Fate of patients with spinal cord ischemia complicating thoracic endovascular aortic repair

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Objective: **Spinal cord ischemia (SCI) is a potentially devastating complication of thoracic endovascular aortic repair (TEVAR) that can result in varying degrees of short-term and permanent disability. This study was undertaken to describe the clinical outcomes, long-term functional impact, and influence on survival of SCI after TEVAR.**
Methods: **A retrospective review of all TEVAR patients at the University of Florida from 2000 to 2011 was performed to identify individuals experiencing SCI, defined by *any* new lower extremity neurologic deficit not attributable to another cause. SCI was dichotomized into immediate or delayed onset, with immediate onset defined as SCI noted upon awakening from anesthesia, and delayed characterized as a period of normal function, followed by development of neurologic injury. Ambulatory status was determined using database query, record review, and phone interviews with patients and/or family. Mortality was estimated using life-table analysis.**
Results: **A total of 607 TEVARs were performed for various indications, with 57 patients (9.4%) noted to have postoperative SCI (4.3% permanent). SCI patients were more likely to be older (63.9 ± 15.6 vs 70.5 ± 11.2 years; $P = .002$) and have a number of comorbidities, including chronic obstructive pulmonary disease, hypertension, dyslipidemia, and cerebrovascular disease ($P < .0001$). At some point in their care, a cerebrospinal fluid drain was placed in 54 patients (95%), with 54% placed postoperatively. In-hospital mortality was 8.8% for the entire cohort (SCI vs no SCI; $P = .45$). SCI developed immediately in 12 patients, delayed onset in 40, and indeterminate in five patients due to indiscriminate timing from postoperative sedation. Three patients (25%) with immediate SCI had measurable functional improvement (FI), whereas 28 (70%) of the delayed-onset patients experienced some degree of neurologic recovery ($P = .04$). Of the 34 patients with complete data available, 26 (76%) reported quantifiable FI, but only 13 (38%) experienced return to their preoperative baseline. Estimated mean (± standard error) survival for patients with and without SCI was 37.2 ± 4.5 and 71.6 ± 3.9 months ($P < .0006$), respectively. Patients with FI had a mean survival of 53.9 ± 5.9 months compared with 9.6 ± 3.6 months for those without improvement ($P < .0001$). Survival and return of neurologic function were not significantly different when patients with preoperative and postoperative cerebrospinal fluid drains were compared.**
Conclusions: **The minority of patients experience complete return to baseline function after SCI with TEVAR, and outcomes in patients without early functional recovery are particularly dismal. Patients experiencing delayed SCI are more likely to have FI and may anticipate similar life-expectancy with neurologic recovery compared with patients without SCI. Timing of drain placement does not appear to have an impact on postdischarge FI or long-term mortality. (J Vasc Surg 2013;58:635-42.)**

Thoracic endovascular aortic repair (TEVAR) has become a mainstay of therapy for diseases of the thoracic aorta over the last decade. Despite being less invasive than open aortic repair, TEVAR still results in spinal cord ischemia (SCI) in 2% to 15% of patients.[1-4] A variety of patient and procedure-related risk factors for SCI after TEVAR have been reported, including aortic treatment length,[3,5] left subclavian artery coverage,[1,5] obesity,[6] blood loss,[6] procedural urgency,[6] adjunct procedures (eg, conduit, embolization),[6] renal insufficiency,[7] hypotension,[5] and indication for operation.[8] Further, a number of adjunctive therapies for the prevention and treatment of SCI after TEVAR have been reported and include cerebrospinal fluid (CSF) drainage, left subclavian or hypogastric artery revascularization, augmentation of oxygen delivery, and pharmacologically induced hypertension.[9] Despite increased awareness of this problem and judicious application of these interventions, some patients continue to suffer this devastating complication.

SCI leads to varying degrees of short-term and long-term disability, ranging from mild transient paraparesis to permanent flaccid paralysis, and the occurrence of this complication has a known negative impact on long-term survival.[1,10] Additionally, previous reports have suggested that neurologic recovery with delayed paraplegia has a more favorable outcome compared with immediate paraplegia,[7,9,11-13] but small sample sizes make it difficult to draw definitive conclusions about the natural history of

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SCI after TEVAR. Moreover, few reports have focused on the long-term functional outcome of patients with SCI after TEVAR or the prognostic implications of the degree and speed of functional recovery after SCI.

The purpose of this study was to define the outcomes of patients experiencing SCI after TEVAR and determine differences in the evolution of long-term functional recovery and the effect on survival.

METHODS

This study was approved by the University of Florida College of Medicine Institutional Review Board.

