days, $p = 0.017$), and ICU stay (7 vs. 3 days, $p < 0.001$) compared to the zone 1 group.

The 30-day mortality for the entire cohort was 9.0%, but was significantly higher in the zone 0 group (26.5%) compared to zone 1 (6.0%; $p = 0.002$). The most common causes of early mortality included aneurysm rupture (3.0%), extensive cerebral ischemia (1.8%), RTAD (5.1%), septic shock (1.2%), and multiple organ failure (0.6%). Zone 0 patients exhibited a disproportionately higher frequency of neurologic and infectious complications contributing to mortality.

The most common complication was stroke, occurring in 7 patients (6.0%) overall, and significantly more frequently in the zone 0 group (17.6% vs. 1.2%; $p = 0.001$). Pneumonia was observed in 3.4% of patients, predominantly in zone 0 (8.8% vs. 1.2%, $p = 0.037$). Bleeding complications requiring intervention occurred in 4 patients (3.4%), while hemothorax was seen in 5 patients (4.3%).

Late Outcomes and Complications

Late postoperative complications are summarized in Table 3. The overall incidence of late adverse events was low and comparable between the two PLZ groups. RTAD occurred in 2 patients (1.7%), both from the zone 1 group (2.4%), with no cases reported in the zone 0 group ($p = 0.361$). Carotid-carotid bypass graft occlusion was each observed in one patient (0.9%). Late endoleak type Ia was reported in 2 patients (1.7%), again only in the zone 1 group (2.4%), with no events documented in zone 0 ($p = 0.361$).

The median follow-up duration was 40.7 ± 29.6 months, with a range of 0.2 to 122.6 months. Follow-up was successfully completed in 97.4% of patients. The overall survival rates at 1, 3, 5, 7, and 10 years were 82.1%, 75.4%, 72.2%, 63.9% and 47.9% respectively.

Figure 1 presents a stratified Kaplan-Meier analysis comparing long-term survival between patients receiving stent grafts in zone 0 and zone 1 proximal landing zones. The estimated overall survival rates for the zone 0 group at 1, 3, 5, 7, and 9 years were 67.7%, 64.4%, 64.4%, 40.9% and 40.9% respectively. For the zone 1 group, overall survival rates at the same time points were higher: 87.9%, 79.9%, 75.0%, 75.0% and 50.0%. The difference in survival between the two groups was statistically significant, as demonstrated by the log-rank test ($p = 0.019$).

Table 1. Baseline demographic and preoperative characteristics of patients

Variable	Total (n = 117)	Zone 0 (n = 34)	Zone 1 (n = 83)	P
Patient characteristics				
Age – years	63.0 (54.0, 67.0)	63.0 (52.0, 67.0)	62.0 (54.0, 67.0)	0.895
Body mass index	22.2 (20.7, 24.5)	22.0 (20.6, 24.4)	22.7 (20.8, 24.6)	0.313
Male (%)	102 (87.2%)	30 (88.2%)	72 (86.7%)	0.827
Comorbidities				
Hypertension	94 (80.3%)	24 (70.6%)	70 (84.3%)	0.089
Diabetes	7 (6.0%)	4 (11.8%)	3 (3.6%)	0.091
Gout	5 (4.3%)	0 (0.0%)	5 (6.0%)	0.144
Hyperlipidemia	3 (2.6%)	2 (5.9%)	1 (1.2%)	0.146
COPD	6 (5.1%)	3 (8.8%)	3 (3.6%)	0.246
Stroke	6 (5.1%)	1 (2.9%)	5 (6.0%)	0.492
Coronary artery disease	6 (5.1%)	1 (2.9%)	5 (6.0%)	0.492
History of smoke	48 (41.0%)	14 (41.2%)	34 (41.0%)	0.983
History of alcohol	8 (6.8%)	3 (8.8%)	5 (6.0%)	0.586
Pre-operative measurements				
Ascending Aortic Diameter				0.871
Median (Q1, Q3)	36.0 (33.0, 38.3)	36.0 (33.0, 38.5)	36.0 (33.0, 38.3)	
Min, Max	18.0, 47.0	18.0, 44.0	25.9, 47.0	
Aortic Arch Diameter				0.029
Median (Q1, Q3)	31.8 (29.6, 36.0)	33.4 (30.0, 41.0)	31.3 (28.5, 34.3)	
Min, Max	17.3, 62.0	17.3, 62.0	19.8, 57.0	
Descending Aortic Diameter				0.211
Median (Q1, Q3)	30.0 (26.0, 36.0)	29.0 (24.0, 36.0)	31.0 (27.0, 36.0)	
Min, Max	12.7, 98.0	12.7, 98.0	17.8, 70.0	

COPD, Chronic obstructive pulmonary disease; Data are presented as number (%) or median (IQR).

