Short and midterm results after left subclavian artery coverage during endovascular repair of the thoracic aorta

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Background: **To analyze the sequelae of the intentional left subclavian artery (LSA) coverage during thoracic endovascular aortic repair (TEVAR).**

Methods: **Retrospective analysis of prospectively collected data in a single center. Between March 1997 and October 2008, 88 of 220 patients (40%) had thoracic aortic lesions that required LSA coverage during TEVAR. Thirty-four of our patients (39%) were treated under urgent or emergent conditions for acute pathologies. The proximal landing zone was zone 0 in 10 patients (11%), zone 1 in 24 patients (27%), and zone 2 in 54 patients (61%). Debranching procedures of the supra-aortic vessels were performed in patients who were to undergo zone 0 or zone 1 deployment. Primary LSA revascularization was performed in 22 of the 88 patients (25%) at a median of 6 days before TEVAR. Median follow-up was 26.4 months (1-98 months).**

Results: **Technical success was achieved in 97%. Five primary (9%) and two secondary (4%) type Ia endoleaks in patients who underwent zone 2 deployment were observed and required further interventions. Fourteen (16%) primary type II endoleaks were observed; 10 of them fed by the LSA. Paraplegia rate was lower in patients with LSA coverage without revascularization than in other patients (1.5% vs 1.9%; odds ratio [OR], 0.774; 95% confidence interval [CI], 0.038-6.173; $P = 1.000$). Prior or concomitant infrarenal aortic replacement ($P = .0019$), renal insufficiency (glomerular filtration rate < 90 mL/min/1.73 m^2) ($P = .0024$) and long segment aortic coverage (>200 mm) ($P = .0157$) were associated with significant higher risk of postoperative paraplegia. Stroke rate was lower in patients with LSA coverage without revascularization than in other patients (3% vs 3.9%; OR, 0.570; 95% CI, 0.118-2.761; $P = .7269$). Two patients (3%) developed left upper extremity symptoms and another two patients (3%) subclavian steal syndrome and required secondary LSA revascularization. The technical success rate for LSA revascularization was 94%.**

Conclusion: **By using a selective approach to the LSA revascularization, coverage of the LSA can be used to extend the proximal seal zone for TEVAR without increasing the risk of spinal cord ischemia or stroke. Indications for revascularization include long segment aortic coverage, prior or concomitant infrarenal aortic replacement, and renal insufficiency. In addition, a hypoplastic right vertebral artery, a patent left internal mammary artery graft, and a functioning dialysis fistula in the left arm would also be indications to perform revascularization.**

In recent years, thoracic endovascular aortic repair (TEVAR) has, with some exceptions, became the standard of care.[1-4] With growing experience, the early limitations of this method have been resolved and reports on extra-anatomic revascularization procedures of either the supra-aortic or the visceral vessels abound in the international literature.[5-9] With the need for carotid or renal revascularization before stent-grafting being undisputable, the need for left subclavian artery (LSA) revascularization before TEVAR for pathologies of the aortic arch has become the subject of considerable controversy.[10,11] In a recent study from the EUROSTAR registry Buth et al reported a significant fourfold increased risk of postoperative paraplegia with LSA coverage.[12] In this study, we sought to analyze the sequelae of the intentional LSA coverage during TEVAR.

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METHODS

Study design and patient population. A prospectively maintained TEVAR database, medical records, and imaging studies of 220 patients who underwent TEVAR between March 1997 and October 2008 in our institution were reviewed. Of those, 88 patients (40%) had thoracic aortic lesions that required endograft deployment covering the origin of the left subclavian artery. Patient characteristics are listed in Table I. Thirty-four of our patients (39%) were treated under urgent or emergent conditions for acute pathologies. Indications for treatment are listed in Table II.

