

The Single-Stage Solution: Mid-Term Experience with Hybrid Thoracic Endovascular Aortic Repair and Cervical Debranching Bypass in 84 Consecutive Patients

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Abstract

Background

Cervical debranching bypass is frequently performed in conjunction with thoracic endovascular aortic repair (TEVAR). However, reports on the outcomes of the single-stage hybrid procedure remain scarce. This study aimed to assess the feasibility and midterm outcomes of single-stage hybrid TEVAR combined with cervical debranching bypass.

Methods

We included 84 consecutive patients who underwent a single-stage hybrid procedure (TEVAR combined with cervical debranching bypass) between January 2018 and January 2025. Two bypass configurations were used: right common carotid artery-left common carotid artery-left subclavian artery (RCCA-LCCA-LSCA) or left common carotid artery-left subclavian artery (LCCA-LSCA). Demographic and clinical data were collected. Outcomes included in-hospital mortality, stroke, endoleak, other complications, as well as midterm graft patency and survival.

Results

The mean age was 56.5 ± 14.0 years, and 89.3% of patients were male. The technical success rate was 100%. The mean operative time was 278.2 ± 61.3 minutes, which was significantly longer in the RCCA-LCCA-LSCA group than in the LCCA-LSCA group. The in-hospital mortality rate was 3.6%, with a significantly higher rate in the RCCA-LCCA-LSCA group (10.3%) than in the LCCA-LSCA group (0%). The postoperative stroke rate was 3.6%. The long-term prevalence of persistent hoarseness was 2.4%. The endoleak rate was 4.8%. During a median follow-up of 3.3 years, four patients developed bypass graft occlusion. Kaplan–Meier estimates demonstrated comparable 5-year freedom from graft occlusion between the RCCA-LCCA-LSCA and LCCA-LSCA groups (94.1% vs. 93.0%, $P = 0.861$). However, cumulative survival differed significantly ($P = 0.005$), with 1-, 3-, and 5-year rates of 89.7%, 85.4%, and 85.4% in the RCCA-LCCA-LSCA group versus 100% at all three time points in the LCCA-LSCA group.

Conclusions

The single-stage hybrid procedure demonstrated a high technical success rate, low in-hospital mortality and morbidity, and satisfactory midterm survival. Cervical bypass grafts showed excellent midterm patency. Compared with the two-bypass configuration (RCCA-LCCA-LSCA), the single-bypass configuration (LCCA-LSCA) was associated with lower mortality and better survival outcomes.

Clinical trial number:

not applicable.

Background

Thoracic endovascular aortic repair (TEVAR) is a cornerstone treatment for pathologies of the descending aorta, including type B dissections, aneurysms, and penetrating ulcers.^{1–4} However, when lesions involve the distal aortic arch, obtaining an adequate proximal landing zone often requires covering the origins of supra-aortic vessels, such as the left subclavian artery (LSCA) and sometimes the left common carotid artery (LCCA), to ensure an adequate proximal landing zone. To mitigate the risks of ischemia, stroke, and spinal cord injury associated with this coverage, selective revascularization through hybrid techniques (which combine TEVAR with cervical debranching procedures, such as bypass or transposition) has been widely adopted.^{5–8}

Although cervical debranching in conjunction with TEVAR has become more common, reports focusing specifically on single-stage or synchronous hybrid procedures remain relatively limited.^{9, 10} This study presents a detailed retrospective analysis based on the experience accumulated at our center. We focus specifically on evaluating the mid-term safety and efficacy outcomes of synchronous hybrid arch repair for thoracic aortic lesions involving the distal arch.

Methods

Patients

The present study was based on a consecutive cohort of 84 patients who underwent a hybrid procedure (TEVAR combined with cervical debranching bypass) at our center between January 2018 and January 2025. Cervical debranching bypass was indicated for pathologies involving the distal aortic arch that required coverage of the LSCA or LCCA. The surgical approach included two distinct bypass configurations: either a right common carotid artery (RCCA) to the LCCA and then to the LSCA bypass or a direct LCCA-to-LSCA bypass. All procedures were performed as single-stage operations in a hybrid operating room. Indications for TEVAR included type B aortic dissection, penetrating aortic ulcer, intramural hematoma, and thoracic aortic aneurysm. Exclusion criteria comprised aberrant aortic arch anatomy, prior aortic arch surgery, debranching requiring median sternotomy, dissection involving the LCCA or LSCA, and the use of fenestration or chimney stent techniques. The surgical series included both emergency and elective cases. A retrospective analysis was conducted to review patient demographics, perioperative comorbidities, intraoperative details, postoperative complications, and clinical outcomes.

Prosthetic grafts and stent grafts

All prosthetic grafts used in this study were MAQUET Vascular Grafts (InterVascular SAS, La Ciotat, France). In 23 cases, adjunctive embolization was performed using Nester[®] Embolization Coils (Cook

Incorporated, Indiana, USA). Four different thoracic stent-graft systems were implanted: the Relay[®] Plus Thoracic Stent-Graft System (Terumo Corporation, Tokyo, Japan) was used in 60 patients; the GORE[®] TAG[®] Thoracic Endoprosthesis (W. L. Gore & Associates, Flagstaff, AZ, USA) in 19; the Fabulous[®] Thoracic Aortic Stent Graft System (Wei Qiang Medical Technology Co., Ltd, Hangzhou, China) in 3; and the Hercules[®] Thoracic Stent Graft System (MicroPort Endovascular Co., Ltd, Shanghai, China) in 2.

