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Efficacy and safety of debranching technique with zone 1 thoracic endovascular aortic repair in high-risk patients with distal aortic arch lesions

Xiaotian Gao[1*†], Xin Li[1†], Shandong Liu[1] and Chunhui Yu[1]

Abstract

Background To share the results of the debranching technique with zone 1 thoracic endovascular aortic repair (TEVAR) in high-risk patients chosen based on older age, cardiopulmonary comorbidities, and unfit for open surgical procedures, who have distal arch lesions.

Methods Between January 2020 and August 2022, 15 patients treated in our practice were treated with the debranching technique TEVAR (d-TEVAR) for distal aortic arch lesions requiring a stent-graft landing in zone 1. We retrospectively reviewed clinical data and significant outcomes for prognostic analyses. Lesion types included chronic Stanford type B aortic dissections ($n=10$), distal arch aneurysms ($n=4$), and one pseudoaneurysm. All lesions were chronic, with no involvement of visceral vessels. These patients were considered high-risk in a multidisciplinary fashion.

Results All procedures were completed with a technical success rate of 100%. The mean operative time was 317 ± 48 min. No in-hospital mortality or major complications were recorded. One patient had a type I endoleak at 3 months that was treated conservatively due to no symptoms during follow-up (median 16 months, (range 12–20)), and in one patient, this was associated with fatal cerebral infarction at 4 months following the procedure, yielding a stroke rate of 6.7%. Graft survival for all patients, via a Kaplan-Meier analysis, was 89.3%.

Conclusions For distal aortic arch lesions requiring a zone 1 stent-graft landing, d-TEVAR is an effective and safe alternative treatment option with promising short-term results in well-selected high-risk patients and can be applied when open surgery constitutes a significant surgical risk.

Keywords Distal aortic arch lesions, Debranching technique, Thoracic endovascular aortic repair, Zone 1 landing, Open surgery

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Background

Cardiopulmonary bypass with open surgery, deep hypothermic circulatory arrest, and selective cerebral perfusion remain the standard in the treatment of aortic arch pathology [1]. Although surgical technique, intraoperative care, and postoperative care have improved, the challenges of open repair remain. These open-repair approaches are all invasive, and we will now highlight the fact that they may be associated with higher postoperative complications or even higher mortality/morbidity [2]. For more than 20 years, thoracic endovascular aortic repair (TEVAR) has been adopted as an alternative option for aortic arch lesions, with a more favorable risk profile and quicker recovery compared to open surgical methods—especially in those deemed at higher risk for open surgery due to age, cardiopulmonary compromise, and previous thoracic surgery [3–5]. Distal aortic arch lesions—including chronic Stanford type B dissections, aortic arch aneurysms, and pseudoaneurysms—are particularly challenging as the supra-aortic vessels are less complicated than the arch, and these patients will likely have lesions extending into the arch. For this reason, if this portion of the arch is excluded, the stent will need to be deployed and coiled on the descending aorta, proximal to the lesion and landing zone, in zone 1, hence covering the left subclavian artery (LSA) and in rare cases the left common carotid artery (LCCA) [6, 7].

Coverage (if unprotected) can cause complications such as posterior circulation stroke, spinal cord ischemia, and left upper limb ischemia. Thus, pre-emptive or simultaneous revascularization of the supra-aortic branches is essential to preserve cerebral and upper limb perfusion [8]. Zone 1 TEVAR, in conjunction with extra-anatomical bypass or debranching, has been considered a possible replacement for total arch replacement for selected high-risk patients; however, the technical nuances and long-term outcomes of either patient selection remain mostly unstudied or presented in a limited scope, especially about real-world clinical practice [9, 10]. In this study, we share our clinical experience and observations of the debranching technique with zone 1 TEVAR (d-TEVAR) for distal aortic arch lesions requiring a zone 1 stent-graft landing zone.

Materials and methods

Selection of patients

From January 2020 to August 2022, 15 patients with distal aortic arch lesions requiring a zone 1 stent-graft landing underwent d-TEVAR in our center. The clinical records of the patients were retrospectively reviewed, with data on demographic data, comorbidities, imaging findings, details of the surgical process, and follow-up outcomes. All patients were selected consecutively from our institutional thoracic aortic pathology registry. d-TEVAR was performed on patients deemed unsuitable for open surgical repair due to anatomical considerations or surgical risk, and where the anatomical assessment concluded it was possible to reconstruct the debranching. All patients were included using a standard institutional protocol established with the multidisciplinary vascular team.