Pre-interventional imaging and landing zones. The decision on coverage of the LSA was made on preoperative

Table I. Patient characteristics (n = 88)

Variable	*No. or median (% or range)*
Age (y)	64 (19-84)
Gender (male:female)	63:25 (72%:28%)
ASA classification	3 (1-4)
Hypertension	76 (86%)
Smoking history	52 (59%)
Diabetes mellitus	31 (35%)
Hyperlipidemia	36 (41%)
Renal insufficiency (GFR<90 mL/min/1.73 m^2)	18 (20%)
Functioning dialysis fistula in the left arm	3 (2%)
Coronary artery disease	29 (33%)
Previous myocardial infarction	12 (14%)
Patent LIMA graft	4 (4.5%)
COPD	11 (13%)
Previous infrarenal aortic surgery	13 (15%)

GFR, Glomerular filtration rate; *LIMA,* left internal mammary artery; *COPD,* chronic obstructive pulmonary disease; *ASA,* American Society of Anesthesiology.

Table II. Indications for treatment (n = 88)

Indication	*Elective, no.*	*Urgent or emergent, no.*
Degenerative aneurysm	21	6
Stanford type B dissection		
Acute	0	11
Chronic	14	4
Traumatic transection	5	8
PAU	10	2
IMH	1	2
False anastomotic aneurysm	2	1
LSA aneurysm	1	0

PAU, Penetrating aortic ulcer; *IMH,* intramural hematoma; *LSA,* left subclavian artery.

contrast enhanced computed tomography (CTA) or magnetic resonance angiography (MRA) and three-dimensional (3D) image reconstructions with centerline measurements and visualization of both vertebral and the basilar arteries. For elective cases, a proximal landing zone of ≥15 mm length was required. In emergent cases, however, a ≥10 mm proximal "neck" was accepted in patients unfit for open surgery. To classify proximal landing zones, the aortic arch map with zone 0-4 by Mitchell et al was applied.[13] The proximal landing zone was zone 0 in 10 patients (11%), zone 1 in 24 patients (27%), and zone 2 in 54 patients (61%). Ascending arch-innominate artery and left common carotid artery (LCCA) bypasses were performed in patients who were to undergo zone 0 deployment. Patients requiring zone 1 deployment underwent right-to-left carotid-carotid bypass procedures using an 8-mm Dacron graft. Furthermore, preoperative duplex scanning was performed in all elective patients to evaluate extracranial circulation with particular focus on the patency of the right vertebral artery.

Primary LSA revascularization. In our early experience, indications for primary LSA revascularization were a patent left internal mammary artery (LIMA) graft, a functioning dialysis fistula in the left arm, need for long segment aortic coverage, and prior or concomitant infrarenal aortic replacement. With growing experience, our protocol included a hypoplastic right vertebral artery (RVA) and renal insufficiency as indications for LSA revascularization in elective patients. Primary LSA revascularization was performed in 22 of the 88 patients (25%) at a median of 6 days before TEVAR. In three patients (30%) with a proximal landing zone 0 and in 14 patients (58%) with zone 1 TEVAR, primary LSA revascularization was performed by bypass. Among patients with zone 2 TEVAR, four patients (7%) underwent LSA to LCCA transposition and one patient (2%) underwent LCCA to LSA bypass.

Endovascular procedure. All surgical procedures were performed in an operation theater equipped with fluoroscopic and angiographic capabilities (Series 9800; OEC Medical Systems, Inc., Salt Lake City, Utah or Axiom U, Siemens, Forchheim, Germany) and a carbon fiber operating table. All TEVAR procedures were performed in an operation room equipped with a mobile OEC9800 (GE Healthcare, Waukesha, Wis). Our TEVAR surgical protocol has been published before.[14] Eighty-four procedures (95%) were performed under general anesthesia, three under local and one under epidural anesthesia. Vascular access was obtained through the common femoral artery in 66 patients (75%) or through an iliac or aortic Dacron conduit in 14 and eight patients, respectively. Adenosine-induced cardiac arrest (AICA) was used in 64 patients (73%). According to our protocol, AICA is indicated for any pathology located proximal to the LSA. Nevertheless, it could not be applied in all these cases due to missing application knowledge in some emergency cases.