Technique

All single-stage procedures were performed in a hybrid operating room under general anesthesia. Surgical exposure began with a longitudinal incision along the medial border of the right sternocleidomastoid muscle, followed by division of the skin and subcutaneous tissues. The RCCA was meticulously dissected and exposed through this approach. An identical incision and dissection were performed on the left side to expose the LCCA. Subsequently, a separate transverse incision was made in the left supraclavicular fossa to expose and carefully dissect the LSCA (**Figure 1A**). Subcutaneous tunnels were then created: one between the right and left cervical incisions (RCCA-LCCA tunnel) and another between the left cervical and left supraclavicular incisions (LCCA-LSCA tunnel). Systemic heparinization was administered intravenously at a dose of 200 U/kg. An 8-mm diameter prosthetic vascular graft was first anastomosed end-to-side to the RCCA (**Figure 1B, 1C**). The LCCA was then transected. The graft was routed through the RCCA-LCCA tunnel and anastomosed end-to-side to the distal LCCA, and the proximal stump of the LCCA was ligated (**Figure 1D, 1E**). Following this, the LCCA was anastomosed to the LSCA via the LCCA-LSCA tunnel (**Figure 1F, 1G**). In cases where the preoperative planning designated Zone 2 as the proximal landing zone for the stent-graft,¹¹ a direct LCCA-LSCA anastomosis was performed to complete the cervical debranching (**Figure 1H**). The thoracic endovascular component was performed via femoral artery access. The stent-graft was deployed under imaging guidance to achieve accurate placement within the planned landing zone. Completion angiography was performed immediately after deployment to assess the stent-graft's morphology, positioning, and the hemodynamic result (**Figure 2**). When required, proximal embolization of the LSCA was achieved by placing an embolization coil within the artery, just proximal to the stent-graft.

Follow-up

Postoperative complications assessed in this study included both local and systemic events. Local complications comprised bleeding, lymphatic leakage, and surgical site infection. Systemic and neurological complications included stroke, spinal cord ischemia, vocal cord paralysis, phrenic nerve injury, peripheral nerve injury, respiratory complications, renal failure, and upper extremity ischemia. Procedural and graft-related outcomes, such as graft patency, endoleak, and mortality, were also recorded. The diagnosis of neurological complications was confirmed by a combination of diagnostic imaging (e.g., computed tomography [CT]) and formal neurological consultation. Diaphragmatic function was routinely assessed with postoperative chest radiography. Suspected vocal cord paralysis was verified using fiberoptic laryngoscopy in conjunction with an otolaryngology evaluation. Prior to discharge, all patients underwent CT angiography or ultrasound examination to evaluate graft patency

and to screen for upper extremity malperfusion. Postoperative anticoagulation consisted of antiplatelet therapy. The follow-up protocol comprised clinical assessments at 3 months postoperatively, then at 6-month intervals for the first year, and annually thereafter (**Figure 3**). Bypass graft patency was evaluated based on the latest available CT scan or ultrasound examination. As not all patients returned for in-person clinic visits, supplementary follow-up data were obtained via telephone interviews for a portion of the cohort.

Statistical Analysis

Categorical data are presented as frequencies and percentages. Continuous variables are summarized as mean ± standard deviation or as median with interquartile range, based on their distribution. Comparisons of categorical variables were performed using the Chi-square test or Fisher’s exact test, as warranted. A two-sided p-value <0.05 was considered statistically significant. Survival outcomes were assessed using Kaplan-Meier analysis. All statistical analyses were conducted with SPSS software (version 32.0; IBM Corp.) and R (version 4.5.0; R Foundation for Statistical Computing).

Results

Characteristics of the patients

From January 2018 to January 2025, 84 consecutive patients were treated with the hybrid procedure (TEVAR combined with cervical debranching bypass) at our center. Of these, 55 patients (65.5%) underwent a LCCA-LSCA bypass, and 29 patients (34.5%) received a RCCA-LCCA-LSCA bypass. Baseline patient characteristics are summarized in **Table 1**. The overall cohort had a mean age of 56.5 ± 14.0 years; 75 patients (89.3%) were male, and the mean body mass index was 25.4 ± 3.7 kg/m². No significant differences were observed between the two surgical groups regarding age, sex, body mass index, or comorbidities, including hypertension, diabetes mellitus, coronary heart disease, prior percutaneous coronary intervention (PCI), hyperlipidemia, history of cerebral infarction, cancer, chronic obstructive pulmonary disease (COPD), renal insufficiency, smoking, or alcohol use.

Table 1: Baseline characteristics of the study population

Variable	Total(n=84)	RCCA-LCCA- LSCA(n=29)	LCCA- LSCA(n=55)	p- value
Demographic characteristics				
Age (years), mean±SD	56.5±14.0	58.6±15.8	55.4±12.9	0.321
Male gender, n (%)	75(89.3)	27(93.1)	48(87.3)	0.652
BMI Kg/m ² , mean±SD	25.4±3.7	24.8±4.0	25.8±3.5	0.266
Type of aortic pathology, n (%)				0.260
Type B aortic dissection	50(59.5)	18(62.1)	32(58.2)	
Penetrating aortic ulcer	6(7.1)	2(6.9)	4(7.3)	
Intramural hematoma	10(11.9)	1(3.4)	9(16.4)	
Thoracic aortic aneurysm	2(2.4)	0(0)	2(3.6)	
Aortic pseudoaneurysm	16(19.0)	8(27.6)	8(14.5)	
Medical history, n (%)				
Hypertension	66(78.6)	22(75.9)	44(80.0)	0.660
Coronary artery disease	7(8.3)	3(10.3)	4(7.3)	0.688
PCI history	2(2.4)	1(3.4)	1(1.8)	> .99
Hyperlipidemia	10(11.9)	4(13.8)	6(10.9)	0.973
Diabetes	7(8.3)	3(10.3)	4(7.3)	0.688
Stroke	7(8.3)	4(13.8)	3(5.5)	0.227
Cancer	4(4.8)	2(6.9)	2(3.6)	0.606
COPD	1(1.2)	1(3.4)	0(0)	0.345
Renal insufficiency	3(3.6)	1(3.4)	2(3.6)	> .99
Smoking	57(67.9)	23(79.3)	34(61.8)	0.103
Alcohol	16(19.0)	6(20.7)	10(18.2)	0.781