Patients and database. All TEVAR patients at the University of Florida between September 2000 and November 2011 were identified from a prospectively maintained endovascular aortic database. Patients diagnosed with postoperative SCI were further analyzed and compared with patients without SCI. Patients with neurologic deficits confirmed to be secondary to stroke or peripheral neuropathy were excluded from the analysis. Demographics, comorbidities, history of previous aortic surgery, and preoperative ambulatory status were determined by review of the electronic medical record. Procedure-related data pertaining to indication, aortic coverage zone(s), device type, timing of spinal drain use, anesthetic classification, and adjunct use were obtained from the database. Comorbidities and complications were defined and retrospectively recorded using the Society for Vascular Surgery reporting guidelines.[14]

TEVAR technique and procedural adjuncts. The endovascular technique, sequence of graft implantation, need for adjuncts, and spinal drain use was left to the judgment of the operating surgeon. Typically, patients with >150 mm of aortic coverage,[3] previous open or endovascular aortic surgery,[15] or an unrepaired infrarenal aneurysm[15] were considered high-risk for paraplegia and preoperative CSF drainage was used. Perioperative management of the spinal drain was based on a previously published standardized protocol,[3,16] and management of symptomatic patients is briefly outlined below. Patients undergoing elective repair were systemically heparinized (100 U/kg) to achieve an activated clotting time of ≥300 seconds, although heparin was used selectively in urgent and emergent cases (eg, aortic transection or aneurysm rupture). Protamine (1 mg/100 U heparin) was generally used at case completion to achieve normalization of clotting parameters.

SCI diagnosis and management. SCI after TEVAR was defined as any new lower extremity motor or sensory deficit not attributable to other causes (eg, epidural hematoma, intracranial pathology, peripheral neuropathy, or neuropraxia). Patients underwent a gross neurologic examination in the operating room whenever possible. Patients who had a documented change from their preoperative neurologic examination noted at the first postoperative examination were considered to have *immediate* SCI, whereas those who experienced an interval of normal postoperative function, followed by injury recognition, were considered to have a *delayed* presentation. Consultation with neurology or confirmatory imaging with spinal magnetic resonance imaging, or both, were obtained in equivocal cases.

Patients were admitted postoperatively to a dedicated cardiothoracic intensive care unit for hourly neurologic assessment and continuous hemodynamic monitoring. If SCI developed and the patient did not have a CSF drain, a drain was placed immediately (usually ≤1 hour of consultation) by the regional anesthesia service and managed according to our institutional protocol.[3,16] CSF is drained to keep the pressure ≤10 mm Hg (14 cm H_2O), with a serial decrease in pressure titrated to neurologic recovery.

To further optimize spinal cord perfusion, other maneuvers used include volume resuscitation and vasopressor support (goal mean arterial pressure ≥90 mm Hg) with or without a drop in spinal drain height, as well as augmentation of oxygen delivery with maintenance of a cardiac index >2.0 L/min using vasoactive medications (if patients have invasive hemodynamic monitoring), pulse oximetry ≥96%, and maintenance of hemoglobin above 10 mg/dL.

Although drains in asymptomatic patients are typically removed 36 to 48 hours after placement, in those with documented SCI, the drain remains open for at least 72 hours after the onset of symptoms (irrespective of return of function), or up to 5 days, depending on whether neurologic recovery was observed.

After recovery in the intensive care unit, patients were transferred to a dedicated cardiovascular nursing ward and received intensive inpatient physical and occupational therapy, with disposition to home or to a rehabilitation unit determined by the degree of neurologic recovery and functional assessment at time of discharge.

Study end points and definition of functional outcome. The primary end points included perioperative mortality, long-term survival, and overall functional outcome measured by ambulatory status. Perioperative mortality was defined as any death ≤30 days of the procedure or during the initial hospitalization. Functional status and survival was determined by a review of the electronic medical record as well as discussion with the patient or a close family member. When patients could not be contacted directly or through family, current survival status was verified by query of the Social Security Death Master file. Phone interviews were completed with a standardized questionnaire focusing on functional outcomes defined by ambulation status and the subjective assessment of functional improvement (FI) (Appendix, online only). Patients were asked to describe if they had return to preoperative global *functional* status, as well as best ambulation status. Ambulation status was divided into four categories: (1) ambulating independently, (2) ambulating with assistance (cane, walker, etc), (3) nonambulatory, but mobile (stand/pivot and transfer, wheelchair use), and (4) bedridden.

Statistical analysis. SAS 9 software (SAS Institute, Cary, NC) was used to calculate means, standard