Stent grafts. A total of 129 endografts were implanted. Sixty-three patients received a single stent graft (median 1; range 1-5). For stent graft diameter selection, 15% to 20% oversizing was applied. Median stent graft length and diameter were 150 mm (range: 100-200) and 34 mm (range: 24-44), respectively. The median length of the aorta covered by stent grafts was 150 mm (range: 100-350). Stent grafts included the TAG (W.L. Gore and Associates, Flagstaff, Ariz) in 59 patients, the Talent/Valiant (Medtronic Vascular, Santa Rosa, Calif) in 20, the Zenith (Cook Inc, Bloomington, Ind) in six, and the Endofit (LeMaitre Vascular, Inc., Burlington, Mass) in three patients.

Follow-up. Follow-up included history, physical examination, CTA or MRA, and plain chest radiography before discharge, 6 months, 1 year, and annually thereafter in uneventful cases. In complicated cases, follow-up was adjusted accordingly. Patients were specifically assessed for neurologic and left arm symptoms.

Definitions and statistics. Technical and clinical success were defined according to the reporting standards for endovascular aortic aneurysm repair.[15] Primary technical success can include the use of additional modular components, stents, or angioplasty, and adjunctive surgical procedures. However, if unplanned endovascular or surgical

procedures are necessitated, the terms *assisted primary* or *secondary technical success*, respectively, should be used.[15] Endoleaks were categorized as previously described by White et al.[16] Primary endoleaks were defined as apparent on intraoperative control angiography or primary postoperative CTA control (≤30 days). Endoleaks occurring during follow-up were defined as secondary endoleaks.

SAS software (Release 9.1; SAS Institute, Inc, Cary, NC) was used for statistical analysis. Quantitative variables are expressed as median and range. The differences in proportions of neurologic complications (paraplegia and stroke) between patients with LSA coverage without revascularization (n = 66) and other patients (n = 154) were analyzed using the Fisher exact test. Furthermore, the same test was used to correlate patient characteristics (renal insufficiency, prior/concomitant infrarenal aortic replacement) and operative technical factors (length of aortic coverage >200 mm) with the incidence of paraplegia. The corresponding odds ratios (OR) with 95% confidence intervals (CI) were calculated using logistic regression analysis. Two-sided *P* values were always computed and a difference was considered statistically significant at $P \leq .05$. Overall survival from the date of TEVAR procedure was calculated by the Kaplan-Meier estimate. Patients alive at the last follow-up were censored, as was one patient who needed open conversion 40 days after TEVAR. The survival rates after 1-, 3-, and 5-years were estimated.

RESULTS

Technical success. Technical success could be achieved in 85/88 patients (97%). An 81-year-old patient with a symptomatic 7-cm aneurysm died intraoperatively of massive bleeding from the ascending aorta, which was chosen as access vessel for antegrade endograft deployment. This patient had a history of high Leriche syndrome and axillobifemoral bypass surgery. Two other patients who underwent zone 2 deployment showed type Ia endoleaks on the first postoperative CTA controls, but primarily refused further interventions. One of these patients (a 76-year-old, ASA 4) died 4 months postoperatively of severe pneumonia and the other is scheduled for proximal endograft extension.

Primary, assisted primary, and secondary technical success rates were 78%, 85%, and 90% respectively. Six patients required unplanned endovascular procedures to achieve assisted primary technical success. Among them, four patients who underwent zone 1 deployment showed primary type I endoleaks (2 type Ia, 2 type Ib) and required endograft extension. On the other hand, 10 patients required unplanned surgical procedures to achieve secondary technical success. Among them, three patients who underwent zone 2 deployment showed primary type Ia endoleak requiring supra-aortic debranching bypass procedures before endograft extension. Four patients (7%) intended for zone 2 deployment required emergent revascularization of the LCCA when endografts accidentally covered its origin. Two patients treated for acute type B dissection and intramural hematoma, respectively, both with TAG stent-grafts, suffered an intraoperative retrograde type A dissection and underwent open aortic arch repairs. One patient survived and continues to do well, but the other died of multisystem organ failure (MSOF) at 20 days.