SD, standard deviation; PCI, percutaneous coronary intervention; COPD, chronic obstructive pulmonary disease

Procedural characteristics

Technical success was achieved in all cases. The mean operative time for the entire cohort was 278.2 ± 61.3 minutes. Procedures in the RCCA-LCCA-LSCA group required a significantly longer operative time compared to the LCCA-LSCA group (309.1 ± 51.5 minutes vs. 261.9 ± 60.2 minutes; $P=0.001$). The indications for TEVAR included type B aortic dissection ($n=50$, 59.5%), penetrating aortic ulcer ($n=6$, 7.1%), intramural hematoma ($n=10$, 11.9%), thoracic aortic aneurysm ($n=2$, 2.4%), and aortic pseudoaneurysm ($n=16$, 19.0%). The distribution of these indications did not differ significantly between the two surgical groups ($P=0.260$). All operations were performed as single-stage procedures under general anesthesia in a hybrid operating room. Emergency procedures accounted for 15.5% (13/84) of the cohort, with no statistically significant difference in the proportion of emergency cases between the RCCA-LCCA-LSCA and LCCA-LSCA groups (20.7% vs. 12.7%; $P=0.521$). Intraoperative and postoperative data for the study cohort are shown in **Table 2**.

Table 2: Intraoperative and postoperative data of the study population

Variable	Total(n=84)	RCCA-LCCA-LSCA(n=29)	LCCA-LSCA(n=55)	p-value
Operation duration (min), mean±SD	278.2±61.3	309.1±51.5	261.9±60.2	0.001
Emergency setting, n (%)	13(15.5)	6(20.7)	7(12.7)	0.521
In-hospital mortality, n (%)	3(3.6)	3(10.3)	0(0)	0.038
Postoperative complications, n (%)				
Stroke	3(3.6)	2(6.9)	1(1.8)	0.273
Respiratory complications	1(1.2)	1(3.4)	0(0)	0.345
Renal failure	2(2.4)	2(6.9)	0(0)	0.116
Cardiovascular disease	0(0)	0(0)	0(0)	NA
Early endoleaks	4(4.8)	2(6.9)	2(3.6)	0.606
Late endoleaks	1(1.2)	0(0)	1(1.8)	> .99
Incisional bleeding	0(0)	0(0)	0(0)	NA
Lymphatic leakage	1(1.2)	0(0)	1(1.8)	> .99
Wound infection	0(0)	0(0)	0(0)	NA
Infection of bypass graft or stent graft	0(0)	0(0)	0(0)	NA
Laryngeal nerve injury	2(2.4)	0(0)	2(3.6)	0.542
Peripheral nerve injury	12(14.3)	3(10.3)	9(16.4)	0.673
Phrenic nerve injury	0(0)	0(0)	0(0)	NA
Subclavian steal syndrome	2(2.4)	0(0)	2(3.6)	0.542

SD, standard deviation

Mortality

The overall in-hospital mortality rate was 3.6% (3/84). Mortality was significantly higher in the RCCA-LCCA-LSCA group than in the LCCA-LSCA group (10.3% [3/29] vs 0% [0/55]; P=0.038), with all three deaths occurring in the former group. Among the deceased patients, two had undergone emergency surgery. The first patient presented with an aortic dissection characterized by a severely compressed true lumen and a markedly dilated false lumen on preoperative computed tomography, indicative of profound visceral malperfusion. Postoperatively, the patient developed organ ischemia-reperfusion injury, which progressed to multiple organ failure. The second patient presented with an aortic arch aneurysm,

active pulmonary infection, and severe hemoptysis requiring emergency surgery. Despite prolonged antimicrobial therapy and tracheostomy, the pulmonary infection persisted, ultimately leading to respiratory failure and septic shock. The third patient, with a history of cerebral infarction, underwent elective surgery but developed postoperative renal failure, which resulted in death.

Postoperative Complications

The incidence of early postoperative local complications was low. Transient hoarseness occurred in 10 patients (11.9%), with normal voice function recovering in 8 cases. Two patients (2.4%) were diagnosed with permanent recurrent laryngeal nerve injury during long-term follow-up, with no significant difference in incidence between the groups (RCCA-LCCA-LSCA: 0% vs. LCCA-LSCA: 3.6%; $P=0.542$). No patient experienced major ipsilateral upper limb functional impairment. During follow-up, 12 patients (14.3%) reported occasional upper limb numbness or weakness, with no significant intergroup difference (RCCA-LCCA-LSCA: 10.3% vs. LCCA-LSCA: 16.4%; $P=0.673$). One patient (1.2%) experienced delayed wound healing secondary to lymphatic leakage, which resolved after surgical re-exploration and lymphatic vessel ligation, with no significant difference between groups ($P > 0.99$). Notably, no significant wound infections, prosthetic graft infections, postoperative incisional bleeding, or phrenic nerve injuries were observed. The occurrence of local complications was not significantly associated with the bypass configuration.

Regarding systemic perioperative complications, one patient developed respiratory complications (RCCA-LCCA-LSCA: 3.4% vs. LCCA-LSCA: 0%; $P=0.345$), and two patients developed renal failure (both in the RCCA-LCCA-LSCA group: 6.9% vs. 0%; $P=0.116$). No major cardiac complications were recorded.

Endoleaks

Early postoperative endoleaks occurred in four patients (4.8%). Among these, three were minor endoleaks evident on intraoperative angiography, all of which resolved spontaneously by the three-month follow-up CT scan. At mid-term follow-up, only one patient (1.2%) showed a persistent endoleak. In this case, with the stent graft anchored in Zone 2, the leak originated from the LCCA, with blood entering the space between the stent and the aortic wall. The patient has been monitored for over three years, during which the endoleak has gradually enlarged; however, a decision regarding reintervention is pending. No significant difference in endoleak rates was observed between the groups in either the early or mid-term follow-up periods ($P = 0.606$ and $P > 0.99$, respectively). Proximal coil embolization of the LSCA was performed in 23 patients (27.4%).