Inclusion criteria were: (1) a confirmed distal aortic arch lesion not amenable to standard TEVAR due to inadequate landing zone; (2) high surgical risk based on factors such as old age (> 70 years), chronic cardiopulmonary disease, or prior thoracic surgery; and (3) debranching of the aorta anatomy deemed feasible on preoperative computed tomographic angiography (CTA). Exclusion criteria included active infection, uncontrolled coagulopathy, and uncorrectable contraindications to endovascular repair.

15 patients were included, of which 10 had chronic Stanford-type B dissections, 4 had distal arch aneurysms, and 1 had a pseudoaneurysm. All lesions were chronic, and none of the lesions included branches involving visceral arteries. After meeting the above conditions, no patients were excluded based on anatomical ineligibility or comorbidity. CTA was performed preoperatively to assess arch morphology, the involvement of supra-aortic branches, and the measurement of potential landing zones.

The Ethics Committees of The First Affiliated Hospital of Anhui Medical University approved the present study, and individual consent was waived owing to the retrospective study design.

Surgical procedures

All procedures were conducted in a hybrid operating room with the patient under general anesthesia. The patient was placed in the supine position, with the head turned to the right for access. Bilateral axillary arteries were exposed through infraclavicular incisions, and the left common carotid artery (LCCA) was exposed using an oblique incision over the anterior border of the sternocleidomastoid muscle. Systemic heparinization was instituted intravenously at 1 mg/kg body weight. Discussion to the right axillary artery, the first 8 mm GORE-TEX prosthetic graft was anastomosed end-to-side. The free end of the graft was tunneled subcutaneously across the anterior chest to the left side and temporarily cannulated into the LCCA using a 10 Fr arterial cannula to maintain cerebral perfusion. Once the LCCA was cannulated, two vascular clamps were placed below the cannulation site. A second 8 mm graft was anastomosed end-to-side to the LCCA between the clamps. After the anastomosis, blood flow through the LCCA was restored by removing the two clamps and the cannula.

Subsequently, the free end of the first graft was connected end-to-side to the left axillary artery. Lastly, the

free end of the second graft was connected end-to-side to the body of the first graft in the suprasternal fossa. This configuration resulted in a "T"-shaped extra-anatomical bypass that re-established arterial blood supply from the right axillary artery to the LCCA and the left axillary artery. The native LCCA was ligated approximately 5–10 mm distal from its origin to prevent retrograde flow or competitive perfusion. Intraoperatively, the bypass system's final configuration was verified and illustrated angiographically in Fig. 1. Although a schematic drawing was omitted, the text has been amended, and additional details have been added describing each anatomical step to improve understanding of the bypass technique.

Endovascular technique

After the extra-anatomical bypass, the right or left femoral artery dissociation was performed according to the intraoperative requirements. Firstly, the aortic angiography was performed using a 5 Fr pigtail with side holes, further confirming the details and the diameter of lesions of the aortic arch. The size of the stent graft was chosen with a 20% oversizing relative to the diameter of the proximal landing zone based on current endovascular standards. The proximal landing zone was defined as zone 1 per the Ishimaru classification [7]. If the length of aortic lesions exceeded the length of the stent graft, a second stent graft was placed to connect with the first one. Finally, another aortic angiography was performed to ensure that the prosthetic graft was patent and whether there was an obvious endoleak. Devices used included Zenith TX2 (Cook Medical) and RelayPlus (Bolton Medical), with lengths ranging from 130 to 200 mm based on individual anatomy.

These stent grafts were selected for their acceptable clinical profile regarding delivery, conformability related to aortic arch angulation, and institutional experience.