Table III. Primary type II endoleaks from the LSA (n = 10)

No. of patients	*Management*	*Outcome*
4	Conservative	Spontaneous seal during follow-up
2	Conservative	6-month control CTA pending
1	Conservative	Patient died of pneumonia within 30 days after TEVAR
1	Ligation of the LSA	Sealed
1	Transbrachial deployment of an occluder plug proximal to the LVA	Sealed
1 (patient with subclavian steal syndrome)	LSA transposition	Sealed

LSA, Left subclavian artery; *LVA,* left vertebral artery; *CTA,* computed tomography angiography; *TEVAR,* thoracic endovascular aortic repair.

Type II endoleaks. Furthermore, there were 14 primary type II endoleaks (16%). Ten of them were fed by the LSA. Thus, the rate of primary type II endoleaks from a not primary revascularized LSA was 10/66 (15%). Management and outcome of these endoleaks are summarized in Table III. In one patient with a LSA aneurysm, stent graft deployment was followed by transbrachial deployment of an occluder plug proximal to the left vertebral artery (LVA) (Fig 1). Another three endoleaks from intercostal arteries sealed spontaneously during follow-up. In one patient with a Crawford type II aneurysm, proximal ligation of the celiac trunk after visceral debranching was forgotten during a 6-hour operation. The patient developed an extended type II endoleak and unfortunately died of aortic rupture 5 months after TEVAR and before a scheduled coil embolization.

Initial clinical success. The 30-day mortality rate was 17% (15/88), in-hospital mortality was 19% (17/88). Five patients died from MSOF as a complication of acute type B dissections, five patients from cardiac failure, two patients from respiratory failure, and two patients died of concomitant injuries after successful TEVAR for traumatic aortic transections (TAT). Finally, two patients died on the first postoperative day for unknown reasons after technically successful TEVAR for ruptured aneurysms. Autopsy was denied in both cases and the clinical findings were noncontributory. Furthermore, a 30-year-old patient (1%) who underwent TEVAR for TAT required open conversion at 40 days due to hematogenic endograft infection. The patient is doing well at 4-year follow-up. Thus, initial clinical

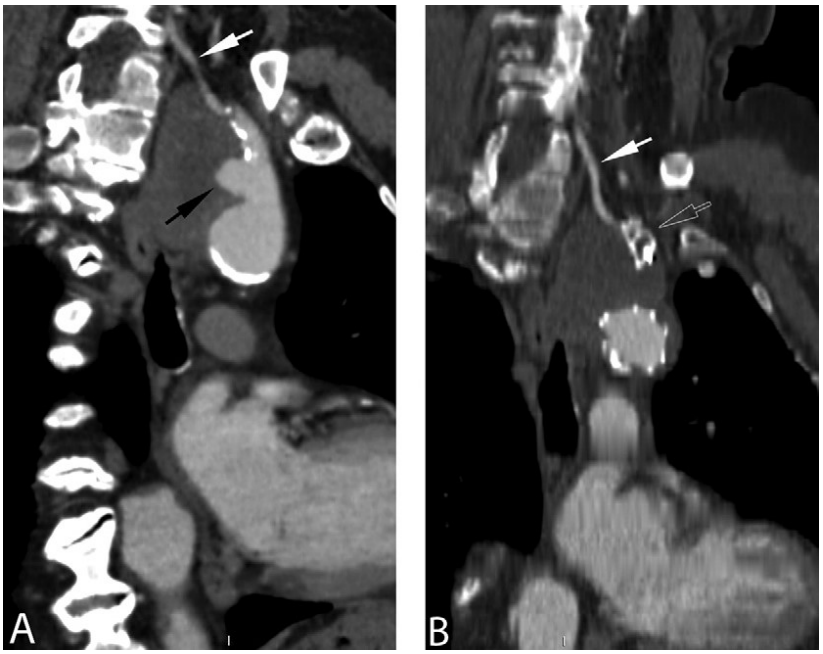

Fig 1. Coronal multiplanar reformatted computed tomography angiography (*CTA*) images of a large left subclavian artery aneurysm (*black arrow*) before (**A**) and after (**B**) stent graft deployment followed by transbrachial deployment of an occluder plug (*empty arrow*) proximal to the left vertebral artery (*white arrow*).