Table I. Patient demographics and comorbid medical conditions

Variables[a]	*No SCI*	*SCI*	*OR (95% CI)*	P
Demographics[b]				
Patients	550 (90.6)	57 (9.4)		
Age, years	63.9 ± 15.6	70.5 ± 11.2		.002
Male	377 (69.2)	36 (63.2)		.34
Comorbidities[c]				
Hypertension	149 (27.1)	50 (87.7)	18.7 (8.2-42.7)	<.0001
Smoking	78 (14.2)	21 (36.8)	3.4 (1.9-6.2)	<.0001
Dyslipidemia	66 (12.0)	25 (43.9)	5.1 (2.8-9.3)	<.0001
Renal Insufficiency	37 (6.7)	18 (31.6)	6 (3.1-11.7)	<.0001
COPD	34 (6.2)	16 (28.1)	5 (2.5-9.9)	<.0001
CVOD	14 (2.6)	11 (19.3)	8 (3.4-18.9)	<.0001
PVOD	18 (3.3)	7 (12.3)	3.3 (1.3-8.4)	.01
CAD	47 (8.6)	10 (17.5)	NA	.10
CHF	15 (2.7)	2 (3.5)	NA	.89
Diabetes	26 (4.7)	3 (5.3)	NA	.90
Composite total	0.9 ± 1.6	2.9 ± 1.5	NA	<.0001

CAD, Coronary artery disease; *CHF,* congestive heart failure; *CI,* confidence interval; *COPD,* chronic obstructive pulmonary disease; *CVOD,* cerebrovascular occlusive disease; *NA,* not applicable; *OR,* odds ratio; *PVOD,* peripheral vascular occlusive disease; *SCI,* spinal cord ischemia.
[a]Categoric data are shown as number (%) and continuous data as mean ± standard deviation.
[b]The χ^2 or *t*-test were used for comparisons, when appropriate.
[c]Multivariable regression analysis to control for age and sex.

deviations, and frequencies. The χ^2 or Fisher exact test were used to compare categoric variables in patients with or without SCI and the Student *t*-test or Mann-Whitney tests were used to compare continuous or integer variables, when indicated. SPSS 20 software (SPSS Inc, Chicago, Ill) was used to estimate long-term survival using Kaplan-Meier curves. If the individual died, the time (in months) between TEVAR and death was analyzed as the survival time. If the patient did not die, time between TEVAR and December 1, 2011 (the date of SSDI review), was the survival time. Because the groups were significantly imbalanced with respect to age, sex, and comorbidities, a Cox logistic regression analysis was performed to account for potential confounding of these two variables. A value of $P < .05$ was considered significant.

RESULTS

Study cohort characteristics. Between September 2000 and November 2011, 607 TEVARs were performed, and SCI was noted in 57 patients (9.4%). A permanent deficit from preoperative baseline was documented in 26 patients (4.3%). Analysis of the demographic and clinical variables of patients with and without SCI is reported in Table I. Notably, development of SCI was more frequent in older patients (70.5 ± 11.2 vs 63.9 ± 15.6 years, $P = .002$), and there were a variety of comorbidities that were more prevalent in the SCI group (2.9 ± 1.5 mean total number of comorbidities vs 0.9 ± 1.6 in no SCI patients; $P < .0001$).

Table II further details differences in SCI vs no SCI patients, including history of open or endovascular aortic surgery, procedural indications, and operative details. Notably, previous aortic surgery was *not* more frequently associated with development of SCI ($P = .23$), and acute dissection was the only indication more likely associated with SCI (odds ratio, 2.6; 95% confidence interval [CI], 1.3-5.2; $P = .007$). Overall, 261 patients (43.6%) received a preoperative spinal drain, and no difference in the rate of preoperative spinal drainage was noted between patients experiencing SCI (21 of 57 [36.8%]) vs no SCI (240 of 550 [43.6%]; $P = .52$). No differences were detected when comparing patients with and without SCI regarding procedural urgency, proximal aortic coverage zones, open or endovascular conduit use, prophylactic spinal drain use, or frequency of subclavian revascularization. However, there was a significant difference in the mean number of aortic stent grafts used in the repair of patients with SCI (2.1 ± 1.1 in no SCI vs 2.4 ± 0.93 in SCI; $P = .0007$).

Procedural outcome data and length of stay are highlighted in Table III. As expected, SCI patients had significantly greater length of stay (15.5 ± 12.3 vs 8.4 ± 11.5 days; $P < .0001$). SCI patients also more commonly had pulmonary complications (odds ratio, 3.2; 95% CI, 1.5-6.7; $P = .002$) and experienced a greater average number of total complications (exclusive of SCI, 0.7 ± 1 vs 0.4 ± .8; $P = .04$), even when controlling for age, sex, and procedural urgency. Despite differences in complication rates, in-hospital mortality was similar between the two groups ($P = .49$).

Functional outcomes. Table IV reports outcomes of the 57 patients with SCI and depicts condition on discharge, disposition, and FI during follow-up. One-third of patients were discharged home, and the remaining 33 (57.9%) were transferred to an inpatient facility. Delayed SCI was documented in 40 patients, with 25 of these (62.5%) reporting some degree of neurologic recovery and independently ambulating or ambulating with minimal assistance (eg, cane) at hospital discharge. Function status improved after discharge in three additional patients in the delayed SCI subgroup (28 of 40 [70%] with FI, in total).