Neurological Outcomes and Graft Patency

The incidence of postoperative stroke was 3.6% ($n=3$). Two patients developed left hemisphere cerebral infarction; neither experienced hemiplegia or permanent motor deficit. One event occurred eight months postoperatively, and the other occurred three days after surgery. The latter patient had a history of atrial fibrillation, though a direct association remains unclear. A third patient experienced a posterior

circulation lesion one week postoperatively and had largely recovered by discharge. No recurrent cerebral infarction was observed during follow-up. Although the incidence was lower in the LCCA-LSCA group (1.8%) than in the RCCA-LCCA-LSCA group (6.9%), the difference was not statistically significant (P=0.273).

All bypass grafts remained patent during the initial hospitalization. The grafts used were uniformly 8-mm diameter polyester prostheses. During follow-up, graft occlusion occurred in four patients at 8, 13, 18, and 22 months postoperatively. Survival analysis revealed a mid-term (5-year) Kaplan-Meier estimate of 93.3% for freedom from occlusion, with no significant difference between the RCCA-LCCA-LSCA and LCCA-LSCA configurations (94.1% vs. 93.0%, P= 0.861; **Figure 4**). Postoperative follow-up revealed subclavian steal syndrome in two patients. Of these, one was symptomatic, manifesting as dizziness, numbness, and weakness in the left upper extremity, whereas the other was asymptomatic.

Follow-up and Survival

The mean and median follow-up durations were 3.4 and 3.3 years, respectively. Of the 81 hospital discharge survivors, 75 patients completed clinical follow-up, with six patients lost to follow-up between 9 and 79 months, yielding a follow-up completion rate of 92.6%. The estimated survival rates for the entire cohort at 1, 3, and 5 years were 96.4%, 95.0%, and 95.0%, respectively. The RCCA-LCCA-LSCA cohort exhibited estimated survival rates of 89.7%, 85.4%, and 85.4% at the respective time points, and the LCCA-LSCA cohort maintained a consistent 100% survival rate across all corresponding intervals (**Figure 5**). This intergroup comparison identified a statistically significant difference in survival (P= 0.005). A sub-analysis excluding all emergency cases (n=13) revealed an overall mortality rate of 1.4% (n=1). The two groups were comparable in terms of age, sex, functional status, comorbidities, and surgical indications. No significant differences were found in perioperative mortality (P=0.324) or major morbidity. The results of the subgroup analysis comparing elective RCCA-LCCA-LSCA versus LCCA-LSCA are presented in **Table 3**.

Table 3: Subgroup analysis for elective RCCA-LCCA-LSCA vs LCCA-LSCA

Variable	Total(n=71)	RCCA-LCCA-LSCA(n=23)	LCCA-LSCA(n=48)	p-value
Type of aortic pathology, n (%)				0.481
Type B aortic dissection	40(56.3)	15(65.2)	25(52.1)	
Penetrating aortic ulcer	6(8.5)	2(8.7)	4(8.3)	
Intramural hematoma	10(14.1)	1(4.3)	9(18.8)	
Thoracic aortic aneurysm	2(2.8)	0(0)	2(4.2)	
Aortic pseudoaneurysm	13(18.3)	5(21.7)	8(16.7)	
Operation duration (min), mean±SD	276.9±62.4	310.2±53.7	260.9±60.4	0.001
In-hospital mortality, n (%)	1(1.4)	1(4.3)	0(0)	0.324
Postoperative complications, n (%)				
Stroke	2(2.8)	1(4.3)	1(2.1)	0.546
Respiratory complications	0(0)	0(0)	0(0)	NA
Renal failure	1(1.4)	1(4.3)	0(0)	0.324
Cardiovascular disease	0(0)	0(0)	0(0)	NA
Early endoleaks	4(5.6)	2(8.7)	2(4.2)	0.591
Late endoleaks	1(1.4)	0(0)	1(2.1)	> .99
Incisional bleeding	0(0)	0(0)	0(0)	NA
Lymphatic leakage	1(1.4)	0(0)	1(2.1)	> .99
Wound infection	0(0)	0(0)	0(0)	NA
Infection of bypass graft or stent graft	0(0)	0(0)	0(0)	NA
Laryngeal nerve injury	2(2.8)	0(0)	2(4.2)	> .99
Peripheral nerve injury	12(16.9)	3(13.0)	9(18.8)	0.793
Phrenic nerve injury	0(0)	0(0)	0(0)	NA
Subclavian steal syndrome	2(2.8)	0(0)	2(4.2)	> .99

SD, standard deviation

Discussion

Although cervical debranching is not a novel technique, it has become widely used in the field of endovascular aortic interventions over the past decade.^{12–15} However, more evidence is required to validate the feasibility and durability of the single-stage hybrid procedure, which combines cervical debranching bypass with concurrent TEVAR. The present retrospective study demonstrates that in-hospital mortality and morbidity following a synchronous procedure remains low, with satisfactory mid-term follow-up results.

In this series, the overall in-hospital mortality rate was 3.6% (3/84). Comparison between surgical groups indicated that the mortality rate was higher in the RCCA-LCCA-LSCA group than in the LCCA-LSCA group, a difference that may be associated with the increased number of anastomoses and longer operative duration required for the more complex bypass procedure. These findings align with a previous report by Bellamkonda et al.,¹² who reported that TEVAR combined with two concomitant cervical bypasses was associated with significantly higher mortality compared to a single-bypass strategy, with emergent surgical status also being an important risk factor. In our cohort, after excluding emergency cases, the mortality rate decreased to 1.4% (1/71), which was considered acceptable, and no significant difference in mortality was observed between the two surgical approaches in this elective subgroup. This finding suggested that emergency status might be an important confounding factor influencing outcomes.

