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Results with a Selective Revascularization Strategy for Left Subclavian Artery Coverage During Thoracic Endovascular Aortic Repair

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Abstract

Background—The need for routine left subclavian artery (LSCA) revascularization when this vessel is covered during thoracic endovascular aortic repair (TEVAR) remains controversial. Here, we report our results with a selective LSCA revascularization strategy during TEVAR.

Methods—Between 5/2002 and 3/2010, 287 TEVAR procedures were performed at our institution. Of these, 145 (51%) had coverage of the LSCA and form the basis of this report.

Results—LSCA revascularization was performed in 32 patients (22%) via left common carotid-LSCA bypass. Indications for selective LSCA revascularization included: spinal cord protection ($n = 10$), patent pedicled left internal mammary artery graft ($n = 9$), left arm ischemia following LSCA coverage ($n = 5$), origin of the left vertebral artery from the arch ($n = 4$), dialysis access in the left upper extremity ($n = 2$), and vertebrobasilar insufficiency ($n = 2$). There were no instances of dominant left vertebral artery. There was no difference in the rate of death (6.3% vs 1.8%; $p = 0.21$), stroke (3.1% vs 3.5%; $p = 1.00$), permanent paraplegia/paraparesis (3.1% vs 0%; $p = 0.22$), or type II endoleak (4.3% vs 6.5%; $p = 1.00$) between the revascularized and non-revascularized groups, respectively. There were no instances of ischemic stroke related to left posterior circulation hypoperfusion. Four complications of carotid-subclavian bypass occurred in three patients (9.4%).

Conclusions—Selective LSCA revascularization is safe and does not appear to increase the risk of neurologic events. Further, subclavian revascularization is not without complications, which should be considered with regards to a non-selective revascularization strategy.

Keywords

aorta; endovascular procedures; revascularization; subclavian artery

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INTRODUCTION

Intentional left subclavian artery (LSCA) coverage during thoracic endovascular aortic repair (TEVAR) is required in 10–50% of cases to achieve an adequate proximal seal [1]. The LSCA contributes arterial flow to the left upper extremity, the posterior cerebral circulation via the left vertebral artery, and the coronary circulation in patients with a left internal mammary artery (LIMA) bypass graft. The left vertebral artery further contributes to spinal cord perfusion by providing branches to the cephalad portions of the anterior and posterior spinal arteries. Despite contributing to these critical vascular beds, LSCA coverage from within the aorta is well tolerated by most patients due to collateral blood flow to the LSCA primarily from the right vertebral artery/basilar artery/Circle of Willis arcade. Nonetheless, left upper extremity ischemia, posterior circulation stroke, and spinal cord injury are feared complications of LSCA coverage that occur with low frequency. LSCA revascularization via left common carotid-LSCA bypass or transposition can be performed to treat or prevent these complications.

Indications for preemptive LSCA revascularization are without consensus, with some advocating a selective approach and others suggesting routine LSCA revascularization in all cases of planned LSCA coverage. The Society for Vascular Surgery (SVS) convened a panel of experts to develop clinical practice guidelines for the management of the LSCA with TEVAR, published in November 2009 [2]. For this purpose, a meta-analysis of the available medical literature was commissioned to provide for evidence-based recommendations [3]. The meta-analysis pooled 51 observational studies reporting LSCA coverage and found a significantly increased risk of arm and vertebrobasilar ischemia and trends toward an increased risk of paraplegia and anterior circulation stroke with LSCA coverage; there was a significantly increased risk of phrenic nerve injury with LSCA revascularization. Primary revascularization procedures were found only to reduce the risk of arm ischemia, and selective versus non-selective revascularization strategies were not included in the analysis. Despite the admittedly low quality observational data, lack of evidence that preemptive LSCA revascularization affords protection against stroke or spinal cord ischemia, and despite no assessment of the benefit of selective versus non-selective revascularization strategies, the SVS panel suggested routine preoperative revascularization in all elective cases requiring LSCA coverage. Justification for the recommendation was provided by a values statement placing a higher value on preventing the catastrophic complications of neurologic injury over the less devastating complications of LSCA revascularization, even though non-selective LSCA revascularization had not been shown to reduce neurologic complications.