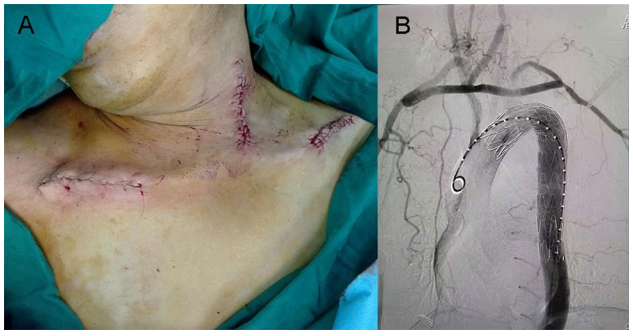

Fig. 1 d-TEVAR was performed in a case
(A) Intraoperative photograph showing the surgical field with the axillary–carotid–axillary bypass graft configuration
(B) Intraoperative aortic angiography confirms successful stent graft deployment and good bypass flow
This figure illustrates the hybrid approach to maintain cerebral and upper extremity perfusion during Zone 1 TEVAR.

Zenith TX2 and RelayPlus have been used in our practice for their total arch trackability in complex arch anatomies and excellent proximal seal performance noted in previous studies, which is essential for zone 1 TEVAR. Each stent graft was selected to meet the specific patient needs based on preoperative CTA regarding arch morphology and lesion length.

Postoperative care

All patients were admitted to the intensive care unit (ICU) after d-TEVAR. Arterial blood pressure was maintained below 120 mmHg, and the intubation tube was withdrawn once the patient awoke. Postoperative ICU management strategies were carried out according to standard institutional practices. Patients were transferred to the general ward when stable physiological parameters were achieved.

Follow-up

CTA was conducted before discharge and at 3, 6, and 12 months after surgery, and annually thereafter. Radiological follow-up collected information on the presence of endoleak, patency of the bypass graft, aneurysm sac characteristics, and evidence of stent migration or thrombosis. Clinical follow-up collected information on cerebrovascular events, ischemia of the left arm, and death. No patients were lost to follow-up until that time point. The definitions of complications included stroke, endoleak (type I–III), spinal cord injury, acute kidney injury, posterior circulation ischemia, ischemia of the left upper limb, and death.

Statistical analysis

As appropriate to the distribution, continuous variables were presented as mean ± standard deviation (SD) or median (interquartile range). Categorical variables were represented as counts and percentages. A Kaplan–Meier approach was used for survival analysis. To improve the interpretation of the survival curve, 95% confidence intervals (CIs) were included. Statistical analyses were completed using IBM SPSS Statistics for Windows (version 22.0) (IBM Corp., Armonk, NY, USA).

Although Kaplan–Meier analysis was completed, we acknowledge this limitation, based on the sample size and the relatively short follow-up period, which may limit the accuracy of the survival estimates and generalizability of the results.

Results

Clinical characteristics

Among the 15 subjects, 10 were male, with a mean age of 64.4 ± 4.3 years. The causes of the distal aortic arch lesions included chronic Stanford type B aortic dissection ($n = 10$), thoracic aortic aneurysm ($n = 4$), and

Table 1 Patients' clinical characteristics ($N=15$)

Variable	Mean ± SD or number (%)
Demographics	
Age (years)	64.4 ± 4.3
Gender(male)	10 (66.7%)
Height (cm)	165 ± 6.6
Weight (kg)	66.2 ± 10.1
Comorbidities	
Smoking	5 (33.3%)
Drinking	3 (20.0%)
Hypertension	13 (86.7%)
Diabetes mellitus	4 (26.7%)
Cerebral infraction	3 (20.0%)
Chronic kidney disease	2 (13.3%)
Medications	
β-blocks	6 (40.0%)
CCB	4 (26.7%)
ACEI/ARB	4 (26.7%)
Diuretics	3 (20.0%)
Etiologies	
Stanford type B aortic dissection	10 (66.7%)
Thoracic aortic aneurysm	4 (26.7%)
Pseudoaneurysm of the aortic arch	1 (6.7%)

CCB: calcium channel blocker; ACEI/ARB: angiotensin-converting enzyme inhibitor/angiotensin receptor blocker

Table 2 Clinical outcomes during hospitalization ($N=15$)

