Incidence, prevention, and management in spinal cord protection during TEVAR

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Until recently, patients with aneurysms of the thoracic and thoracoabdominal aorta had only one treatment option: open surgical repair. For those patients who could not tolerate an operation because of medical comorbidities, continued aneurysm enlargement and eventual rupture was a constant, yet unpredictable threat to their lives. Several studies have documented improved survival rates in those patients treated surgically.[1,2]

Despite advances in surgical reconstruction and organ protection, the mortality rate for elective surgical repair of thoracoabdominal aortic aneurysm is 4% to 21%; advanced age, renal failure, and postoperative paraplegia are the most important risk factors predicting death at 30 days. In addition, for those patients aged ≥79 with an emergency presentation, history of diabetes or congestive heart failure, 30-day mortality is 50%. For aneurysms isolated to the distal thoracic aorta, the risk of paraplegia is 0% to 4% and is dependent on the extent of aorta replaced.[3] A substantial number of patients surviving the operation have prolonged, complicated courses secondary to renal, cardiac, and pulmonary dysfunction. Perhaps the most devastating complication of these complex procedures for patients and their surgeon is paraplegia.[4]

A myriad of techniques have been developed to protect the spinal cord during open surgical repair of the thoracic and thoracoabdominal aorta, including clamp-and-sew, distal aortic and visceral perfusion, complete cardiopulmonary bypass, profound hypothermia and circulatory arrest, direct spinal cord cooling, cerebrospinal fluid (CSF) drainage, and the use of pharmacologic adjuncts; some of these principles may be useful in preventing paraplegia at the time of endovascular repair. When the thoracic aorta is cross-clamped, spinal arterial perfusion pressure decreases while CSF pressure increases, resulting in decreased perfusion pressure.

In an important study of 1004 patients by Safi et al,[5] immediate postoperative neurologic deficit occurred in 6.8% of patients operated on without the adjuncts of CSF drainage and distal aortic perfusion, whereas only 2.4% of those operated on with adjuncts suffered this devastating complication. These authors also stressed the importance of reimplantation of intercostal arteries, especially in the vulnerable area between T9 and T12, which frequently gives rise to the anterior spinal artery. Relative hypertension in the immediate postoperative period (maintaining mean arterial pressure between 90 and 100 mm Hg) is also advocated. Other risk factors for paraplegia in their series included extent of aneurysmal disease, advanced age, emergency presentation, preoperative renal dysfunction, active smoking, and cerebrovascular disease. Delayed paraplegia has been noted as late as 2 weeks after surgery, and has been successfully treated by placement of a spinal drain.[6]

PARAPLEGIA AND PARAPARESIS IN THE ERA OF THORACIC ENDOVASCULAR AUERYSM REPAIR

Substantial controversy exists with respect to elective repair of abdominal aortic aneurysms with endografts in good-risk patients due to the excellent perioperative mortality and long-term durability of open surgical repair.[7] The promise of endovascular repair of thoracic aortic aneurysms (TEVAR), however, is one of decreased perioperative mortality and morbidity, especially with respect to paraplegia, permanent renal failure and stroke, in a population of patients who heretofore did not have an alternative to open surgical therapy or expectant treatment. Although there is a paucity of well-controlled data on which to base definitive statements and clinical practice, a review of case series within the available literature allows for some general assumptions to be made.

In one of the first reported series by Dake et al[8] in 1994, 13 patients were treated with homemade endovascular stent grafts during a 24-month period. All grafts were successfully deployed, no patients died, and no patients suffered stroke, paraplegia, or distal embolization; these results generated incredible enthusiasm for this novel procedure.

Subsequent reports in larger groups of patients were more sobering, however. The European Collaborators on Stent-Graft Techniques for Aortic Aneurysm Repair (EUROSTAR) and United Kingdom registries, reported in 2004 by Leurs et al,[9] examined 443 patients who had undergone endovascular repair of a variety of pathologies involving the thoracic aorta, including degenerative aneurysms, aortic dissections, anastomotic aneurysms, and traumatic ruptures. In the entire cohort, 11 instances of paraplegia or paresis occurred, for an incidence of 2.5%. Ten of

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the 11 patients with this particular complication were in the group that had an atherosclerotic aneurysm. One patient in the aortic dissection group and no patients in the false aneurysm or traumatic rupture groups were affected. Given the heterogeneous nature of the patient population and practice variability across the 62 participating centers, there are no reported data regarding the use of spinal drains.