Table II. History of aortic surgery, indication for procedure, and procedural characteristics[a]

Variables[b]	*No SCI (n = 550)*	*SCI (n = 57)*	P
Previous AAA repair	99 (18)	14 (24.6)	.23
Indication			
Thoracic aortic aneurysm	248 (45.4)	25 (43.9)	.16
Aortic dissection			
Chronic type B	74 (13.6)	9 (15.8)	.16
Acute	67 (12.3)	13 (22.8)	.007
Penetrating aortic ulcer	62 (11.4)	8 (14)	.93
Traumatic aortic transection	40 (7.3)	0	.97
Postsurgical	24 (4.4)	1 (1.8)	.39
Other	24 (4.4)	0	.96
TAAA	7 (1.3)	1 (1.8)	.79
Procedural variables			
Urgency			
Elective	362 (65.9)	32 (56.1)	
Urgent (symptomatic)	91 (16.6)	14 (24.6)	
Emergent (rupture)	96 (17.5)	11 (19.3)	.25
Proximal coverage zone			
0	42 (7.8)	4 (7)	
1	15 (2.8)	0	
2	217 (40.5)	30 (52.6)	
3	134 (25)	12 (21.1)	
4	128 (23.9)	11 (19.3)	.37
Stents	2.1 ± 1.1	2.4 ± 0.93	.0007
Open conduit	128 (23.9)	17 (29.8)	.28
Carotid-subclavian bypass	74 (13.5)	10 (17.5)	.39
Preoperative spinal drain	240 (43.6)	21 (36.8)	.324

AAA, Abdominal aortic aneurysm; *TAAA*, thoracoabdominal aortic aneurysm; *TEVAR*, thoracic endovascular aortic repair.
[a]χ^2 test or Fisher exact test when appropriate.
[b]Categoric data are shown as number (%) and continuous data as mean ± standard deviation.

Table III. Complications, length of stay, and mortality after thoracic endovascular aortic repair (TEVAR) with and without spinal cord ischemia (*SCI*)[a]

Outcomes[b]	*No SCI (n = 550)*	*SCI (n = 57)*	P
Length of stay, days	8.4 ± 11.5	15.5 ± 12.3	<.0001
In-hospital death	35 (6.4)	5 (8.8)	.49
Complication			
Other[c]	60 (10.9)	5 (8.8)	.62
Pulmonary	36 (6.6)	11 (19.3)	.002
Renal	27 (4.9)	6 (10.5)	.11
Ischemic	24 (4.4)	2 (3.5)	>.99
Bleeding	22 (4.0)	4 (7.0)	.29
Cardiac	19 (3.5)	3 (5.3)	.45
Gastrointestinal	14 (2.6)	2 (3.5)	.66
Wound	7 (1.3)	2 (3.5)	.20
Total complications (95% CI)	0.4 ± 0.81 (0.3-0.5)	0.65 ± 1 (0.4-0.9)	.04

CI, Confidence interval.
[a]χ^2 test or Fisher exact test when indicated.
[b]Categoric data are shown as number (%) and continuous data as mean ± standard deviation, or as indicated.
[c]Includes mycotic, endoleak, and device failure complications of the endograft.

Table IV. Disposition and outcomes of patients with spinal cord ischemia

Outcome	*No. (%) (n = 57)*[a]
Disposition	
Home	19 (33.3)
Inpatient facility	33 (57.9)
In-hospital death	5 (8.8)
Condition on discharge	
Ambulating independently	7 (12.3)
Ambulating with assistance[b]	20 (35.1)
Nonambulatory	9 (15.8)
Bedridden	10 (17.5)
Unknown	6 (10.5)
Best postoperative ambulation status	
Ambulating independently	15 (26.3)
Ambulating with assistance[b]	16 (28.1)
Nonambulatory	9 (15.8)
Bedridden	10 (17.5)
Unknown	2 (3.5)
Return to pre-op baseline functional status	
Yes	13 (22.8)
No	21 (36.8)
Unknown	18 (31.6)
Any improvement in-hospital	
Yes	23 (40.3)
No	26 (45.6)
Unknown	8 (14)
Any additional improvement after discharge	
Yes	26 (45.6)
No	8 (14)
Unknown	18 (31.6)
Assistance with activities of daily living	
Yes	13 (22.8)
No	17 (29.8)
Unknown	22 (38.6)

[a]Fifty-one patients had complete hospital records documenting ambulatory status; 40 delayed and 12 immediate patients with spinal cord ischemia.
[b]Cane or walker.

This is in sharp contrast to the 12 patients with immediate onset of SCI, where only 25% had documented neurologic recovery at time of hospital discharge ($P = .04$), and only one additional patient had any FI after discharge.

Owing to late deaths and inability to complete follow-up in some patients (eg, move or no contact information), comprehensive postdischarge data (including patient questionnaires) on FI were available for only 34 patients (60%). In total, 28 of these patients (82%) reported some degree of additional FI after hospital discharge, but only 13 (38%) experienced complete return to preoperative baseline functional status. At the last follow-up, 15 of 34 patients (44%) had achieved independent ambulation. The remaining six patients reported no improvement in their lower extremity deficit after discharge.