Table IV. Postoperative morbidity and mortality (n = 88)

	n	*Percentage (%)*
30-day mortality	15	17
In-hospital mortality	17	19
Paraplegia/paraparesis	1	1
Stroke	3	3
Subclavian steal syndrome	2	3*
Arm claudication	3	5*
Cardiac complications	13 (5 lethal)	15
Respiratory complications	23 (2 lethal)	26
Renal failure	11	13
MSOF	5 (5 lethal)	6
Groin wound	3	3
Access vessel injury	3	3
Primary endolecks	23	26
Type I	9	10
Type II	14	16
Secondary endolecks	3	3
Type I	3	3
Secondary LSA revascularization	9	16*
Conversion	1	1

LSA, Left subclavian artery; *MSOF,* multisystem organ failure.
*Percent of the 66 patients with LSA coverage without primary revascularization.

Table V. Correlation of LSA coverage with neurologic complications

Group no.		*Paraplegia no. (%)*	*Stroke no. (%)*
1	LSA coverage (n = 88)	1 (1.1%)	3 (3.4%)
1a	without primary revascularization (n = 66)	1 (1.5%)	2 (3%)
1b	with primary revascularization (n = 22)	0	1 (4.5%)
2	No LSA coverage (n =132)	3 (1.5%)	5 (3.8%)
1b+2	LSA with antegrade flow (n = 154)	3 (1.9%)	6 (3.9%)
1+2	Overall (n = 220)	4 (1.8%)	8 (3.6%)

LSA, Left subclavian artery.

success was achieved in 61/88 patients (69%). Perioperative complications are presented in Table IV.

Paraplegia. One transient paraplegia developed in a patient with a symptomatic 6.5-cm thoracoabdominal aneurysm Crawford type II who underwent an urgent simultaneous hybrid procedure with debranching of the visceral and renal arteries followed by endovascular exclusion of the aneurysm and LSA coverage without primary revascularization. Once paraplegia manifested a few hours after the operation, we performed an emergent transposition of the LSA, along with augmentation of mean arterial pressure and cerebrospinal fluid drainage. Thereafter, the paraplegia resolved to paraparesis, and the patient is currently able to stand and make a few steps with assistance.

Thus, paraplegia rate in patients with LSA coverage was 1.1% (1/88). The correlation of LSA coverage and perioperative neurologic complications are summarized in Table V. Paraplegia rate was lower in patients with LSA coverage without revascularization (n = 66) than in other patients (n = 154) (Table V: 1.5% vs 1.9%; OR, 0.774; 95% CI,

Table VI. Risk factor analysis for paraplegia

Risk factor	*Incidence of paraplegia (n = 4) (%)*	P *value*	*OR (95% CI)*
LSA			
closed	1/66 (1.5%)	1.000	.774 (.038-6.173)
open	3/154 (1.9%)		
Prior/concomitant infrarenal aortic replacement			
yes	4/47 (8.5%)	.0019	. . .[a]
no	0/173		
Renal insufficiency (GFR<90 mL/min/1.73 m^2)			
yes	4/50 (8%)	.0024	. . .[a]
no	0/170		
Length of aortic coverage			
>200 mm	3/37 (8%)	.0157	16.06 (1.62-159)
≤200 mm	1/183 (0.5%)		

LSA, Left subclavian artery; *GFR,* glomerular filtration rate; *OR,* odds ratio; CI, confidence interval.
[a]Not applicable.

Table VII. Indications for secondary LSA revascularization (n = 9)

No. of patients	*Indication*	*LSA revascularization*
4	Type Ia endoleak	Bypass
2	Arm claudication	1 transposition, 1 bypass
2	Subclavian steal	Transposition
1	Paraplegia	Transposition

LSA, left subclavian artery.

0.038-6.173; $P = 1.000$). Prior or concomitant infrarenal aortic replacement, renal insufficiency (glomerular filtration rate [GFR] < 90 mL/min/1.73 m^2) and long segment aortic coverage (>200 mm) were associated with significant higher risk for postoperative paraplegia (Table VI).