Chiesa et al[10] reported 103 patients treated electively for thoracic aortic lesions, 88 (85%) of which were atherosclerotic aneurysms. Preoperative CSF drainage was used in seven patients (based on data extrapolated from their experience with open surgical repair), including those with aneurysms involving critical intercostal arteries at T8 to T12, those requiring coverage of a long segment of the thoracic aorta (>20 cm), and in patients with prior repair of an abdominal aortic aneurysm. Four patients (4%) had delayed neurologic deficit that completely resolved after the institution of CSF drainage, systemic steroid therapy, and pharmacologic support of blood pressure. Univariate analysis identified only a perioperative mean arterial blood pressure of <70 mm Hg as a significant predictor of spinal cord ischemia ($P < .0001$).

Greenberg et al[11] prospectively evaluated their results in 100 patients treated with investigational Zenith devices (Cook, Bloomington, Ind) at Cleveland Clinic. Of note, a spinal drain was placed in 84% of their patients preoperatively. Acute spinal cord ischemia (SCI) was noted in 7.4% of 81 patients treated for atherosclerotic aneurysms, although only two of these six patients had a permanent deficit. No paraplegia or paraparesis developed in patients with aneurysm or other indications who were treated for chronic dissection.

Finally, Makaroun et al[12] reported results from a multicenter trial of the Gore TAG thoracic endograft (W. L. Gore and Associates, Flagstaff, Ariz) in which 139 patients underwent successful implantation of the device. Spinal drains were not routinely placed before the procedures. Temporary or permanent spinal cord deficit developed in four patients (3%). Paraplegia was found in one patient immediately after the procedure that did not resolve after placement of a spinal drain. In a second patient, symptoms developed 6 hours after surgery associated with an episode of hypotension. Symptoms improved—but did not abate entirely—after stabilization of blood pressure and placement of a spinal drain. Symptoms in the third and fourth patients developed on the first postoperative day, and both were ambulating at the time of their discharge.

Mortality and the incidence of paraplegia/paraparesis after thoracic aortic endografting, compiled from the peer reviewed literature (and reporting at least 20 cases) are listed in Table I. The weighted average mortality at 30 days was 6.6% in this complex patient group (range, 0% to 19%). Similarly, there was a broad range in the incidence of SCI, with an average of 3.9% in 5349 patients (range, 0% to 13.3%).

A review of these citations suggests that there is no consensus regarding the use of CSF drains in patients undergoing TEVAR; some centers use spinal drains selec-

Table I. Mortality and incidence of paraplegia/paraparesis after endovascular repair of thoracic aortic pathology (1999-2009)

Author, year	*No.*	*30-day mortality No. (%)*	*Paraplegia/ paraparesis No. (%)*
Mitchell, 1999	103	9 (9)	3 (3)
Won, 2001	23	0	0
Taylor, 2001	37	3 (8)	0
White, 2001	26	1 (4)	1 (4)
Gravereaux, 2001	53	0	3 (5.6)
Cambria, 2002	28	1 (3.5)	0
Thompson, 2002	46	2 (4.3)	0
Criado, 2002	47	1 (2.1)[a]	0
Lepore, 2002	43	3 (7)	3 (6.9)
Usui, 2002	24	0	3 (12.5)
Ellozy, 2003	84	5 (6)	3 (3.6)
Bell, 2003	67	5 (7.4)	3 (4.5)
Chabbert, 2003	47	4 (8.5)	0
Krohg-Sorensen, 2003	20	2 (10)	0
Lambrechts, 2003	26	0	0
Schoder, 2003	28	0	0
Matravers, 2003	24	2 (7)	0
Lamme, 2003	21	0	0
Orend, 2003	74	7 (9.5)	2 (2.7)
Neuhauser, 2004	31	6 (19)	2 (6)
Bortone, 2004	132	4 (4)	0
Brandt, 2004	22	1 (4.5)	1 (4.5)
Leurs, 2004	443	41 (9)	11 (2.5)
Hansen, 2004	59	10 (16.9)	1 (1.7)
Makaroun, 2005	139	2 (1.5)	4 (3)
Chiesa, 2005	103	1 (1)	4 (4)
Greenberg, 2005	100	17 (17)	6 (6)
Melissano, 2005	45	0	1 (2)
Chiesa, 2005	103	2 (2)	4 (4)
Iyer, 2006	70	1 (2.9)	0 (0)
Morales, 2007	186	15 (8)	7 (3.7)
Buth, 2007	606	60 (9.9)	15 (2.5)
Khoynezhad, 2007	153	15 (9.8)	8 (5.2)
Kawaharada, 2007	149	3 (2)	3 (2)
Sandroussi, 2007	65	3 (4.6)	2 (3)
Qu, 2008	87	8 (9.2)	3 (3)
Amabile, 2008	67	6 (8.9)	5 (7.5)
Feezor, 2008	326	24 (7.4)	33 (10)
Misfeld, 2008	56	3 (5.4)	2 (3.6)
Pearce, 2008	127	17 (13.3)	17 (13.3)
Hnath, 2008	121	Not reported	5 (4.1)
Siegenthaler, 2008	21	1 (4.8)	1 (4.8)
Matsumura, 2008	160	3 (1.9)	9 (5.6)
Fairman, 2008	195	4 (2.1)	17 (8.7)
Kim, 2009	72	0 (0)	0 (0)
Preventza, 2009	346	Not reported	14 (4)
Nakamura, 2009	36	0 (0)	1 (2.8)
Kische, 2009	180	9 (5)	5 (2.8)
Nienaber, 2009	72	2 (2.9)	2 (2.9)
Chaikof, 2009	197	12 (6)	4 (2)
Cambria, 2009	59[b]	7 (11.9)	1 (1.7)
Total	5349	322 (6.6)[c]	209 (3.9)