In the setting of recently published clinical practice guidelines supporting routine preoperative LSCA revascularization without supporting evidence, we sought to review our experience with a selective LSCA revascularization strategy developed at our institution since the advent of TEVAR in 2002. We propose that selective LSCA revascularization may be the optimal method for simultaneously reducing the risks of both LSCA coverage and LSCA revascularization by avoiding unnecessary LSCA revascularizations.

MATERIAL AND METHODS

Between May 2002 and March 2010, 287 TEVAR procedures were performed at our institution. Of these, 145 (51%) had coverage of the LSCA performed as part of the procedure and form the basis of this report. Patient data were retrospectively reviewed from a prospectively maintained aortic surgery database after Duke Institutional Review Board (IRB) approval. The IRB waived the need for individual patient consent. Our strategies for patient selection, surgical indications, technique of device delivery and deployment, and

postoperative surveillance have been described previously [4, 5]. All three currently FDA-approved thoracic stent-grafts were utilized. Location of the proximal landing zone was described according to the Ishimaru classification [6].

Preoperative planning of endograft procedures was performed using the TeraRecon system (TeraRecon Inc., San Mateo, CA) to obtain centerline measurements of flow lumen diameter. Preoperative planning included computed tomography angiography (CTA) of the neck to assess arch vessel, carotid, and vertebral artery anatomy up to the base of the skull. The Circle of Willis was not routinely imaged.

Our selective LSCA revascularization strategy has been published previously [4] and is predicated upon preoperative and intraoperative indications (Table 1). Indications for revascularization identified preoperatively include a patent pedicled LIMA graft, left arm dialysis access, origin of the left vertebral artery from the aortic arch, a dominant left vertebral artery with a diminutive right vertebral artery, or patients considered high risk for paraplegia due to planned aortic pavement from the LSCA to the celiac axis, prior abdominal aortic aneurysm (AAA) or other thoracic/thoracoabdominal aortic repair, or prior hypogastric artery ligation/embolization. Intraoperative indications for LSCA revascularization identified early in our experience include evidence of left arm ischemia following device deployment, primarily evidenced by loss of pulsatility of the left radial arterial line when viewed on a standard scale hemodynamic monitor (Figure 1). As a result, bilateral radial arterial lines are now placed in all TEVAR cases where left subclavian arterial coverage is either planned or felt possible. Additional findings of arm ischemia that usually accompany loss of arterial line pulsatility and may further prompt LSCA revascularization include a systolic pressure differential greater than 50 mm Hg between the left and right upper extremities (Figure 1), or loss of the left upper extremity pulse oximetry signal. Postoperative indications for LSCA revascularization included left arm claudication or vertebrobasilar insufficiency.

LSCA revascularization was performed via left common carotid-LSCA bypass in all instances. A transverse supraclavicular incision was performed on the left with dissection carried down through the platysma and clavicular head of the sternocleidomastoid muscle. The anterior scalene muscle was divided to expose the LSCA. The phrenic nerve was identified and preserved. The left common carotid to LSCA bypass was performed using an 8 mm polytetrafluoroethylene graft in an end-to-side fashion for both the common carotid and subclavian arteries. The proximal LSCA was preemptively occluded by ligation or endovascular embolization based on surgeon preference, although at present LSCA endovascular occlusion is performed selectively only if a significant type II endoleak is identified due to retrograde flow in the LSCA. Twenty-five patients (78%) underwent revascularization prior to endograft deployment, while four patients (13%) underwent revascularization subsequent to endograft deployment. An additional three patients (9%) underwent delayed revascularization (Table 1).

On-line monitoring of spinal cord function with somatosensory and motor evoked potentials was used intraoperatively in elective cases and when available for urgent-emergent cases using previously described techniques [7]. Cerebrospinal fluid drainage was used selectively for previously described indications [4, 8].