Postoperative stroke occurred in 3 patients (3.6%) in our series, with no significant difference in incidence between the two surgical groups. The stroke rate in our cohort was lower than rates reported in other studies.^{12, 14–18} This lower incidence may be attributed to the relatively younger age of our patient population, as advanced age is generally associated with reduced physiological reserve and a higher prevalence of atherosclerotic plaque, which can increase perioperative neurological risk. Our protocol emphasizes comprehensive preoperative assessment, including assessment of carotid artery plaques, evaluation of contralateral carotid compensatory flow, and imaging of the circle of Willis variants. Intraoperatively, anastomotic sites were carefully selected to avoid areas of significant plaque, thereby minimizing the risk of embolization. Cerebral oxygen saturation was monitored in real-time to assess cerebral perfusion. All procedures were conducted by experienced vascular surgeons, who aimed to minimize carotid cross-clamp duration during anastomosis. For patients deemed at high embolic risk, low-dose antiplatelet therapy was administered postoperatively to reduce the risk of cerebrovascular events.

The incidence of perioperative hoarseness in the present cohort was 11.9%, a rate that appears elevated relative to certain earlier reports. Importantly, the majority of affected patients regained normal voice function during follow-up. The long-term prevalence of persistent hoarseness was 2.4%, which was attributed to vocal cord paralysis secondary to recurrent laryngeal nerve injury. The likely mechanism involves indirect traction or thermal injury to the vagus nerve during carotid artery dissection, though other potential etiologies—such as direct compression from retraction, or even endotracheal intubation—cannot be definitively excluded. The observed rate of recurrent laryngeal nerve injury in this series (2.4%)

is consistent with the reported range of 1–8% in other studies of carotid–subclavian bypass procedures.^{13, 15, 19, 20} Meticulous surgical technique and intraoperative neural monitoring may help mitigate this risk.

Notably, no cases of phrenic nerve injury or diaphragmatic elevation were documented in our series, a finding that contrasts with certain earlier reports.^{13, 14, 20, 21} Phrenic nerve injury in this context is generally attributed to intraoperative mechanisms such as direct compression, traction, or thermal damage from electrocautery. The left phrenic nerve courses anterior to the medial portion of the LSCA before descending into the thorax. During the division of the anterior scalene muscle to access the subclavian artery, the phrenic nerve is at risk of iatrogenic injury, due to its course within the surgical field and delicate structure. The absence of such injury in our cohort may be explained by the specific surgical approach employed: a longitudinal incision along the medial border of the sternocleidomastoid muscle combined with a transverse supraclavicular incision, which allows for careful dissection and obviates the need to directly expose or manipulate the phrenic nerve.

For the anastomosis to the LSCA, a supraclavicular fossa approach was utilized. This technique offers distinct advantages. First, it allows for a shorter graft length between the LCCA and the LSCA compared to an axillary artery target. A shorter graft may reduce flow turbulence and stasis, potentially lowering the risk of thrombosis and improving long-term patency. Second, this approach avoids direct dissection near the phrenic nerve, thereby minimizing the risk of nerve injury and subsequent diaphragmatic paralysis. However, the supraclavicular approach also presents specific challenges. The anatomy in this region houses critical structures such as the brachial plexus and lymphatic network, which presents a risk for procedural complications. In our series, one patient developed a lymphatic fistula. Transient postoperative numbness or weakness in the ipsilateral upper limb were also reported by some patients, likely related to intraoperative traction or manipulation near the brachial plexus. These findings show that LSCA exposure and anastomosis via the supraclavicular route is technically demanding. It requires careful dissection and the careful use of electrocautery to prevent injury to nearby nerves and tissues.

The 5-year graft patency rate in our cohort was 93.3% and consistent with the 90–93% mid- to long-term patency rates previously reported for similar procedures.^{15, 20, 21} Graft occlusion is typically multifactorial, with potential etiologies including anastomotic stenosis, intimal hyperplasia, or irregular postoperative medication management. No cases of anastomotic pseudoaneurysm or graft infection occurred. Postoperative follow-up revealed subclavian steal syndrome in two patients, presumably due to hemodynamically significant anastomotic stenosis. Future studies should focus on detailed hemodynamic assessments of the vertebral and subclavian arteries following cervical debranching procedures to better understand the physiologic consequences and optimize patient selection.

Endoleaks represent a known complication following TEVAR. Among these, a proximal type Ia endoleak is regarded as an independent risk factor for early adverse outcomes and may lead to aneurysm expansion or rupture.^{22–25} The primary technical risk factor for a type I endoleak is an inadequate proximal or distal landing zone. Severe calcification or tortuosity in the proximal landing zone can

compromise complete apposition of the stent graft to the aortic wall, creating a potential channel for endoleak. In the present cohort, the overall endoleak rate was low. This may be attributed to several procedural strategies: stringent selection to ensure an adequate proximal landing zone, systematic ligation of the proximal LCCA in cases requiring RCCA-LCCA-LSCA bypass, and selective prophylactic coil embolization of the LSCA origin based on intraoperative angiography findings. Postoperative surveillance with regular contrast-enhanced CT is critical for the early detection of endoleak and for monitoring its progression. When identified, timely re-intervention is essential to prevent sac expansion and improve long-term survival.

This study has several limitations inherent to its design. First, as a single-center, retrospective analysis, the findings are subject to potential selection bias and may not be fully generalizable. The sample size, though consecutive, remains modest, which limits the statistical power for subgroup comparisons and the detection of rare complications. Second, the follow-up duration, while providing meaningful mid-term data, is insufficient to evaluate very long-term graft durability, endoleak rates, and other late complications. Third, the incidence of recurrent laryngeal nerve injury might be underestimated, as postoperative laryngoscopy was not performed routinely. Furthermore, the non-randomized, observational design introduces the possibility of unmeasured confounding. Finally, the lack of a control group undergoing staged open surgical repair or alternative endovascular strategies precludes definitive comparative conclusions regarding the optimal treatment approach.