Stroke. Three of the 88 patients (3.4%) with LSA coverage suffered perioperative strokes. Stroke rate was lower in patients with LSA coverage without revascularization (n = 66) than in other patients (n = 154) (Table V: 3% vs 3.9%; OR, 0.570; 95% CI, 0.118-2.761; $P = .7269$). Furthermore, no strokes occurred in the posterior circulation.

In particular, one patient with cardiac arrhythmia had LSA coverage without primary revascularization and suffered a right-hemispheric stroke with transient hemiparesis on the third postoperative day. A second patient with LSA coverage without revascularization suffered also a right-hemispheric stroke with transient hemiparesis on the second postoperative day after an episode of atrial fibrillation. The third patient had a debranching procedure of the supra-aortic vessels with primary LSA revascularization before TEVAR and suffered an intraoperative left-hemispheric stroke with transient aphasia.

Secondary LSA revascularization. Nine patients (14%) underwent secondary LSA revascularization (Table VII). Arm claudication developed in three patients (4.5%). In two of them (3%), the symptoms were severe, requiring a secondary revascularization. In another two patients, finger discoloration did not warrant intervention. Two patients (3%) developed a subclavian-steal syndrome also requiring secondary revascularization. One of the last two patients additionally had a primary type II endoleak from the LSA. Four patients underwent supra-aortic debranching bypass procedures, including LSA revascularization, when type Ia endoleaks required proximal endograft extension.

Technical success for LSA revascularization. The technical success rate for both primary and secondary LSA revascularization was 94% (31/33). In two patients with aortic arch aneurysms who underwent debranching procedures before TEVAR, the intended primary LSA revascularization was intraoperatively assessed as too risky, due to steep aortic arches and the vicinity to the aneurysms, and was omitted. These patients did not require secondary revascularization. Complications related to LSA revascularization consisted of three small lymphoceles (9%) that resolved with parenteral nutrition within days and one large lymphocele (3%) that required surgical revision. No neurologic complications were observed in association with LSA revascularization. The patency rate of the LSA reconstructions throughout follow-up was 100%.

Mid-term clinical success. Median follow-up of patients alive was 26.4 months (1-98 months). The estimated survival rates after 1, 3, and 5 years were 76.7%, 73.2%, and 64.7%, respectively (Fig 2). There were eight late deaths during follow-up, four of them were aorta-related. One patient who underwent TEVAR for chronic expanding aortic type B dissection (CEAD) died of infrarenal aortic rupture at approximately 33 months. Another patient treated for CEAD died of an aortobronchial fistula at 7 months. A third patient treated for an aneurysm of the descending aorta and unfit for open aortic repair died of rupture of the ascending aorta at 25 months. Finally, a patient died of aortic rupture due to a large type II endoleak at 5 months, as described above.

Secondary endoleaks occurred in three patients (3%). Two patients with zone 2 deployment developed type 1a endoleaks (at 12 and 36 months) requiring supra-aortic debranching bypass procedures and proximal endograft extension. In the third patient, a type 1b endoleak (at 12

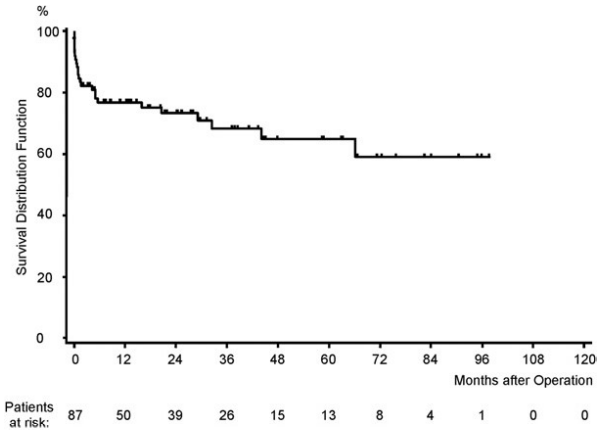

Fig 2. Overall survival of 88 patients with left subclavian artery (*LSA*) coverage.

months) was resolved with distal endograft extension. No late conversions were necessary. Thus, midterm clinical success could be achieved in 57/88 patients (65%).