An analysis was performed to determine the relationship of the patient's functional status at time of hospital discharge to neurologic recovery as an outpatient. Not surprisingly, patient ambulatory ability at discharge strongly correlated with his or her ability to gain measurable improvement in ambulation status during the follow-up interval (Spearman $r = 0.89$; $P < .0001$; Fig 1). Specifically,

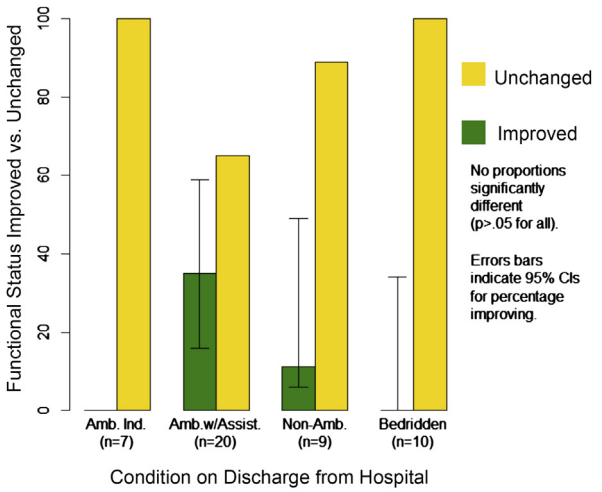


Fig 1. Ambulation status improvement is demonstrated *after* hospital discharge based on the ambulation status determined *at* discharge. There were no significant differences between the groups but were notable trends toward less likelihood for improvement with various degrees of reduced functional status at discharge. No patients reported a decline in function after discharge, and no patients with complete paralysis reported *any* functional improvement (FI) after discharge. *CI,* Confidence interval.

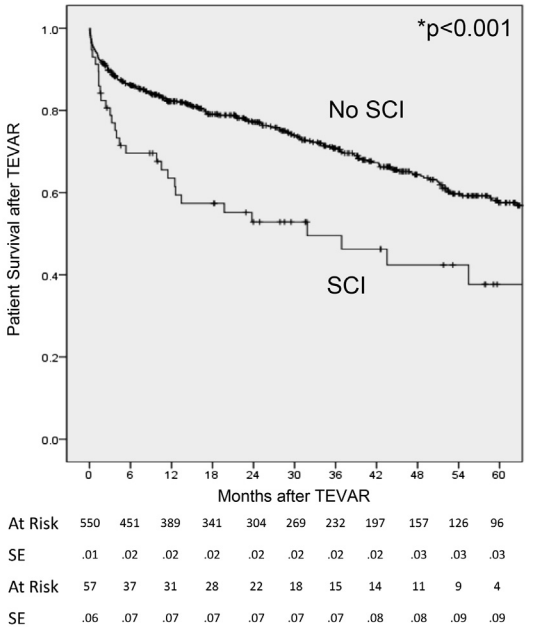


Fig 2. Demonstrates a significant difference in survival between patients with spinal cord ischemia (*SCI*) vs those without ($P < .001$) after thoracic endovascular aortic repair (*TEVAR*). *SE,* Standard error.

if patients only needed a cane or walker at discharge, a higher proportion reported subsequent improvement in ambulatory status after hospitalization compared with patients who were bedridden at discharge ($P = .07$). Of note, no patient who was bedridden and unable to ambulate at discharge from the hospital achieved *any* neurologic recovery after leaving the hospital.

CSF drainage. Among the patients who developed SCI, a spinal drain was placed in 54 (94.7%) either preoperatively or postoperatively. Three patients did not receive a drain due to coagulopathy or hemodynamic instability, or both. Preoperative spinal drains were placed in 23 patients (40.4%); of these, 15 had data regarding long-term functional outcome after discharge, and 12 of these patients (80%) experienced some element of neurologic recovery. Within the postoperative cohort of 31 patients (54.4%) who received drain placement cohort (19 with outpatient follow-up data), 73.7% experienced some degree of FI, which was not different than the preoperative drain group ($P > .99$). Further, timing of spinal drain placement was not differentially associated with survival, ambulation status on discharge, best postoperative ambulation status, return to preoperative baseline function, or subjective FI on long-term follow-up.

Survival. Long-term survival was estimated using Kaplan-Meier life-table methods (Fig 2). Estimated mean (± standard error) survival time for all SCI patients was 37.2 ± 4.5 months, which was significantly less than the 71.6 ± 3.9 months observed in non-SCI patients ($P < .0006$). Notably, the significant survival difference remained when controlling for the increased age of the SCI cohort (hazard ratio, 1.7; 95% CI, 1.2-2.6; $P = .007$). Overall survival of patients with any SCI was 64% at 12 months compared with 82% in the non-SCI group (log-rank $P < .001$).