Variable	Mean ± SD or number (%)
Operation time (minutes)	317 ± 48
Postoperative mechanical ventilation duration (hours)	7.0 ± 3.9
ICU stay (hours)	16.3 ± 7.2
Hospitalization time (days)	17.5 ± 6.4
Complications	
Endoleak	0 (0%)
Acute kidney injury	2 (33.3%)
Spinal cord injury	0 (0%)
Left upper limb ischemia	0 (0%)
Posterior circulation ischemia	0 (0%)
Stroke	0 (0%)
Death	0 (0%)

pseudoaneurysm of the aortic arch ($n=1$). All lesions were chronic, and acute dissections and traumatic causes were excluded. The patients were classified as high risk based on advanced age, comorbidities (the most common being hypertension in 12 patients, chronic obstructive pulmonary disease in 5, and coronary artery disease in 4), and preoperative American Society of Anesthesiologists (ASA) physical status scores of III or IV in 11 patients, which were components of a multidisciplinary consensus on debranching TEVAR over open arch repair as a less invasive option. Hypertension was the most common comorbidity, and management included beta-blockers, calcium channel blockers, angiotensin-converting enzyme inhibitors (ACEIs), angiotensin receptor blockers (ARBs), and diuretics. Their demographic and clinical characteristics are summarized in Table 1.

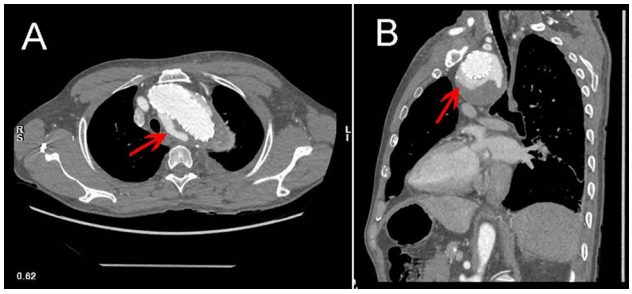

Fig. 2 CTA showed proximal endoleak in a case the third month after discharge
(A) The axial CTA view demonstrates contrast leakage adjacent to the proximal end of the stent graft, consistent with Type IA endoleak
(B) Sagittal reconstruction further visualizes the endoleak and confirms the absence of aneurysmal sac expansion
This figure highlights the importance of imaging follow-up in detecting potentially serious but initially asymptomatic complications.

Inpatient outcomes

Clinical outcomes during the hospitalization period are given in Table 2. The success rate of d-TEVAR was 100%, and the mean operation time was 311 ± 47 min. Completion angiography demonstrated patent prosthetic grafts and no evidence of endoleak in all cases. Within the first 48 h following the operation, a noticeable increase of more than 0.3 mg/dL in serum creatinine was observed in two patients, indicating the occurrence of acute kidney injury. After the treatment of hydration and diuresis, the serum creatinine returned to the preoperative level. No other complications, including spinal cord injury, left upper limb ischemia, posterior circulation ischemia, or stroke, occurred. Notably, there were no in-hospital strokes or deaths. The mean postoperative mechanical ventilation duration, ICU stay, and hospitalization time were 6.5 ± 4.0 h, 15.0 ± 7.4 h, and 20 ± 6.6 days, respectively.

Outcomes at follow-up and survival

The median duration of follow-up was sixteen months, with a range of twelve to twenty months. One individual developed a proximal type IA endoleak three months post-discharge (Fig. 2). However, the patient remained asymptomatic, and there was no significant increase in size of the aortic sac on imaging that would warrant concern for rupture, however, due to the potential for progression of the aorta, the late development of this complication, the clinical significance of the complication, we decided on a conservative approach to manage this in an asymptomatic patient with close imaging surveillance. This case illustrates the critical notion that even

