Review Article

Cerebrospinal fluid drains reduce risk of spinal cord injury for thoracic/thoracoabdominal aneurysm surgery: A review

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Abstract

Background: The risk of spinal cord injury (SCI) due to decreased cord perfusion following thoracic/thoracoabdominal aneurysm surgery (T/TL-AAA) and thoracic endovascular aneurysm repair (TEVAR) ranges up to 20%. For decades, therefore, many vascular surgeons have utilized cerebrospinal fluid drainage (CSFD) to decrease intraspinal pressure and increase blood flow to the spinal cord, thus reducing the risk of SCI/ischemia.

Methods: Multiple studies previously recommend utilizing CSFD following T/TL-AAA/TEVAR surgery to treat SCI by increasing spinal cord blood flow. Now, however, CSFD (keeping lumbar pressures at 5–12 mmHg) is largely utilized prophylactically/preoperatively to avert SCI along with other modalities; avoiding hypotension (mean arterial pressures >80–90 mmHg), inducing hypothermia, utilizing left heart bypass, and employing intraoperative neural monitoring [somatosensory (SEP) or motor evoked (MEP) potentials]. In addition, preoperative magnetic resonance angiography (MRA) and computed tomographic angiography (CTA) scans identify the artery of Adamkiewicz to determine its location, and when/whether reimplantation/reattachment of this critical artery and or other major segmental/lumbar arterial feeders are warranted.

Results: Utilizing CSFD for 15–72 postoperative hours in T/TL-AAA/TEVAR surgery has reduced the risks of SCI from a maximum of 20% to a minimum of 2.3%. The major complications of CSFD include; spinal and cranial epidural/subdural hematomas, VI nerve palsies, retained catheters, meningitis/infection, and spinal headaches.

Conclusions: By increasing blood flow to the spinal cord during/after T/TL-AAA/TEVAR surgery, CSFD reduces the incidence of permanent SCI from, up to 10-20% down to down to 2.3-10%. Nevertheless, major complications, including spinal/cranial subdural hematomas, still occur.

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INTRODUCTION

Here we reviewed the pros, cons, and complications of cerebrospinal fluid drains (CSFD) used in thoracic/thoracoabdominal aneurysm surgery (T/TL-AAA)/thoracic endovascular aneurysm repair (TEVAR) [Tables 1-3]. Previously, without preoperative placement of CSFD, the incidence of spinal cord injury (SCI)/paraplegia following T/TL-AAA/TEVAR approached 20%; unfortunately the failure to prophylactically place CSFD resulted in too many permanent paraplegic injuries. Now since most surgeons prophylactically place CSFD to increase spinal cord perfusion, the risk of SCI has been reduced to 2.3-10% [Tables 1-3]. Additional adjunctive measures to decrease SCI with CSFD include; avoiding hypotension, using hypothermia, selectively employing left heart bypass, routinely performing intraoperative neural monitoring [somatosensory (SEP) or motor evoked potentials (MEP)], and using magnetic resonance angiography (MRA) and computed tomographic angiography (CTA) to identify and reimplant critical lumbar/intercostal arteries including the artery of Adamkiewicz. However, major risks/complications of CSFD include; spinal/cranial subdural hematomas, VI nerve palsies, retained catheters, meningitis/infection, and spinal headaches.

MATERIALS AND METHODS

We identified 18 articles utilizing PubMed and the terms “Thoracic/Thoracoabdominal Aortic Aneurysm Surgery (T/TL-AAA),” “Thoracic Endovascular Aneurysm Repair (TEVAR),” “Cerebrospinal Fluid Drainage (CSFD),” and “Spinal/Neurological Complications” to assess the pros, cons, risks, and complications without and with CSFD in patients undergoing these procedures [Tables 1-3].