DISCUSSION

These results indicate that the risk of paraplegia or stroke associated with the intentional LSA coverage during TEVAR may be overestimated in recent reports[10-12] and that primary LSA revascularization should be considered in selected patients, with the selection criteria being defined.

With the first implantation dating back 15 years,[17] TEVAR has not just become an alternative, but proven to be safe and effective replacing open surgery as the therapy of first choice for a variety of thoracic aortic pathologies.[1-4] A large portion of patients undergoing TEVAR, 40% in our series, have lesions requiring coverage of the ostium of the LSA to obtain proximal seal.[19] The importance of antegrade flow through the LSA for brain, spinal cord, and arm perfusion and, thus, the need for primary LSA revascularizations are still subjects of great scientific debate.[10,11] In this study, we report our experience with the management of patients requiring LSA coverage with TEVAR (zones 0-2).

An overall technical success rate of 97% in our series demonstrates the effectiveness of TEVAR in the very challenging anatomy of the aortic arch. One should also keep in mind that a big amount of these procedures (39% in this report) take place under urgent or emergent conditions with sometimes very short proximal landing zones. In this context, five primary (9%) and two secondary (4%) type Ia endoleaks in patients who underwent zone 2 deployment are in accordance with the results of other large series[6,19-21] and demonstrate that LSA coverage is not always sufficient in establishing adequate seal. In such cases, secondary supra-aortic debranching procedures are needed for more proximal endograft extension.

The risk of stent graft displacement in the aortic arch is also substantial. As described above, in four patients (7%) stent grafts (all TAG) that were to be deployed in zone 2 accidentally covered the origin of the LCCA. Three of the four patients were younger patients (median age: 47 years) with an acute complicated Stanford type B dissection. The acute angle of the aortic arch in younger patients makes an exact stent graft deployment difficult. Furthermore, the TAG device cannot always be exactly deployed into the steep distal aortic arch of younger patients. Nevertheless, in many cases the authors preferred the TAG device to treat pathologies of the aortic arch due to its high flexibility. With the fear of retrograde type A dissection, the authors feel more comfortable with the proximal covered flares of the TAG endoprosthesis than with open bare springs of other devices.[22] AICA can enhance precise stent graft deployment in the aortic arch but cannot totally prevent stent-graft displacement.[22] Two of the above 4 patients had stent-graft displacement despite AICA. On the other hand, AICA is not always available under emergent conditions, as in our other 2 patients with accidental LCCA coverage.

Regarding type II endoleaks, we favor conservative management of primary type II LSA endoleaks.[23] Seven of 10 primary type II LSA endoleaks sealed spontaneously during follow-up. Only in cases of large type II endoleaks we go on with ligation of the LSA or its occlusion by a vascular plug proximal to the LVA.[10]

Technical success does not warrant clinical success. An initial clinical success rate of 69% and a midterm clinical success rate of 65% in our series are comparable with other series and are mostly due to a highly comorbid patient collective.[6] The median ASA score of these patients was 3, and 33% of them had manifest coronary artery disease. Most of these patients were unfit for open repair of the aortic arch and/or the thoracoabdominal aorta, at least under urgent or emergent conditions.

Fifty percent of our patients undergoing zone 0 or zone 1 stent graft deployment had a primary LSA revascularization vs 9% of our patients with zone 2 TEVAR. In the setting of debranching procedures of the innominate artery and/or the LCCA, the chance of LSA revascularization is obviously greater than in cases of sole LSA revascularization. Indications for primary LSA revascularization in our elective patients were a patent LIMA graft, a functioning dialysis fistula in the left arm, and increased risk for spinal cord ischemia. Such risk factors are believed to be the reason for the need of long segment aortic coverage, prior or concomitant infrarenal aortic replacement and, as shown recently, renal insufficiency.[10-12,24-26]