Conclusion

The single-stage hybrid procedure combining cervical debranching with thoracic endovascular repair demonstrates a high technical success rate, low perioperative complication rates, and satisfactory mid-term survival outcomes. Cervical debranching bypass grafts showed excellent mid-term patency. In this series, TEVAR with a single bypass (LCCA-LSCA) was associated with more favorable mortality and survival outcomes compared to TEVAR with two sequential bypasses (RCCA-LCCA-LSCA). However, these findings are derived from a relatively small, single-center cohort. Furthermore, the available follow-up period remains limited. Larger, prospective studies with extended long-term follow-up are required to further validate the durability, safety, and efficacy of this hybrid approach.

Abbreviations

TEVAR: Thoracic endovascular aortic repair

RCCA: Right common carotid artery

LCCA: Left common carotid artery

LSCA: Left subclavian artery

CT: Computed tomography

PCI: Percutaneous coronary intervention

COPD: Chronic obstructive pulmonary disease

Declarations

Ethics approval and consent to participate

This study received approval from the Medical Ethical Committee of the Guangdong Provincial Hospital of Chinese Medicine (ZE2022-303-01). The research adhered to the principles outlined in the Declaration of Helsinki. Because the data were de-identified and retrospective, informed consent from individual participants was not applicable.

Consent for publication

Because the data were de-identified and retrospective, informed consent from individual participants was not applicable.

Competing Interests

The authors declare no conflicts of interest.

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None.

Author Contributions

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Figures

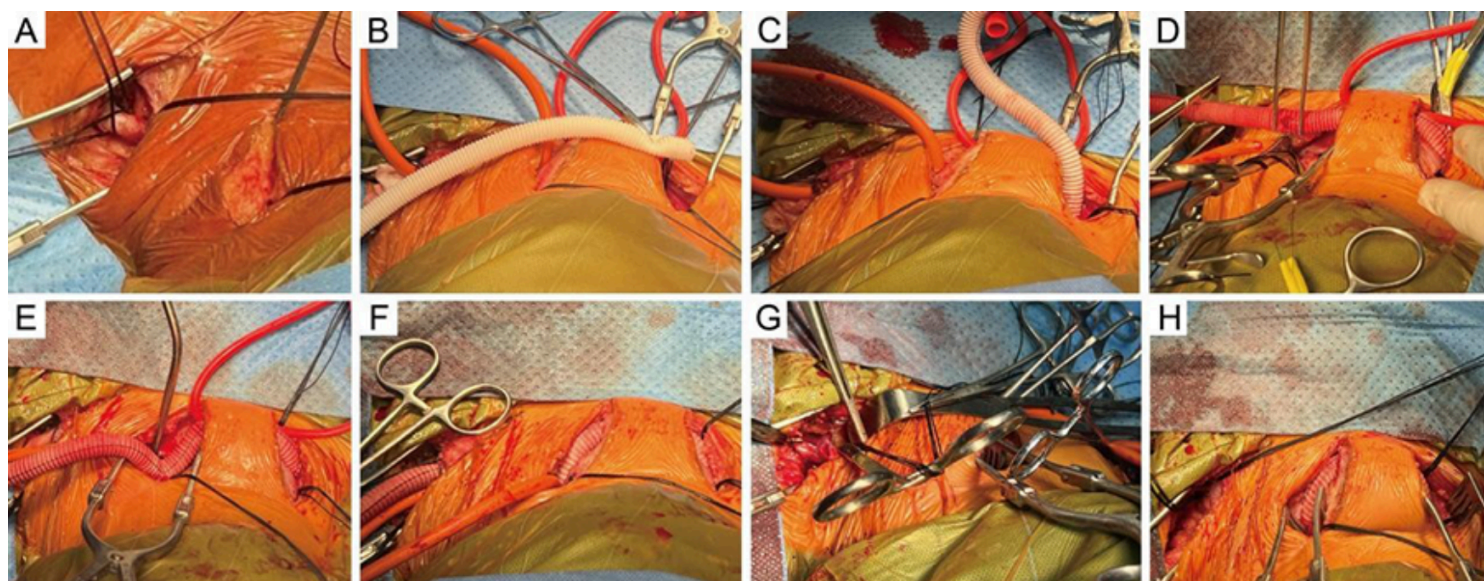


Figure 1

(A) The right common carotid artery (RCCA), left common carotid artery (LCCA), and left subclavian artery (LSCA) were carefully dissected and fully exposed. (B, C) An 8-mm diameter prosthetic vascular graft was anastomosed end-to-side to the RCCA. (D, E) The graft was routed through the RCCA-LCCA tunnel and anastomosed end-to-side to the distal LCCA. (F, G) The LCCA was anastomosed to the LSCA via the LCCA-LSCA tunnel. (H) The RCCA-LCCA-LSCA anastomosis was performed to complete the cervical debranching.