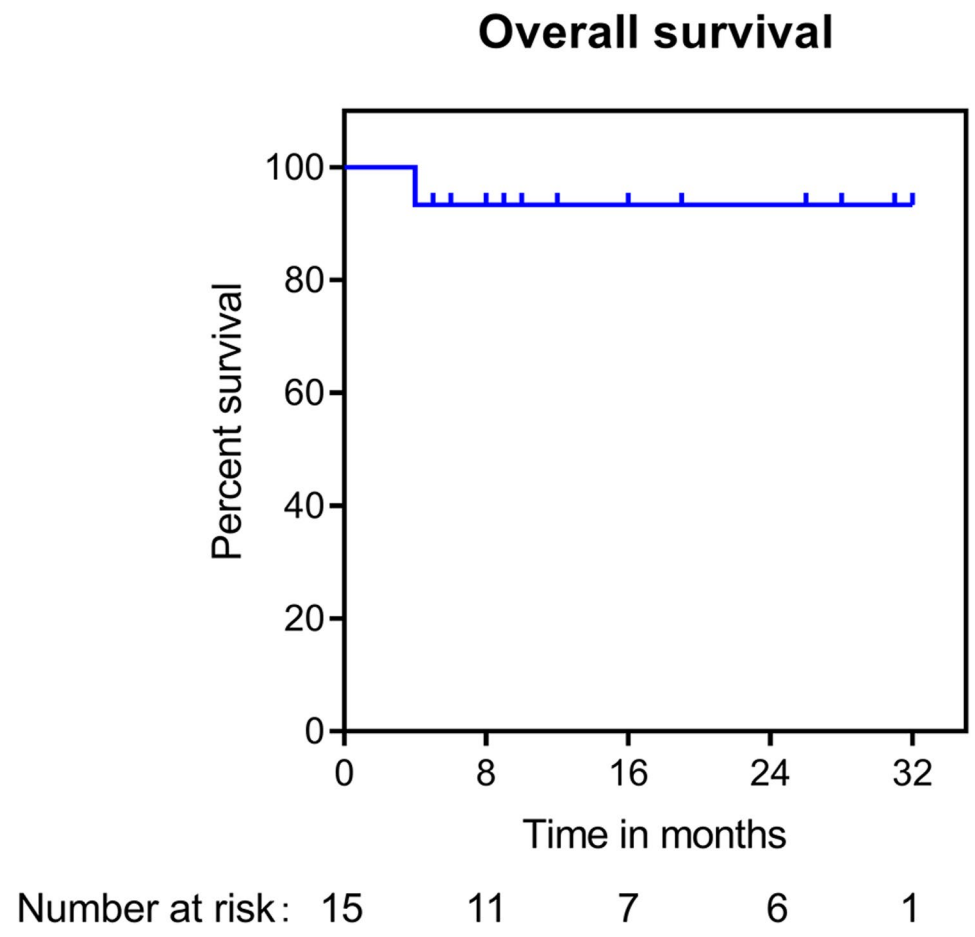

Fig. 3 Kaplan–Meier analysis of overall survival
Graph showing cumulative survival probability among patients treated with d-TEVAR during the follow-up period
The survival curve illustrates favorable short-term outcomes, though longer follow-up is necessary to assess durability.

if an individual with a type IA endoleak is asymptomatic, clinicians must be aware of the requirement to continue to follow these significant complications in a high-risk patient.

It is worth noting that one patient suffered a fatal ischemic stroke at four months postoperatively, yielding a stroke rate of 6.7%. This adverse complication highlights the neurological risk of arch intervention.

There were no other serious complications related to the operation, such as spinal cord injury, limb ischemia, neurologic deficits, etc. Kaplan-Meier survival estimates out of 100 demonstrated that of the initial population, 89.3% were alive at the end of follow-up (Fig. 3). Confidence intervals are provided to convey the precision of the survival estimates.

Discussion

Over the past two decades, TEVAR has emerged as a well-established and effective clinical approach for managing thoracic aortic diseases, yielding favorable outcomes. Currently, using TEVAR to treat aortic arch lesions instead of open surgery is accepted by many physicians. TEVAR provides a minimally invasive alternative to open surgery, avoiding extensive incisions and prolonged interruption of blood flow. Additionally, TEVAR can be integrated with prior open and hybrid approaches to mitigate risks and potentially enhance patient outcomes. TEVAR provides a minimally invasive alternative to open surgery, avoiding extensive incisions and prolonged interruption of blood flow [8]. Additionally, TEVAR can be integrated with prior open and hybrid approaches to mitigate risks and potentially enhance patient outcomes. Nevertheless, no consensus was reached on how to vascularize and maintain sufficient blood flow of the supra-arch arteries due to the stent-graft blocking the opening of the vessels.