[a]An additional patient died of aortic rupture after 30 days.
[b]All 59 patients presented with acute aortic pathology.
[c]Two studies with mortality not recorded were not included in overall mortality calculation.

Table II. Indications for the use of cerebrospinal drains in patients requiring thoracic endografts

1. Anticipated endograft coverage of T9 to T12 (location of anterior spinal artery)
2. Coverage of a long segment of thoracic aorta (>20 cm)
3. Compromised collateral pathways; for example, previous infrarenal aortic aneurysm repair, occluded hypogastric arteries, coverage of the left subclavian artery without revascularization
4. Symptomatic spinal ischemia in a patient who did not have a drain placed preoperatively
5. Extensive aneurysmal disease

tively in high-risk anatomic situations, while others use them only after patients become symptomatic in the postoperative period. The use of this important adjunct must be individualized and must also be based on its safety and ease of use in the individual institution. Placement of a spinal drain is not entirely benign, but with well-trained personnel, placement and management of a spinal drain can be performed with minimal morbidity and mortality.

In a recent review by Estera et al[13] spanning 15 years and 1107 patients, CSF drain placement for open thoracoabdominal surgery showed a technical success rate of 99.8% and a drain-related complication rate of 1.5%. Subdural hematoma developed in five patients (0.4%); however, since implementing a limited CSF drainage protocol, this complication has not developed in any patients.

Certain clinical situations may prevent the placement of a spinal drain, such as patients with symptomatic or ruptured thoracic aortic pathology or patients with prior lumbar spine surgery. Indications for placing a spinal drain, based on our current practice, are listed in Table II. The drain remains in place for 24 hours in an intensive care unit setting, and is then removed. While in place, it is allowed to drain to maintain a CSF pressure of 10 mm Hg. Table III outlines our institution's protocol for managing CSF drains after TEVAR.

RISK FACTORS FOR DEVELOPING SCI AFTER TEVAR

Numerous groups have tried to identify patient or procedural variables that may increase the risk of SCI during TEVAR. Preventza et al[14] reviewed 346 consecutive TEVAR procedures spanning 8 years. TEVAR was performed for atherosclerotic aneurysms in 45.9%, acute and chronic dissections in 31.5%, penetrating ulcers in 8.9%, and miscellaneous lesions in 13.6%. Fourteen patients (4%) developed paraparesis (1.7%) or paraplegia (2.3%). CSF drainage was used in seven of eight paraplegic patients. Paraplegia after TEVAR was associated with female gender, long segment coverage, and aneurysmal disease of the thoracic aorta.

Khoynezhad et al[15] reviewed 153 patients who underwent TEVAR for various pathologies. This cohort had an overall paraplegia rate of 5.2% (8 patients), with permanent deficit in four patients. On univariate analysis, aneurysmal pathology, use of an iliac conduit, and coverage of a hypogastric artery were highly associated with a spinal cord injury after TEVAR.