Table 2. Intraoperative and early postoperative outcomes according to proximal landing

Zone				
Variable	Total (n = 117)	Zone 0 (n = 34)	Zone 1 (n = 83)	p
Peri-operative outcomes				<0.001
Operative time - min	175.0 (150.0 - 210.0)	245.0 (180.0 - 290.0)	160.0 (140.0 - 185.0)	0.047
Stent deployment time - min	40.0 (30.0 - 60.0)	50.0 (30.0 - 80.0)	40.0 (30.0 - 60.0)	0.017
Total length of hospital stay – days	21.0 (15.0 - 28.0)	24.5 (19.0 - 39.0)	20.0 (14.0 - 28.0)	<0.001
Post-operative hospital stay – days	12.0 (9.0 - 18.0)	19.0 (11.0 - 31.0)	11.0 (8.0 - 14.0)	<0.001
Length of ICU stay - days	4.0 (2.0 - 7.0)	7.0 (5.0 - 19.0)	3.0 (1.0 - 5.0)	0.002
30-day mortality	15 (9.0%)	9 (26.5%)	5 (6.0%)	0.009
Causes of 30-day mortality				
Aneurysm rupture	5 (3.0%)	3 (8.8%)	1 (1.2%)	
Extensive cerebral ischemia	3 (1.8%)	3 (8.8%)	0 (0.0%)	
Multiple organ failure	1 (0.6%)	1 (2.9%)	0 (0.0%)	
RTAD	4 (2.4%)	1 (2.9%)	3 (3.6%)	
Septic shock	2 (1.2%)	1 (2.9%)	1 (1.2%)	
Early in-hospital complications				
Spinal cord injury	1 (0.9%)	1 (2.9%)	0 (0.0%)	
Surgical site infection	2 (1.7%)	0 (0.0%)	2 (2.4%)	
Early RTAD	6 (5.1%)	1 (2.9%)	5 (6.0%)	
Hemothorax	5 (4.3%)	2 (5.9%)	3 (3.6%)	
Stroke	7 (6.0%)	6 (17.6%)	1 (1.2%)	
Cardiac arrest	2 (1.7%)	1 (2.9%)	1 (1.2%)	
Pneumonia	4 (3.4%)	3 (8.8%)	1 (1.2%)	
Renal failure	7 (6.0%)	2 (5.9%)	5 (6.0%)	
Multiple organ failure	3 (2.6%)	1 (2.9%)	1 (1.2%)	
Cervical lymphatic fistula	1 (0.9%)	1 (2.9%)	2 (2.4%)	
Early endoleak	3 (2.6%)	2 (5.9%)	1 (1.2%)	
Sepsis	1 (0.9%)	0 (0.0%)	1 (1.2%)	
Data are presented as number (%) or median (range)				

Table 3. Late postoperative complications and follow-up events				
Variable	Total (n = 117)	Zone 0 (n = 34)	Zone 1 (n = 83)	p
Late complications				
RTAD	2 (1.7%)	0	2 (2.4%)	0.361
Carotid–carotid bypass graft occlusion	1 (0.9%)	0	1 (1.2%)	0.520
Carotid steal syndrome	1 (0.9%)	0	1 (1.2%)	0.520
Late endoleak (type Ia)	2 (1.7%)	0	2 (2.4%)	0.361
RTAD: retrograde type A dissection				