Comorbidities were defined using standard definitions. All procedural outcomes and complications were prospectively recorded. Patient follow-up included clinical examination, four-view chest x-ray, and CTA at 1 month, 6 months, and 12 months postoperatively and annually thereafter. All follow-up was done at the Duke University Center for Aortic Surgery. Data are presented in accordance with the "Reporting Standards for Endovascular

Aortic Aneurysm Repair” of the Ad Hoc Committee for Standardized Reporting Practices in Vascular Surgery of The Society for Vascular Surgery/American Association for Vascular Surgery [9]. Patients were divided into revascularized and non-revascularized groups for comparison. Statistical analyses were performed using Graphpad software (Graphpad Software, Inc., La Jolla, CA). The Fisher’s exact test was used to assess for statistical significance. P values ≤ 0.05 were considered significant. An intention-to-treat analysis was also performed by assigning postoperative revascularization patients (n = 3) to the non-revascularized group and revealed no change to statistical associations given that no adverse events occurred in these patients.

RESULTS

Patient Demographics

LSCA revascularization was performed in 32 (22%) of 145 patients undergoing LSCA coverage during TEVAR. Patient baseline demographics for the entire cohort are listed in Table 2. Indications for TEVAR included both elective and urgent/emergent procedures to treat a variety of aortic pathologies as listed in Table 3. The extent of aortic coverage is summarized in Table 4.

Outcomes

Technical success for left carotid-LSCA bypass was 100%. Thirty-day/in-hospital mortality did not differ between the revascularized versus non-revascularized groups (6.3%, n = 2/32 vs 1.8%, n = 2/113; p = 0.2). Permanent paraplegia/paraparesis rates were 3.1% (n = 1/32) in the revascularized group versus 0% in the non-revascularized group (p = 0.22).

The rate of stroke was 3.1% (n = 1/32) in the revascularized group and 3.5% (n = 4/113) in the non-revascularized group (Table 5, p = 1.0). The single stroke in the revascularized group occurred in a patient with a history of prior open thoracoabdominal aortic aneurysm repair complicated by stroke with residual right-sided hemiparesis who underwent hybrid arch repair with LSCA revascularization for spinal cord protection. She was discharged on postoperative day 6 but readmitted the next day with worsening right-sided paretic symptoms. The patient was found to have thrombus in the right internal jugular vein, a patent foramen ovale, and multiple acute infarcts within the left occipital and frontal lobes on magnetic resonance imaging, all consistent with a thromboembolic phenomenon.

Two of the four strokes in the non-revascularized group were related to recognized intraoperative events. The first patient experienced a plaque embolus to the left carotid artery during TEVAR, requiring intraoperative embolectomy. A CT scan performed on postoperative day 1 for altered mental status demonstrated a left posterior inferior cerebellar artery infarct. Follow-up CTA of the head and neck demonstrated a patent Circle of Willis with reconstitution of LSCA flow via the left vertebral artery, suggesting the stroke was a consequence of the intraoperative embolic event as opposed to vertebral artery hypoperfusion from LSCA coverage. The second patient had a right-sided aortic arch with a right descending aorta and experienced unintended carotid artery coverage due to intraoperative endograft migration.

The remaining two strokes in the non-revascularized group are likely to have resulted from embolic phenomena, although a contribution of ischemia from LSCA coverage cannot be definitively excluded. The third patient was found to have grade V mobile arch atheroma on intraoperative transesophageal echocardiography. She initially had an uncomplicated course following TEVAR but was readmitted to the hospital on postoperative day 8 with symptoms of dysarthria and ataxia and was found to have multiple bilateral cerebellar infarcts of various ages suggestive of bilateral atheroemboli. A follow-up CTA of the head and neck

revealed an 80% stenosis at the origin of the right vertebral artery that was later stented; however, the Circle of Willis and distal LSCA remained patent, suggesting an intact posterior circulation. The fourth patient experienced a left visual field cut on postoperative day 0 following surgery, and a CT scan revealed a possible left posterior occipital lobe infarct. The patient refused confirmatory magnetic resonance imaging/angiography due to claustrophobia, however, a patent foramen ovale was identified on echocardiography. The patient's visual symptoms resolved by the time of hospital discharge and he experienced no further posterior territory symptoms during follow-up.