From the EUROSTAR registry, Buth et al[16] found an overall paraplegia or paraparesis rate of 2.5% in 606 patients treated with TEVAR for various thoracic aortic pathologies. Their multivariate regression analysis showed four factors were associated with a higher incidence of SCI: left subclavian artery coverage without revascularization, renal failure, concomitant open abdominal aortic surgery, and use of three or more stent grafts to treat the lesion.

Table III. Minneapolis Heart Institute at Abbott Northwestern Hospital: Spinal cord pressure monitoring and cerebrospinal fluid drainage protocol after thoracic aortic procedures

Vital signs and monitoring parameters
- Every hour for 8 hours then Q 2 hours
- If the head of bed (HOB) is >15 degrees assess neurologic status prior to elevating the HOB and Q 15 minutes while the HOB is elevated
- Spinal cord assessment should include hip flexion, feet dorsi/plantarflexion
- Spinal cord pressure (SCP) monitoring
  - Monitor SCP and spinal cord perfusion pressure Q hourly
  - Maintain SCP ≤10 mm Hg. If SCP elevated, place HOB flat and ensure drain is patent
  - Maintain spinal cord perfusion pressure >60 mm Hg and mean arterial pressure (MAP) >80 mm Hg
  - Use Neo-Synephrine IV infusion as necessary

Activity
- HOB 1 to 15 degrees, OK to raise HOB for meals
- Do not change HOB position without consultation with vascular surgery

Nursing
- No anticoagulation while drain is in place
- Continuous CSF draining
  - If CSF output >20 mL/h × 2 hours or >150 mL over 8 hours, clamp drain and notify neurointerventional radiology
  - If patient is intubated, clamp drain during positioning or suctioning
- Notify vascular surgery
  - Changes in neurological function
  - Patient complains of a headache, clamp the drain and notify surgeon
  - CSF output >20 mL/h × 2 hours or >150 mL over 8 hours, clamp drain and notify surgeon
  - SCP >10 mm HG or SCPP <60 mm Hg for more than 10 minutes
  - MAP <80 mm Hg
  - CSF leak at insertion site
  - New blood in the lines
  - New signs of meningeal irritation
  - Temperature >38.5° C
  - INR >1.5
  - Hemoglobin <10 mg/dL
  - Platelet count <100,000
- Pneumatic compression device

Prophylaxis antibiotics until the drain is out
- Ancef or vancomycin IV

Laboratory
- INR 4 hours after drain placement and daily until drain is out
- Hgb and platelet count 4 hours after drain placement and daily

Finally, Feezor et al[17] reviewed their results of TEVAR in 326 patients to determine if the extent of coverage of the aorta was a significant risk factor. SCI developed in 33 patients (10%), and these patients tended to be older (72.7 ± 10.6 vs 64.7 ± 15.8 years) and had longer intraoperative procedure times. An analyses of the amount of aorta covered found that patients who developed SCI had a greater absolute length (260 ± 40.9 vs 185.8 ± 81.6 mm) as well as proportionate length (88.8% ± 12.1% vs 67.6% ± 24%) of thoracic aorta covered compared with patients without an SCI after TEVAR. Conversely, the mean length of uncovered aorta proximal to the celiac artery was much less in patients who developed SCI compared with those that did not (17.3 ± 21.8 vs 63.1 ± 62.9 mm). A similar finding was seen in a study by Amabile et al[18] examining 67 patients who underwent TEVAR from 2000 to 2005. SCI developed in five (7.5%) patients after TEVAR. Multivariate logistic regression analysis showed that >205 mm of aortic coverage with a stent graft was the only significant predictor for SCI.

In a recent systematic review and meta-analysis by Cheng et al[19] comparing TEVAR with open surgery for descending thoracic aortic disease, 42 studies with 5888 patients were reviewed. The overall incidence of SCI was 3.4% in the TEVAR group and 8.2% in the open surgery group, which was highly statistically significant. Interestingly, the odds ratio for paraplegia did not differ by the type of study (prospective vs retrospective design, historic vs concurrent control, or consecutive vs nonconsecutive patient recruitment). In addition, their meta-regression analysis did not show any difference in the incidence of SCI by year of study or year of patient recruitment, suggesting that the overall incidence of SCI after TEVAR has not changed significantly with time.