Figure 2

Intraoperative angiography after the cervical debranching bypass graft and thoracic endovascular aortic repair

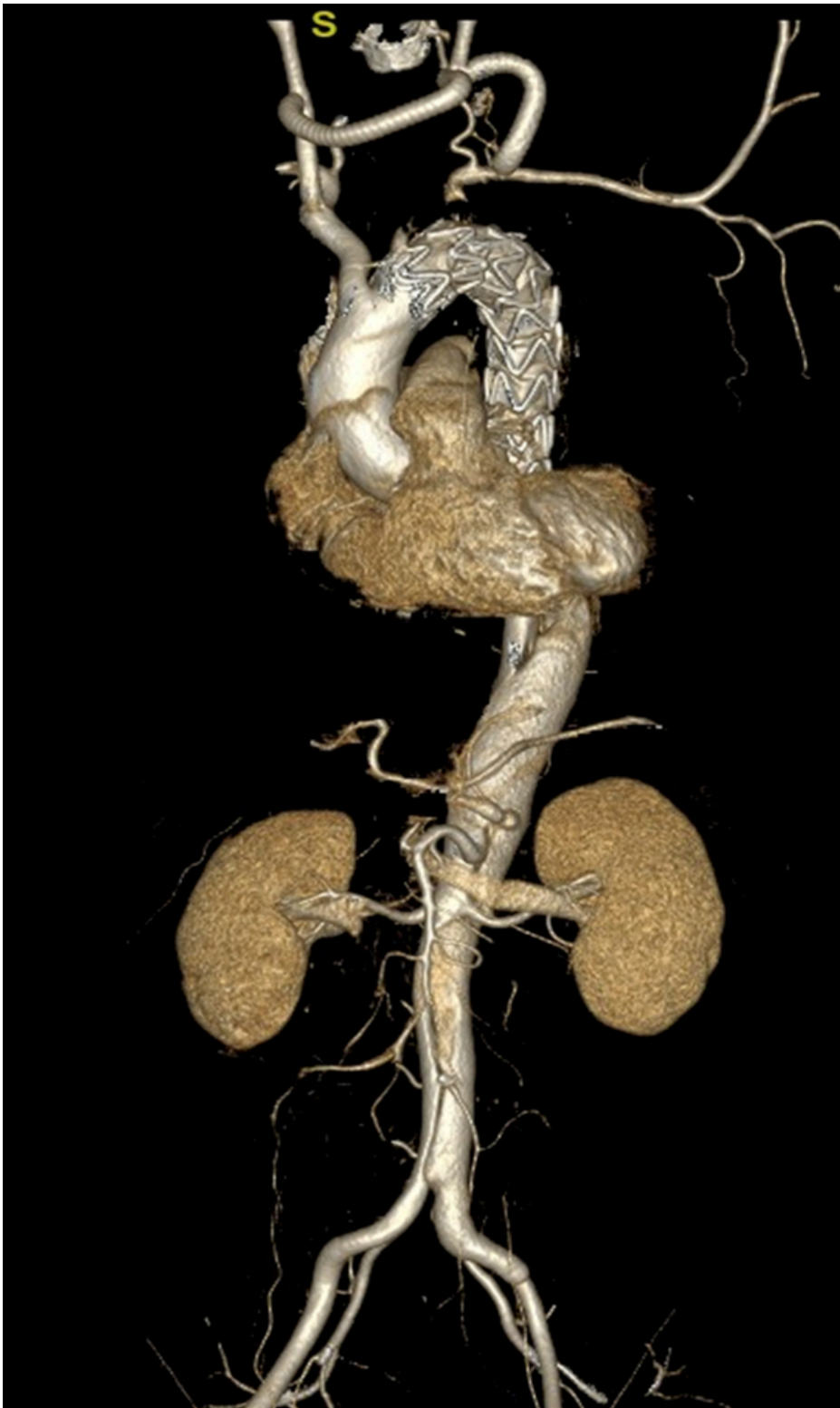


Figure 3

Follow-up computed tomography angiographic scan of the hybrid procedure

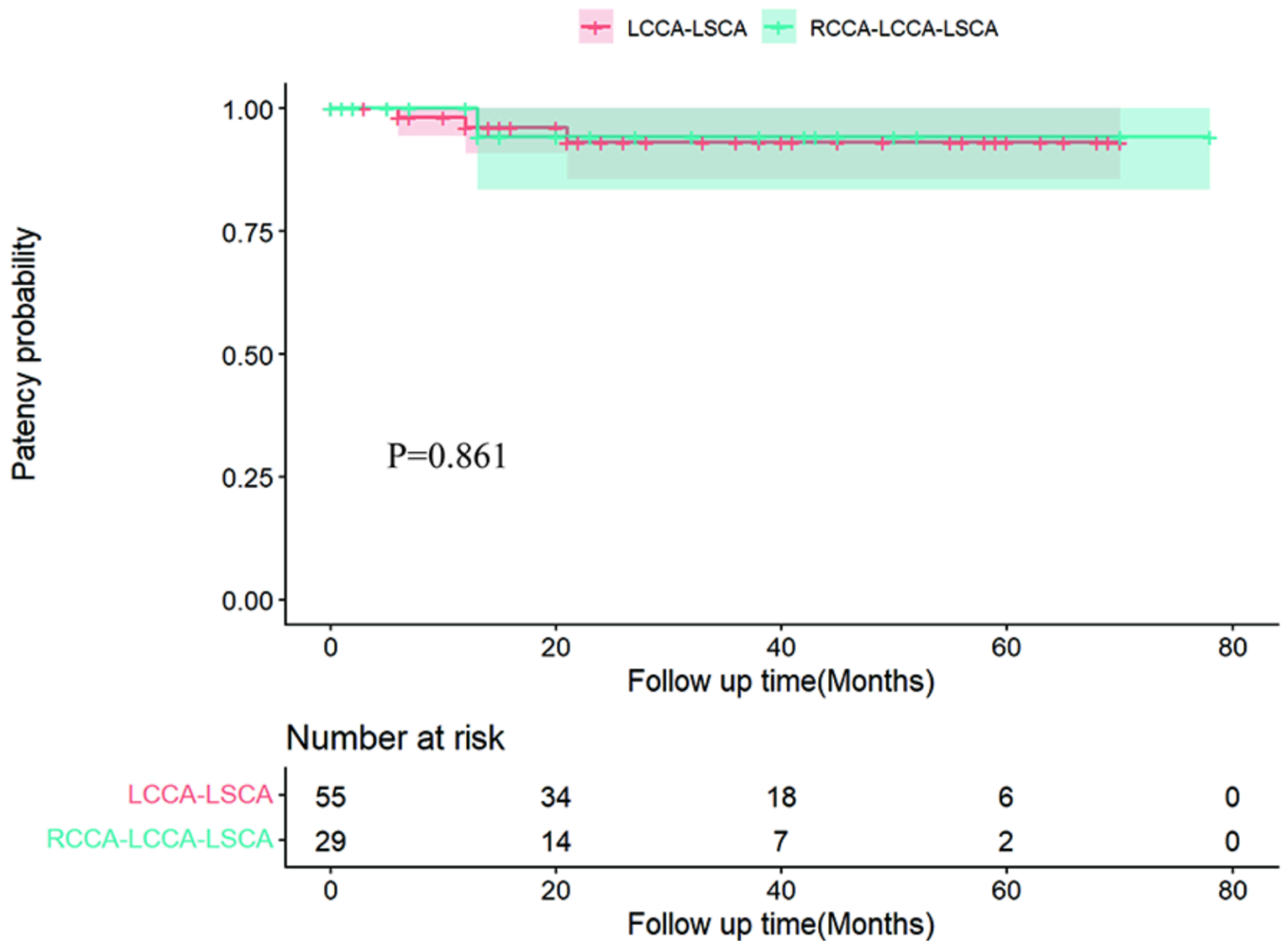


Figure 4

Kaplan-Meier bypass patency estimates. No significant difference in patency was observed between the two surgical groups ($P=0.861$). RCCA-LCCA-LSCA, right common carotid