In current clinical practice, total endovascular repair is the most commonly used strategy, including the fenestration technique [9–11], the chimney technique [12–14], and the branched stent-graft [15, 16]. Among these techniques, complex procedures of the fenestration technique, especially in-situ fenestration and external fenestration, have resulted in uncertainty regarding the

therapeutic efficacy. Meanwhile, the possible damage to the structure of the stent graft could affect the long-term clinical outcomes. In addition, a noteworthy problem in the in-situ fenestration procedure is the opening of the supra-arch arteries, which could be occluded immediately when the stent-graft is deployed, thereby causing cerebral complications. An endoleak could be present for the Chimney technique due to the gap between the stent graft, the chimney stent, and the aortic wall. Two recent single-center clinical reports showed that the endoleak rate of the chimney technique varies from 16.0 to 32.1%, most of which were type I [17, 18]. An alternative, the Castor ™ (Endovastec, Shanghai), is the first branched stent-graft to treat distal arch lesions while reconstructing the left subclavian artery (LSA) [19]; however, currently there is no widely available off-the-shelf multi-branched device. The outcomes of these methods for zone 2 thoracic endovascular aortic repair (TEVAR) are extensively described. Still, total endovascular repair becomes considerably problematic when there is a need to revascularize both the left subclavian artery (LSA) and the left common carotid artery (LCCA). Limited data is available specifically addressing the therapy of distal arch lesions with a zone 1 TEVAR. Our experience has demonstrated that the hybrid debranching TEVAR (d-TEVAR) method is a reasonable and technically feasible option for this type of management, particularly in patients who are not candidates for open arch repair with surgical risk.

Our center subsequently used this particular axillary-carotid-axillary debranching configuration based on anatomical feasibility, surgeon exposure preference, and shortening of the cross-clamp time. When comparing our approach with the usual carotid-carotid, or carotid-subclavian bypass, these were advantageous since there was no handling of the ascending aorta and subsequent chance of bilateral cerebral ischemia to the patient. Although Zone 0 or multi-branched configurations (up to octopus grafts) have been described in the literature, these would not be considered in our high-risk cohort, with multiple comorbid illnesses and advanced age [20].

Several studies have shown that d-TEVAR is less invasive, has fewer complications, and is more effective, with short-term efficacy no less than conventional surgery [21, 22]. In our current investigation, d-TEVAR was performed successfully in each case. There were no in-hospital mortalities or significant neurologic complications. Several short-term outcomes were satisfactory, which indicates that d-TEVAR may be a safe and effective approach to repair in patients where anatomical feasibility and patient risk are accurately assessed. Only two cases of transient acute kidney injury were recorded with no traces of sequelae. On the other hand, our cohort consisted mostly of high-risk patients with old age and multiple comorbid factors, as well as ASA class III-IV, which supported the decision to utilize d-TEVAR rather than an open repair approach.

Proximal type I endoleak was the primary concern after TEVAR, which was the key factor for postoperative death and reintervention after TEVAR, with a reported incidence of 0-42% [23, 24]. A meta-analysis showed that zone 1 TEVAR was associated with a high rate of endoleak [25]. Moreover, it has been reported that total supra-aortic debranching combining zone 0 TEVAR could effectively prevent the occurrence of endoleak; however, it may increase the perioperative mortality rate [23, 26]. Although a sufficient proximal landing zone is crucial to avoid endoleak, many other factors may play important roles, such as aortic arch morphology, angulation of the arch, intimal tear site, stent-graft size, and blood flow.

Type IA endoleaks are identified as high risk because of the risk of delayed rupture and generally result from issues related to inadequate proximal landing zones, poor apposition, and slippage related to the device [27]. In our case, the endoleak occurred in a patient with a conservative oversizing, and the anatomy may have also played a role in the inadequate sealing. Some possible methods to avoid this complication include rapid ventricular pacing to reduce systolic blood pressure during deployment, pre-prediscussive embolization prior to deployment, or stent grafts designed for more conformability. Given the lack of symptoms and no sac expansion, we elected to pursue conservative management; however, the role of long-term imaging surveillance in these patients cannot be underestimated.

Accordingly, to prevent endoleaks, detailed anatomic characteristics of the aortic arch should be obtained before the surgery to develop an individualized strategy for stent-graft selection and placement.

Stroke continues to be a significant concern as a complication following d-TEVAR. Possible etiologies are carotid artery occlusion, thromboemboli from bypass manipulation, and instrumentation of the diseased arch. A meta-analysis of 27 studies reported a broad range of stroke rates of 0.8–18.8% [25]. Upon reviewing our data, we established a stroke rate of 6.7% based on one fatal ischemic stroke that occurred at 4 months after discharge, consistent with that in the literature and reflective of the inherent risk for stroke when intervening on the arch in higher-risk patients [26]. Notably, there were no perioperative stroke events, and they only occurred after long-term follow-up. For this reason, we emphasized the importance of longer monitoring strategies and careful cerebral protection strategies during the perioperative period.