Three patients (2.6%, $n = 3/116$) treated early in the series required LSCA revascularization postoperatively due to failure of adherence to the current selection criteria (Table 6). The first required LSCA revascularization on postoperative day 2 after developing left upper extremity weakness and coolness with no measurable blood pressure in the extremity. This patient did not have bilateral radial arterial line monitoring and presumably would have been revascularized intraoperatively for loss of left radial artery pulsatility had current monitoring been employed. The second patient underwent TEVAR with coverage of the LSCA as well as an aberrant right subclavian artery and required LSCA revascularization on postoperative day 40 after presenting to clinic with symptoms of dizziness and ataxia. With adherence to our current algorithm he should have undergone preemptive revascularization to avoid bilateral vertebral artery coverage, similar to patients with a dominant left vertebral artery. The third patient underwent LSCA revascularization on postoperative day 204 after presenting to clinic with symptoms of dizziness. This patient was noted to have loss of left radial artery pulsatility following LSCA coverage that improved somewhat with blood pressure augmentation. His symptoms of dizziness were initially managed by cessation of anti-hypertensive medications; however, this was ultimately ineffective and LSCA bypass was required. Here again, intraoperative revascularization should have been performed with strict adherence to our current selective revascularization strategy given loss of left radial artery pulsatility. There were no permanent sequelae of delayed revascularization amongst these three patients.

Nine of 32 patients with LSCA revascularization underwent LSCA ligation ($n = 8$) or endovascular embolization ($n = 1$) at the time of surgery. Of the remaining 23 patients, 4.3% ($n = 1/23$) developed postoperative type II endoleak from the LSCA requiring delayed endovascular occlusion. Five of 113 patients in the non-revascularized group underwent LSCA endovascular embolization at the time of surgery. Of the remaining 108 patients, 6.5% ($n = 7/108$) developed postoperative type II endoleak requiring LSCA endovascular occlusion. The rate of type II endoleak related to the LSCA was equivalent between the two groups ($p = 1.0$).

Four complications of left carotid-LSCA bypass occurred in three (9.4%) patients (Table 1). One patient developed a neck hematoma requiring re-exploration; that patient also suffered left recurrent laryngeal nerve palsy requiring vocal cord medialization. The second patient was found on intraoperative angiogram to have a focal dissection of the LSCA artery after revascularization correlating with a decrease in left radial artery pressure. This was immediately repaired by taking down the subclavian artery anastomosis and repairing the flap as part of a new distal anastomosis. A third patient developed transient left phrenic nerve palsy after delayed left carotid-LSCA bypass on postoperative day 2 for symptomatic left upper extremity ischemia.

COMMENT

Recent SVS clinical practice guidelines recommend routine preoperative LSCA revascularization when the LSCA is covered during TEVAR to reduce the rate of stroke,

spinal cord, and left upper extremity ischemia [2]. Here, we describe a selective algorithm for LSCA revascularization applied to the largest single-center series of patients in the literature undergoing TEVAR with intentional LSCA coverage. Of the 145 patients with LSCA coverage, this approach led to intraoperative LSCA bypass in 20% (29/145) and postoperative LSCA bypass in 2% (3/145). After taking into account that all three postoperative revascularizations likely would have occurred at the time of the initial surgery using our current criteria, our selective revascularization strategy appears to have successfully captured all patients who would benefit from preemptive LSCA revascularization. A non-selective revascularization strategy applied to our series therefore would be predicted to have led to 113 unneeded revascularizations and 11 extra complications of carotid-LSCA bypass, assuming a 9.4% rate of complication. The rates of death, permanent paraplegia/paraparesis, and stroke were equivalent between the revascularized and non-revascularized groups, suggesting that withholding LSCA revascularization for when there is a clear and logical indication is safe and does not lead to major adverse events.