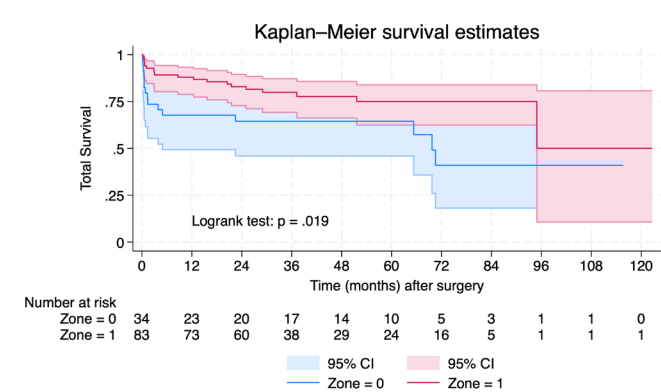


Figure 1. Kaplan-Meier survival curve for Zone 0 and zone 1 repair

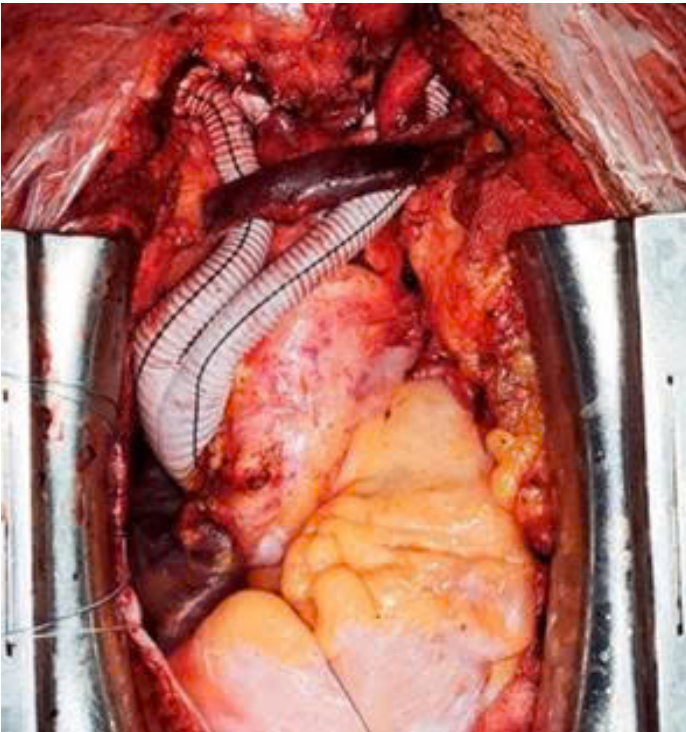


Figure 2. Intraoperative image of aorto-bicarotid and left subclavian bypass for zone 0 repair

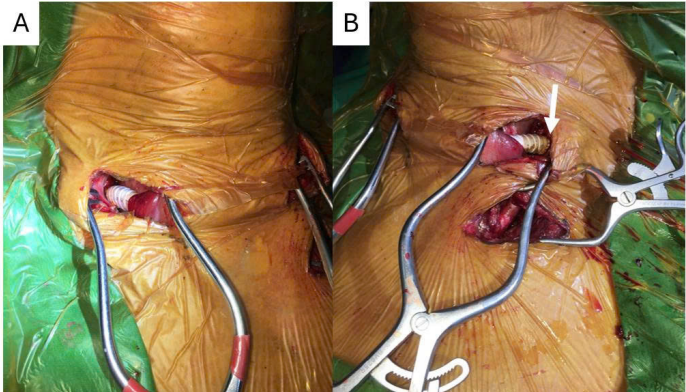


Figure 3. Intraoperative images of carotid–carotid bypass for zone 1 repair: (A) carotid – carotid bypass view from the right side with pre-tracheal tunnel (B) carotid – carotid bypass view from the left side (arrow indicates anastomosis between LSA and left carotid artery)

DISCUSSION

In this study, we analyzed the long-term outcomes of hybrid aortic arch repair over a 10-year period in a Vietnamese cohort and found that patients undergoing zone 0 repair had significantly poorer early and late outcomes compared to those in the zone 1 group. Our findings are consistent with those of Kudo et al. who reported better survival and fewer complications in patients undergoing zone 1 landing, particularly with carotid–carotid bypass [8]. In our cohort, the 30-day mortality rate was 9% (n = 15) and the incidence of early stroke was 6% (n = 7), which fall within but toward the higher end of reported ranges in the hybrid aortic arch literature. For instance, Benrashid et al. reported a 30-day mortality of 8.9% in a large U.S. series of hybrid arch repaired [9].