Another d-TEVAR-related complication is retrograde aortic dissection (RTAD). RTAD was rare after isolated

TEVAR, with a rate of 1.3- 6.3% [28–30]. However, RTAD seems to have occurred more easily in d-TEVAR, especially in a clinical study with 32 patients who reported its incidence as high as 18.7% [31]. The mechanism of RTAD was multifactorial. The risk factors could be the aortic arch's morphology, the vessel wall's fragility, and mismatched stent grafts.

Although we had no examples of RTAD in our series, clinicians should remain sharply aware of RTAD postoperatively, especially in anatomical complexity. While d-TEVAR is an up-and-coming alternative to open arch repair in high-risk patients, concerns remain regarding the future and mid- and long-term outcomes, which pertain to survival, stroke rates, and rates of reintervention, in light of data indicating that some studies have shown an increased risk with the d-TEVAR approach in the long term [28, 32, 33].

Our overall sample size and follow-up duration were limited, so using Kaplan–Meier survival analysis is merely descriptive and should be treated cautiously.

Therefore, our institutional practice recommends open repair when operable physiology exists. d-TEVAR would only be utilized in patients with questionable physiology for open surgery and a highly selective manner, after complete risk stratification and understanding the anatomic features. Our study demonstrates that d-TEVAR technically and clinically is a sound option for high-risk patients with distal aortic arch lesions who need zone 1 landing. In larger cohort studies with long-term follow-up, it is necessary to determine stroke risk, endoleak risk, and durability of the extra-anatomical bypass.

Limitations

This study was a retrospective experience report from a single center with no comparator group to compare clinical outcomes. The sample size was small. Lastly, it should be acknowledged that the follow-up period in this study was relatively short.

The sample size and follow-up period were limited; thus, the Kaplan–Meier survival analysis described herein should be interpreted as descriptive and preliminary.

Moreover, consistent with the 2025 EJVES reporting standards for vascular surgical research [20, 33], our median follow-up period of 16 months represents short-term follow-up, and ongoing surveillance is required to assess medium- and long-term outcomes such as reintervention and graft patency.

Longer follow-up studies are needed to assess the sustained effective treatment and durability.

Conclusion

In conclusion, d-TEVAR is a reasonable and relatively safe consideration for treating distal aortic arch diseases needing zone 1 stent-graft landing, especially in patients deemed high risk for open surgery. The short-term results in our small, single-center retrospective study were promising, with a 100% technical success rate and low in-hospital complication rates. However, the limited sample size, absence of control, and short to intermediate follow-up recommend cautious interpretation of these data. Long-term survival, stroke, reintervention, and graft durability results will need further validation in prospective, multicenter data. Until those data exist, d-TEVAR should be reserved for selected and carefully selected high-risk patients with adequate preoperative assessment and careful postoperative surveillance.

Abbreviations

TEVAR	Thoracic endovascular aortic repair
LSA	Left subclavian artery
LCCA	Left common carotid artery
CTA	Computed tomographic angiography
ICU	Intensive care unit
RTAD	Retrograde aortic dissection

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Not applicable.

Author contributions

XTG is resposible for the guarantor of integrity of the entire study, study design, clinical studies, data analysis, manuscript editing & review; XL is resposible for the guarantor of integrity of the entire study, study concepts & design, definition of intellectual content, clinical studies, data analysis, statistical analysis, manuscript editing & review; SDL is resposible for the definition of intellectual content, literature research, clinical studies, data acquisition, statistical analysis, manuscript preparation; CHY is resposible for the study concepts, literature research, clinical studies, data acquisition, manuscript preparation. All authors read and approved the final manuscript.

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Data availability

All data generated or analysed during this study are included in this. Further enquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate

The present study was approved by the Ethics Committees of The First Affiliated Hospital of Anhui Medical University. Individual consent was waived due to the retrospective study design.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Conflicts of interest

There are no potential conflicts of interest to disclose.

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