The relationship between coverage of the left subclavian artery and spinal cord injury appears to be significant. In a recent systematic review and meta-analysis by Rizvi et al[20] of 51 manuscripts, only 8 described left subclavian artery coverage and SCI (See the article by Drs Matsumura and Rizvi, Fig 3). This meta-analysis found SCI had developed in 27 of 673 patients (4%). The authors documented that left subclavian artery coverage without revascularization during TEVAR resulted in a nonsignificant increase in risk of SCI compared with those who underwent left subclavian artery revascularization before TEVAR. Analyzing the 15 patients who developed paraplegia/paraparesis in the EUROSTAR Registry, they found that the incidence of left subclavian artery coverage without revascularization was 40% in the patients who developed SCI compared with 19% in those patients who did not develop SCI, which was significantly higher (odds ratio, 2.82; 95% confidence interval, 1.00-8.08).[16]

STRATEGIES TO REDUCE SCI AFTER TEVAR

Adjuncts to reduce the incidence of SCI after open thoracoabdominal aortic surgery have been well described. A similar approach has been used in patients undergoing TEVAR who are at high risk for SCI. Cheung et al[21] reviewed their experience with selective lumbar CSF drainage and somatosensory evoked-potential monitoring in a subset of patients they determined were at high risk (prior AAA repair or significant aneurysm extent) for SCI after TEVAR. Paraplegia or paraparesis occurred in 5 of 75 patients (6.6%). Two patients had detectable somatosensory evoked-potential loss after stent deployment. Four of the five with this complication had complete recovery, and one had nearly complete recovery, after blood pressure augmentation or CSF drainage, or both. They concluded that early detection and aggressive intervention to increase the spinal cord perfusion pressure are effective in decreasing the magnitude of SCI after TEVAR in patients at high risk for paraplegia.

Weigang et al[22] came to a similar conclusion in their study of 31 patients undergoing TEVAR, all of whom had preoperative CSF drainage, somatosensory-evoked potential monitoring, and avoidance of hypotension. During the procedure, 11 of 31 patients (35%) demonstrated changes in evoked-potentials that were managed with CSF drainage and blood pressure augmentation. Paraparesis developed in one patient (3.2%) at 25 days after TEVAR.

In an important study from the Albany group, Hnath et al[23] examined their institution's results regarding the use of CSF drainage in 121 patients who underwent TEVAR. They instituted a protocol of routine placement of a CSF drain and augmentation of the blood pressure to maintain a mean arterial blood pressure >90 mm Hg in 56 patients compared with 65 patients who did not have routine CSF drainage or blood pressure augmentation. The incidence of SCI after the protocol was initiated was 0% in the group with routine CSF drainage vs 8% in the group without routine CSF drainage ($P < .05$). Although their data would suggest that mandatory CSF drainage in all patients undergoing TEVAR could substantially reduce the incidence of SCI, further subset analysis determined that patients at risk for SCI who did not undergo CSF drainage included prior AAA repair and those with extensive thoracic aortic coverage and coverage of the left subclavian artery without revascularization.

Coverage of the important intercostal arteries between T9 and T12 during TEVAR is inevitable in patients with extensive disease of the thoracic aorta. A novel stent graft design has been described by Shimamoto et al[24] based on a fenestrated Inoue thoracic stent graft. In a canine model, they described five successful deployments of a thoracic stent graft with a fenestrated side-branch consisting of a small caliber Dacron graft and a 3-mm diameter bare-metal coronary stent into the T 11 intercostal artery. At 12 months after angiography, all fenestrated stents remained patent with a mean in-stent stenosis of 33%.

CONCLUSIONS

The mechanisms of SCI and stroke after endovascular repair or thoracic aortic pathologies are likely multifactorial and remain poorly defined. A thorough knowledge of the etiology of these complications after open surgical repair of thoracic and thoracoabdominal aortic aneurysms is essential as we attempt to eliminate them after TEVAR. Partic-

ular attention to anatomic factors that may place patients at increased risk for SCI—underlying aortic pathology being treated, extent of aorta to be covered with an endograft, compromise of collateral pathways to the anterior spinal artery (ie, planned coverage of the left subclavian artery or diseased hypogastric arteries), and prior infrarenal aortic surgery—may allow for modifications in technique to decrease their incidence. Adjuncts to decrease the risk of SCI, such as CSF drainage, augmentation of blood pressure, and use of somatosensory evoked-potentials, are useful in patients deemed at high risk for developing SCI.

AUTHOR CONTRIBUTIONS

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Writing the article: AR, TS
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