The present study demonstrated a significantly higher 30-day mortality rate in patients undergoing hybrid TEVAR with zone 0 (26.5%) compared to those in zone 1 (6.0%, p = 0.002). This finding is consistent with previous literature indicating that zone 0 TEVAR is associated with increased procedural complexity and perioperative risk [8,10,11]. As reported by Kudo et al., interventions involving zone 0 often

necessitate median sternotomy and management of a dilated or atheromatous ascending aorta—factors known to contribute to higher early mortality and neurological complications [8]. Similarly, Tokuda et al. and colleagues found that while hybrid arch repair may offer comparable short-term outcomes to open arch surgery, its mid-term efficacy appears inferior, particularly among high-risk patients who are more frequently treated using zone 0 techniques [10]. Anatomically, the zone 0 region is haemodynamically demanding, with elevated shear stress and close proximity to the aortic valve, which may predispose to RTAD and type Ia endoleak, further compounding procedural risk.

The observed overall survival rates at 1, 3, 5, 7, and 10 years in our cohort were 82.1%, 75.4%, 72.2%, 63.9%, and 47.9%, respectively. Importantly, the 10-year survival rate of 47.9%—although lower than some international benchmarks—remains clinically significant given the high-risk profiles of patients undergoing hybrid aortic arch repair. Similarly, Kudo et al. in a Japanese population observed 5-year survival rates of approximately 82–86% depending on the PLZ, with better outcomes in zone 1 than zone 0 [8]. Our 1-year survival (82.1%) was lower than both Vekstein et al. and Kudo et al., potentially reflecting differences in baseline characteristics, including a higher prevalence of comorbidities, advanced disease stages, or delays in referral and treatment—common in lower-resource settings. Moreover, our patients may have had a higher proportion of emergency or symptomatic cases, which are known predictors of poorer outcomes [7]. It is also noteworthy that our 10-year survival of 47.9% was comparable to the lower end of long-term survival reported in Western cohorts. This discrepancy may stem from differences in follow-up intensity, access to surveillance imaging, and management of late complications, such as endoleaks or RTAD. Taken together, our findings contribute important long-term outcome data from a Southeast Asian population, which remains underrepresented in hybrid TEVAR literature. Despite slightly lower survival rates, the durability of the hybrid approach appears acceptable, especially considering its application in high-risk patients unfit for open total arch replacement.

Early RTAD was identified in 6 patients (5.1%) in our cohort, 5 of whom had undergone zone 1 hybrid repair. While RTAD is a rare but life-threatening complication of TEVAR, its occurrence exclusively in the zone 1 group in our study is noteworthy and may be related to the interplay between graft positioning, oversizing, and arch curvature. Previous studies have reported RTAD rates ranging from 1.3% to 5.6%, with variable associations to landing zone selection [8,9]. In theory, zone 0 repairs, which anchor the stent graft in the relatively straight ascending aorta, may carry higher mechanical stress and a greater RTAD risk. However, in our series, almost RTAD cases occurred after zone 1 landing, possibly due to graft

oversizing or hostile arch anatomy, such as sharp angulation at the lesser curvature or a tight aortic arch radius [12]. In addition, the manipulation of wires and sheaths in curved segments of the arch during deployment may increase the risk of retrograde intimal tear.

This study has several limitations that should be acknowledged. First, it was conducted at a single tertiary referral center (Viet Duc University Hospital), which may limit the generalizability of findings to broader or more diverse populations. Second, although the study included a 10-year observation period, the sample size was relatively modest ($n = 117$), especially for subgroup analyses comparing zone 0 and zone 1 procedures.

CONCLUSION

Hybrid aortic arch repair with zone 1 proximal landing was associated with better perioperative and long-term outcomes compared to zone 0. Our 10-year experience supports the use of zone 1 as the preferred approach in anatomically suitable patients. These results highlight the importance of strategic landing zone selection and provide valuable long-term data from an Asian population, addressing a gap in the current TEVAR literature.

Ethics Committee Approval: This study was approved by the Institutional Review Board of Hanoi Medical University (HMU IRB; approval code IRB-VN01.001/IRB00003121/FWA00004148; Study code: T2404; approval period: January 1, 2022 – December 31, 2023).

Patient Consent for Publication: Written informed consent was obtained from all participants prior to inclusion.

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.

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Highlight key points: Hybrid aortic arch repair with zone 1 was associated with better perioperative and long-term outcomes compared to zone 0. Our 10-year experience supports the use of zone 1 as the preferred approach in anatomically suitable patients. These results highlight the importance of strategic landing zone selection and provide valuable long-term data from an Asian population, addressing a gap in the current TEVAR literature.

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