Complications of LSCA revascularization have been reported to occur in 2.4 to 12.2% of patients [3, 10, 11], and we report a comparable rate in this series. The choice of bypass versus transposition is essentially one of surgeon or institutional preference, and we have adopted the bypass technique due to the greater speed of the procedure and potentially lower complication rate [1]. Although proximal LSCA occlusion is performed preemptively by some groups in all cases of LSCA revascularization [10], we found equivalent rates of type II endoleak from the LSCA between revascularized and non-revascularized patients in instances where preemptive LSCA occlusion was not performed, suggesting no benefit to routine preemptive LSCA occlusion with revascularization.

LSCA coverage during TEVAR is associated with an increased rate of anterior and posterior circulation stroke compared to when this artery is not covered [3, 12, 13]. Three recent meta-analyses failed to demonstrate a reduction in either anterior or posterior circulation strokes with preemptive LSCA revascularization, suggesting posterior circulation hypoperfusion from LSCA coverage is not a contributing factor [3, 12, 13]. Our data are in agreement with these findings by suggesting an embolic source for all posterior circulation strokes in our series. This suggests the increased rate of posterior circulation stroke with LSCA coverage is secondary to manipulation of wires and catheters in a diseased aortic arch; as such, preemptive LSCA revascularization would not protect against this complication. Interestingly, 75% (3/4) of the embolic strokes in our series were left hemispheric (with the remaining one bilateral), suggesting that LSCA coverage may lead to increased left-sided embolic phenomenon from wire manipulation near the LSCA orifice. We propose that sidedness of stroke may be an important variable to record in future studies of LSCA coverage to help confirm or refute this finding.

A dominant left vertebral artery is ubiquitously reported in the TEVAR literature as occurring in greater than 60% of individuals, and this high incidence has been used to justify routine preoperative LSCA revascularization [2, 12, 14]. However, while small imbalances between right and left vertebral artery caliber are found in most individuals, right vertebral artery hypoplasia occurs in only 1.9 to 7.8% of the population, depending on how it is defined [15]. In our series, 0/145 patients required LSCA revascularization for a dominant left vertebral artery, suggesting the incidence of a clinically relevant dominant left vertebral artery in the TEVAR population is exceedingly low and, therefore, concern for this variant should not be used to endorse preemptive revascularization for all patients. Similarly, the possibility of an incomplete Circle of Willis is also frequently cited as a reason to perform preemptive LSCA revascularization, although the incidence of a clinically relevant

disruption of both the anterior and posterior communicating arteries is exceedingly rare [16]. As a result, we do not routinely assess the Circle of Willis in patients undergoing TEVAR.

Preemptive LSCA revascularization was found in one meta-analysis to reduce the rate of spinal cord injury [12]. Our selective revascularization strategy appeared successful in identifying patients at high risk for spinal cord ischemia who may benefit from preemptive LSCA bypass. Ten patients were considered high risk for spinal cord ischemia due to either extensive aortic pavement from the LSCA to the celiac axis ($n = 4$) or history of prior AAA repair or prior descending/thoracoabdominal aortic surgery ($n = 6$). The rate of spinal cord ischemia was 0% amongst these patients and 0% amongst all 113 non-revascularized patients, suggesting that all patients requiring LSCA bypass for spinal cord protection were identified. The one patient in our series who did suffer paraplegia underwent preemptive LSCA revascularization for a patent LIMA bypass, indicating that preservation of left vertebral artery blood flow was not sufficient to prevent spinal cord injury in this instance.

In conclusion, we herein present a retrospective, single-institution review of results with a selective LSCA revascularization strategy following intentional LSCA coverage during TEVAR. We found that a logical and systematic approach for identifying patients in need of LSCA bypass is safe with no apparent increase in adverse events. This strategy would be expected to prevent all unnecessary preemptive revascularizations, with their associated costs and morbidity, that would otherwise be performed using a non-selective revascularization approach. We therefore suggest a rational, selective revascularization strategy may be sufficient to identify all patients appropriate for LSCA bypass in conjunction with intentional LSCA coverage during TEVAR. We recommend further evaluation of selective revascularization strategies, including appropriate clinical trials, before firm clinical practice guidelines are published or adopted.