artery-left common carotid artery-left subclavian artery; LCCA-LSCA, left common carotid artery-left subclavian artery

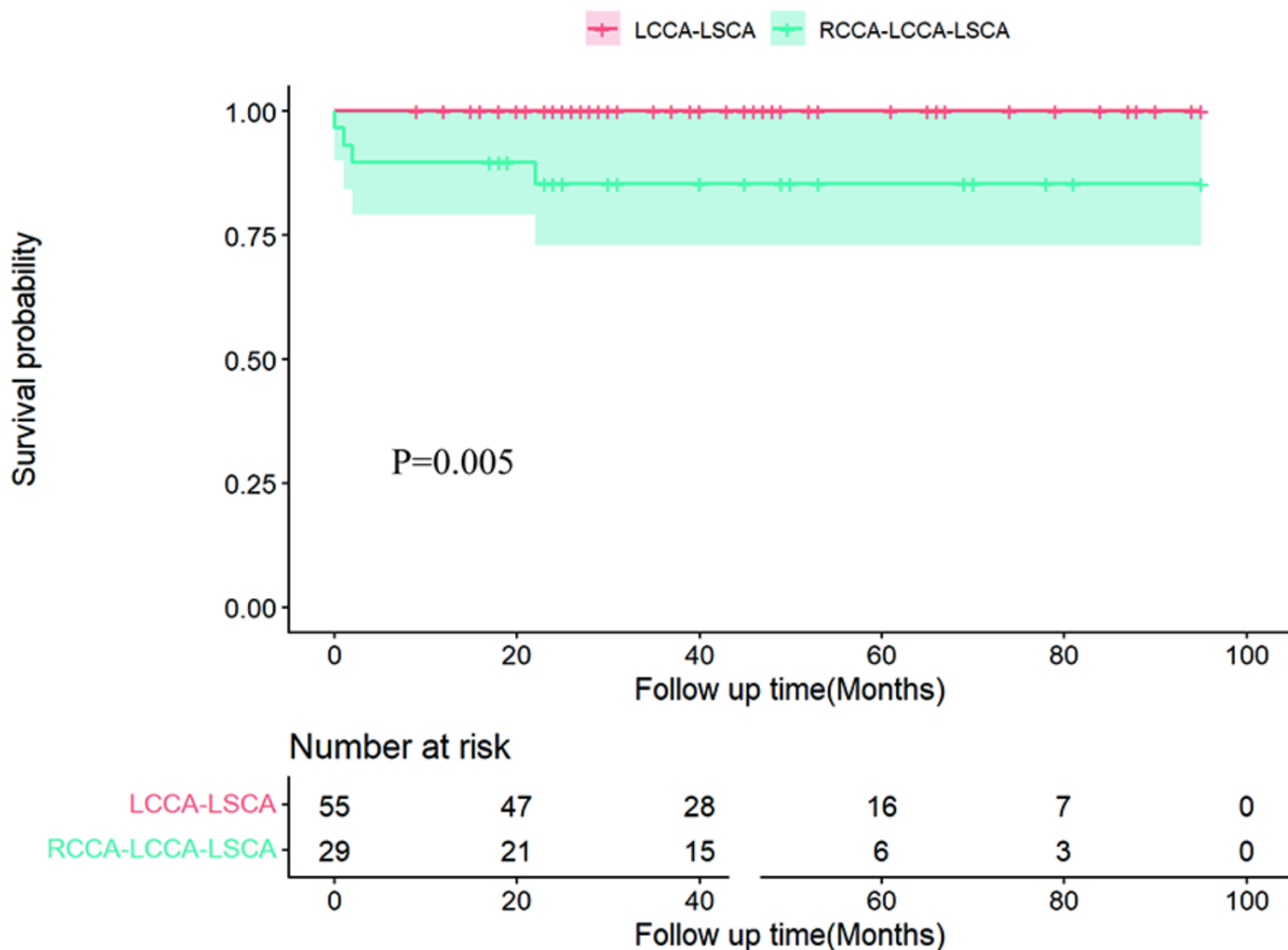


Figure 5

Kaplane-Meier patient survival curve. A statistically significant difference in survival was observed between the two surgical groups ($P=0.005$). RCCA-LCCA-LSCA, right common carotid artery-left common carotid artery-left subclavian artery; LCCA-LSCA, left common carotid artery-left subclavian artery