Survival times were compared between patients who reported some degree of FI and those who had no recovery, with survival being dramatically better for those with FI. The mean survival was 53.9 ± 5.9 months for those with FI and 9.6 ± 3.6 months for those without (hazard ratio, 7.6; 95% CI, 2.2-25.8; $P = .001$; Fig 3). The long-term survival of individuals experiencing any measurable improvement was significantly better than those who did not, even when controlling for differences in comorbidities and demographics between the two subgroups. Strikingly, survival of SCI patients without FI was only 25% at 12 months compared with 92% in those who reported some degree of neurologic recovery (log-rank, $P < .0001$). Interestingly, there was a stepwise increase in survival as the degree of neurologic recovery increased.

Finally, to determine the effect of timing of neurologic injury on long-term survival, a comparison between immediate-onset and delayed-onset SCI is depicted in Fig 4, *A*. A significant difference in all-cause mortality (log-rank, $P < .0001$) was noted between patients who experienced immediate onset of SCI and those who developed delayed SCI or with no evidence of neurologic injury.

Despite the detrimental effect of SCI on survival, patients who returned to baseline function had a further trend toward improved survival vs those who did not return to baseline, and their survival approximates that of patients without SCI (Fig 4, *B*).

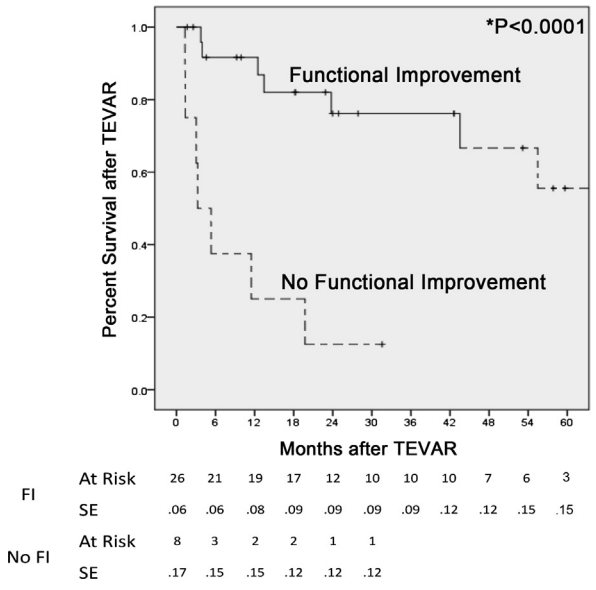


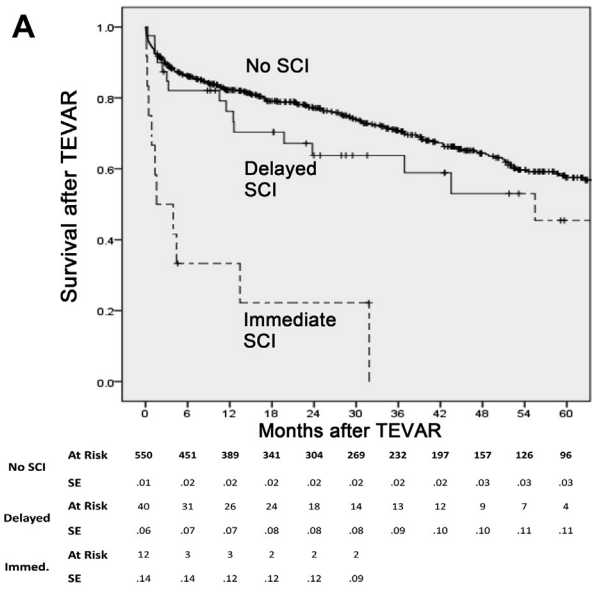
Fig 3. A significant difference in survival ($P < .0001$) is present depending on whether the patients demonstrated any functional improvement (*FI*) after suffering spinal cord ischemia (*SCI*). The 1-year survival was 92% for patients with FI and 25% for those without any neurologic recovery. *SE,* Standard error; *TEVAR,* thoracic endovascular aortic repair.

DISCUSSION

This study analyzed a large cohort of TEVAR patients with and without SCI and further compared patients according to the timing of SCI onset as well as the degree of FI attained after suffering this complication. Consistent with previous reports, SCI patients were noted to have poorer long-term survival than those without this complication. Interestingly, the timing of SCI and trajectory of FI were important indicators of the overall prognosis.

SCI is a well-known complication of TEVAR,[1,17,18] and despite advancements in risk stratification and management, the incidence of this complication still ranges between 2% and 15%.[1,3,4,19-21] Indeed, in our own practice, despite a heightened awareness, liberal CSF drainage, and the judicious use of adjuncts, such as subclavian revascularization and intensive monitoring, the rate of SCI has been consistent over time at 9%, with a permanent deficit rate of 4.3%. Although lower than the usual reported rate of this complication in open aortic repair, this is certainly not insignificant given the devastating impact of SCI.