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Figure 1.

Bilateral radial arterial line tracings demonstrating loss of left radial artery pulsatility and right/left systolic pressure differential > 50 mm Hg following left subclavian artery coverage. This patient would be at risk for left upper extremity ischemia and underwent intraoperative left subclavian artery revascularization to restore pulsatility.

Table 1

Indications for left subclavian artery revascularization

Indication	Total No. (%)	No. w/Revascularization Complication
<i>Preoperative</i>	25 (78%)	
Spinal cord protection	10 (31%)	
Patent pedicled LIMA bypass graft	9 (28%)	2
Origin of the left vertebral artery from the aortic arch	4 (13%)	
Left upper extremity dialysis access	2 (6%)	
Dominant left vertebral artery	0 (0%)	
<i>Intraoperative</i>	4 (13%)	
Loss of left radial artery pulsatility following device deployment	4 (13%)	
<i>Postoperative</i> [*]	3 (9%)	
Vertebrobasilar insufficiency [†]	2 (6%)	
Left arm claudication	1 (3%)	1

LIMA = left internal mammary artery

^{*} All patients likely would have been revascularized at the time of surgery with adherence to the current selective revascularization algorithm.[†] Dizziness, ataxia, or blurry vision.

Table 2

Patient demographics

Variable	No. (%)
Median age	62 +/- 15 years
Female	54 (37%)
Body mass index, mean (kg/m ²)	28.2 +/- 5.6
ASA class, mean	3.6 +/- 0.5
Hypertension	120 (83%)
Diabetes	21 (15%)
Coronary artery disease	39 (27%)
Obstructive pulmonary disease	53 (37%)
Chronic renal insufficiency (baseline Cr ≥ 1.5)	32 (22%)
Peripheral vascular disease	19 (13%)
Previous aortic surgery	45 (31%)

ASA= American Society of Anesthesiologists

Table 3

Indications for TEVAR

Indication	Elective No. (%)	Urgent No. (%)	Emergent No. (%)	Total No. (%)
Aneurysm	56 (39%)	16 (11%)	5 (3%)	77 (53%)
Dissection	29 (20%)	19 (13%)	8 (6%)	56 (39%)
Transection	0 (0%)	5 (3%)	7 (5%)	12 (8%)
Total	85 (59%)	40 (28%)	20 (14%)	145

Table 4

Length of aortic coverage by the endograft(s)

	Revascularized No. (%)	Non-revascularized No. (%)	Total No. (%)
Extent of Aortic "Pavement"			
Zone 0 – 2 to T6 or above	22 (21%)	84 (79%)	106 (73%)
Zone 0 – 2 to below T6	10 (26%)	29 (74%)	39 (27%)

Table 5

Summary of postoperative strokes

Patient	Post-Op Day	Revascularized	Distribution	Etiology
1	7	Yes	L PCA, L ACA	Embolic
2	0	No	L PICA	Intraoperative Embolus
3	0	No	Carotid	Stent Migration
4	8	No	Bilateral PICA	Embolic, R VA stenosis
5	0	No	L PCA	Embolic

ACA = anterior cerebral artery, L = left, PCA = posterior cerebral artery, PICA = posterior inferior cerebellar artery, R = right, VA = vertebral artery

Table 6

Summary of postoperative revascularizations

Patient	Post-Op Day	Indication	Symptoms	Note
1	2	LUE ischemia	LUE weakness, coolness, unable to record blood pressure	Left radial artery pressure not monitored intraoperatively
2	40	Vertebrobasilar insufficiency	Dizziness, ataxia	Bilateral SCA coverage (aberrant right SCA)
3	204	Vertebrobasilar insufficiency	Dizziness	Loss of left radial artery pulsatility intraoperatively

LUE = left upper extremity, SCA = subclavian artery