Indeed, our risk analysis demonstrated a significant association between the above factors and the risk for postoperative paraplegia. In contrast to the Eurostar registry study though,[12] LSA coverage without revascularization was not associated with higher risk of paraplegia in our series. In fact, the only patient with closed LSA developed paraplegia in this series was a “high risk” patient with renal insufficiency, requiring simultaneous infrarenal aortic replacement and long-segment aortic coverage to treat a symptomatic Crawford type II thoracoabdominal aneurysm under urgent conditions. Such a patient may be more dependent on the collateral flow from the LVA for spinal

cord perfusion and should have a primary LSA revascularization before coverage, at least under elective conditions. It is questionable whether an emergent primary LSA revascularization would have prevented postoperative paraplegia in this patient.[11]

Stroke was significantly associated to occlusion of the LSA without previous revascularization in a retrospective registry study with the Talent endoprosthesis.[2] These findings could not be approved in our series. In fact, stroke rate was lower in our patients with LSA coverage without revascularization than in other patients. Furthermore, all strokes in this report were embolic and occurred in the anterior circulation. Cooper et al were similarly unable to demonstrate any reduction in stroke by revascularization of the LSA.[11] Yet, two of our patients developed signs of vertebrobasilar insufficiency and required secondary LSA revascularization. Both patients were documented to have bilateral patent vertebral arteries. In cases of a hypoplastic RVA, we agree with Feezor et al that primary LSA revascularization should be considered to prevent posterior circulation ischemia.[27] As a consequence, CTA or MRA before TEVAR should be used to visualize both vertebral and the basilar arteries.[28]

In terms of the left upper extremity, there is consensus that LSA coverage is well tolerated and may be managed as the need arises.[18,19] Our incidences of approximately 9% (5/64) of left upper extremity symptoms and 3% (2/64) of severe symptoms requiring intervention are congruent with other published experience.[18,19] Patients with an aberrant LVA off the aortic arch, such as one of our two patients requiring secondary revascularization, are especially at risk for developing severe left arm symptoms, since collateral flow to the arm from the LVA is missing in these patients. Furthermore, in one patient with an aberrant right subclavian (lusoria) artery, an abnormality occurring in 0.5% to 1.8% of the population,[29] the stent graft covered the ostium of the artery, but this remained asymptomatic.

LSA revascularization, while associated with some morbidity, shows excellent technical success rates.[30] In cases of sole LSA revascularization, we favor subclavian carotid transposition over bypass because we believe that the hemodynamics are better with transposition and there is no risk of graft infection with this method. Additionally, long-term patency rates of transposition are superior to those of bypass grafting.[31] In cases when revascularization of additional supra-aortic vessels is needed, however, we proceed with bypass grafting of the LSA, because it is technically the most straightforward approach. In two of our patients, the first segment of the LSA could not be exposed and revascularization was omitted; even so LSA coverage was uneventful. In such cases carotid subclavian bypass grafting can be combined with coil embolization of the LSA or its occlusion by a vascular plug proximal to the LVA. In the near future, endovascular methods with branched or fenestrated stent grafts may widen options to preserve the LSA during TEVAR.[31,32]

Limitations. Although this study represents, to our knowledge, the largest single-center series of patients with LSA coverage during TEVAR, it is still limited by the relatively small number of patients and its retrospective design. Furthermore, the study includes a heterogeneous group of patients with a variety of aortic pathologies.

CONCLUSION

With these in mind, we conclude that by using a selective approach to the LSA revascularization, coverage of the LSA can be used to extend the proximal seal zone for TEVAR without increasing the risk of spinal cord ischemia or stroke. Indications for revascularization include long segment aortic coverage, prior or concomitant infrarenal aortic replacement, and renal insufficiency. In addition, a hypoplastic RVA, a patent LIMA graft, and a functioning dialysis fistula in the left arm would also be indications to perform revascularization.

AUTHOR CONTRIBUTIONS

Conception and design: DK, DB
Analysis and interpretation: DK, DB, AD
Data collection: DK, PG, HK
Writing the article: DK, DB
Critical revision of the article: JA, DB
Final approval of the article: DB
Statistical analysis: DK, UH
Obtained funding: Not applicable
Overall responsibility: DK

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