A variety of risk factors have been associated with SCI after TEVAR, and although this was not the focus of this analysis, many of those associations have been corroborated in this analysis. Many previously identified risk factors have been reported, including advanced age, male gender, a history of renal insufficiency, presence (or previous repair) of an abdominal aneurysm, acute dissection, lumbar/hypogastric artery patency, urgency of TEVAR, aortic coverage length, and left subclavian artery coverage.[1,3,10,15,18,21,22] Notably, a history of open or endovascular aortic repair was *not* more frequently associated with the SCI group ($P = .23$), although an association was found in a previous analysis from our group of repaired *or unrepaired* AAA with smaller patient numbers.[15]



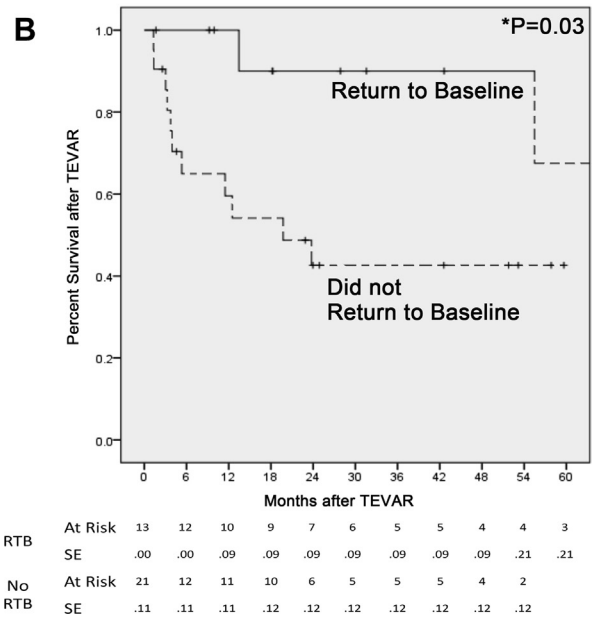


Fig 4. A, Differential survival is noted between patients with return to preoperative neurologic baseline status vs those without return to baseline if spinal cord ischemia (*SCI*) developed ($P = .03$) after thoracic endovascular aortic repair (*TEVAR*). **B,** Differential survival is shown between those patients without SCI vs those with immediate or delayed SCI. Delayed SCI patients can anticipate similar long-term life expectancy compared with patients without SCI. *RTB,* Return to baseline; *SE,* standard error.

Once SCI was recognized, multiple adjuncts were used in our management algorithm, including spinal drainage,

vasopressor-induced hypertension, and volume resuscitation. Unfortunately, despite aggressive use of spinal drainage and the positive effect on short-term neurologic recovery in some patients, the *timing* of drain placement (preoperative vs postoperative) did not appear to affect survival or functional recovery. Although we strongly support the use of spinal drains for the management of SCI due to the clear evidence that this can improve neurologic outcomes, it is not clear what benefit a preoperative drain has over a postoperatively placed drain. In addition, using this analysis, we are not able to determine whether any of the available preventative maneuvers affect the long-term outcomes of SCI.

Perhaps the most interesting findings from this study include the prognostic importance of timing and rate of recovery of SCI after TEVAR. Most patients who develop SCI after TEVAR have an interval of normal neurologic function, followed by neurologic deficit (eg, delayed presentation),[21,23] and this was indeed the case in our series, where 40 SCI patients (70.2%) presented in this manner. Of the delayed SCI patients, 62.5% experienced at least some neurologic recovery and were independently ambulating or ambulating with minimal assistance (eg, cane) at the time of discharge. This contrasts sharply with the 12 patients with immediate onset of SCI, where only 25% ($P = .04$) had any documented improvement at discharge. Further, although occurrence of any SCI is a marker of poor long-term survival, this analysis suggests that patients experiencing rapid return of function can anticipate similar life expectancy compared with patients without SCI (53.9 $\pm$ 5.9 vs 71.6 $\pm$ 3.7 months; $P = .41$) and that those with full return to their baseline function, not surprisingly, fare the best. Notably, whether SCI was delayed or immediate in onset, only 25% of patients without FI were alive at 1 year after TEVAR, compared with 92% of those with FI.

Interestingly, despite the higher overall rate of complications in patients with SCI, the in-hospital mortality rate was not different between patients with and without SCI. Therefore, most of the deaths occurred after hospital discharge. Unfortunately, we do not know the cause of death for most of our patients and can only speculate about the explanation for poorer prognosis in SCI patients. As demonstrated in this analysis, SCI rarely occurs in isolation, and it is difficult to account for the confounding effect of other complications on mortality. In addition, there are many known risks to the immobility caused by spinal cord injury that may affect long-term outcome, including venous thromboembolism/pulmonary embolus, decubitus ulceration, pneumonia, urinary tract infections, and chronic institutionalization.[24] The pulmonary morbidity associated with spinal cord injury is also well known,[25] and indeed, our analysis demonstrated a higher rate of pulmonary complications in our SCI patients ($P = .002$).

This analysis has several important limitations, including a heterogeneous patient population that was clinically diagnosed with SCI, many times without supportive imaging to confirm SCI. The methodology with which we identify SCI lends itself to high sensitivity and potentially low specificity and perhaps accounts for the elevated documented rate of SCI in the series. However, all indications and all pathologies were included in this analysis, which further confounds the observed rate of SCI and the potential trajectory of recovery. In addition, missing data elements in the clinical follow-up for the SCI cohort may introduce the possibility of bias that we are unable to account for in long-term follow-up. Unfortunately, there is no prevailing comprehensive definition of SCI after TEVAR, and we believe that our method is more likely to overestimate rather than underestimate the occurrence of this complication. Owing to inconsistent documentation in medical records, no standardized metric for stratifying the severity of SCI was possible in this analysis. Further, the functional outcome assessment tool was based on a nonvalidated patient questionnaire that was administered retrospectively. Prospective analysis of a larger cohort of TEVAR patients at high risk of SCI with standardized quality of life and physical therapy regimens would likely yield a more definitive assessment about the effect of timing and severity on the potential rate of recovery after hospital discharge.

CONCLUSIONS

SCI continues to be a challenging complication of TEVAR. Although patients with this complication have significantly reduced long-term survival, the subset of patients with delayed-onset SCI with in-hospital recovery can anticipate similar life expectancy compared with TEVAR patients without SCI. Conversely, those patients with immediate-onset SCI and no improvement in functional status before discharge have a dismal prognosis. The findings of this study are important clinical factors that can be used in planning of postoperative rehabilitation and patient/family discussions, as well as being taken into account in preoperative decision making when considering patients with high-risk for development of SCI.

AUTHOR CONTRIBUTIONS

Conception and design: SS, AB
Analysis and interpretation: SS, KD
Data collection: KD, SS
Writing the article: SS, KD, AB
Critical revision of the article: KD, SS, RF, MH, PH, TB, TH, AB
Final approval of the article: KD, SS, RF, MH, PH, TB, TH, AB
Statistical analysis: KD
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Overall responsibility: SS
KD and SS participated equally and share first authorship.

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APPENDIX (online only).

1. **Where were you discharged to and how long were you there? (ie, home, nursing home, rehab facility, Long-term nursing facility, Short-term nursing facility)**
   - ☐ Home
   - ☐ Nursing home/Retirement home
   - ☐ Rehabilitation facility
   - ☐ Long-term nursing facility
   - ☐ Short-term nursing facility
   - ☐ Other _____
   - ☐ Does not wish to answer

   Comments:
   _____
   _____
   _____
   _____

2. **Are you able to walk independently?**
   - ☐ Yes
   - ☐ No
   - ☐ Does not wish to answer

   Comments:
   _____
   _____
   _____
   _____

3. **Do you currently have any physical limitations (ie, cannot perform strenuous activities but can perform light house duties or office work)?**
   - ☐ Yes
   - ☐ No
   - ☐ Does not wish to answer

   Comments:
   _____
   _____
   _____
   _____

4. **Are your current physical abilities different from the time you were discharged from the hospital and/or rehab?**
   - ☐ Yes
     - ► **If Yes: Have your current physical abilities improved or worsened?**
       - ○ Improved
       - ○ Worsened
       - ○ Does not wish to answer
   - ☐ No, Unchanged
   - ☐ Does not wish to answer

   Comments:
   _____
   _____
   _____
   _____

5. **After your discharge from the hospital and/or rehab, how long did it take for you recover to your current state of health?**

   Recovery time: _____

   Comments:
   _____
   _____
   _____
   _____

6. **Do you require any assistance with walking? (ie, cane, walker, etc)**
   - ☐ Yes
   - ☐ No
   - ☐ Does not wish to answer

   Comments:
   _____
   _____
   _____
   _____

7. **If unable to walk, are you able to use a wheelchair?**
   - ☐ Yes
   - ☐ No
   - ☐ Not Applicable
   - ☐ Does not wish to answer

   Comments:
   _____
   _____
   _____
   _____

8. **If unable to walk, are you confined to bed more than 50% of the day?**
   - ☐ Yes
   - ☐ No
   - ☐ Not Applicable
   - ☐ Does not wish to answer

   Comments:
   _____
   _____
   _____
   _____

9. **Can you care for yourself independently with regard to washing up, getting dressed or preparing meals?**
   - ☐ Yes
   - ☐ No
   - ☐ Does not wish to answer

   Comments:
   _____
   _____
   _____
   _____

10. Have you undergone any additional procedures or surgeries since your aortic stenting here at Shands?

☐ Yes

► **If Yes: What was the procedure and when/where was it performed? [List response below, under Comments]**

☐ No

☐ Does not wish to answer

Comments:

_____

_____

_____