Table 1: Risks/complications of cerebrospinal fluid drains in T/TL-AAA/TEVAR surgery (1999-2002)

| Author reference year | Surgery patients | Lumbar drain | Clinical history | Complications | Treatment outcome |
|-----------------------|------------------|--------------|------------------|---------------|------------------|
| Rosenthal 1999. [16]   | TL-AAA            | Lumbar Drain/CSFD | 18 Patients SCI | 16 Aortic Cross Clamps | Paraplegia Postop 6-20 h |
|                       | Not routine use  | Preop CTA/MRA  | Average surgery | Infrarenal     | 5 received CSFD-no improvement |
| Jacobs 2000. [10]     | TL-AAA Surgery   | Complications  | SCI Renal Failure | 2 Suprarenal  | 2.3% SCI risk |
|                       | 170 MEP Monitoring| SCI Renal Failure | Location of ICA-AKA | Protocols to decrease SCI: | |
| McHardy 2001. [15]    | T-L AAA          | Lumbar Drain/CSFD | Died 5 days after Type III TL-AAA | Hypothermia, CSFD | Subdural Hemorrhage |
| Jacobs 2002. [11]     | TL-AAA           | Protocol; Left heart bypass | Intercostal-Lumbar arteries Grafted or Oversewn | 183/184 MEP nl. | Fatal SDH |
|                       | 184 Patients Monitor MEPs | CSFD IONM-MEPs | | 1 Plegic/MEP loss | |
| Dardik 2002. [8]      | TL-AAA           | 8 SDH (3.5%) | Pressures for drain | 4 Normal MEP/deficits; | 6 SDH |
|                       | 230 Patients Preop CSFD | Average age 60.6 | > 5 mm H (2) 0; | 2 Transient | 9.3 Days Postop |
| Ackerman 2002. [1]    | TL-AAA           | 6th Patient: Acute Thrombus | Treatment; Raised BP over 70 mm HG | 2 Permanent | One-1.5 mos. |
|                       | 5 Delayed 12-40 h Due to Hypotension | | | | One- 5 mos. |
|                       |                   |               |                  | | 4 of 8 Died |

TEVAR: Thoracic Endovascular Aneurysm Repair; TL-AAA: Thoracic/Thoracoabdominal Abdominal Aortic Aneurysm; SCI: Spinal Cord Injury; CSFD: Cerebrospinal Fluid Drainage; LD: Lumbar Drains; ICA-AKA: Intercostal-Lumbar Artery-Adamkiewicz Artery; MRA: Magnetic Resonance Angiography; CTA: Computed Tomographic Angiography; IONM: Intraoperative Neural Monitoring; AE: Adverse Events; MEP: Motor Evoked Potentials; ID: Identification; SEP: Somatosensory Evoked Potential Monitoring; BP: Blood Pressure; ECC: Extracorporeal Circulation; SDH: Subdural Hematoma; hrs: Hours; yo: Year old; nl: Normal; preop: Preoperative
1986 definition of Crawford types I–IV of TL-AAA
In 1986, Crawford described four types of TL-AAA.\(^{[1]}\)
Type I included the majority of the descending thoracic aorta from the left subclavian to the suprarenal abdominal aorta. Type II extended from the subclavian to the aortoiliac bifurcation (most extensive). Type III included the distal thoracic aorta to the aortoiliac bifurcation. Type IV involved the abdominal aorta below the diaphragm.

Canine study; CSFD avoids SCI with experimental thoracic aortic occlusion
To determine the onset of SCI, Benicio et al. cross-clamped the descending thoracic aorta (60 minutes) in 18 canines divided into 3 groups; 6 controls (only aortic cross clamping), 6 with ischemic preconditioning, and 6 with prophylactic CSFD (e.g. lumbar drains opened just before cross clamping) [Table 2].\(^{[3]}\) At 7 postoperative days, the Tarlov neurological scores were significantly higher for the animals receiving CSFD, and they demonstrated faster/fuller recovery of adverse SEP changes.

Incidence of spinal cord injury/paraplegia with and without CSFD
The risk of spinal cord injury (SCI) without CSFD for TL-AAA ranges up to 20%, while with CSFD it was reduced to 2.3–10% [Tables 1-3].\(^{[1,2,4,6-13,16,17]}\)

Higher incidence of SCI without preoperative CSFD for T/TL-AAA/TEVAR
Several studies documented the higher rates (10-20%) of SCI occurring when CSFD was not employed prior to TL-AAA/TEVAR surgery [Tables 1 and 2].\(^{[1,2,11,16]}\)

In 1999, Rosenthal et al. identified 18 patients who exhibited SCI after TL-AAA [Table 1].\(^{[16]}\) Notably, preoperative CTA and MRA did not help avoid ICA-AKA (Intercostal-Lumbar Artery–Adamkiewicz Artery injuries). When paraplegia was diagnosed in 5 patients (6 to 20 hours postoperatively), all underwent

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**Table 2: Risks/complications of cerebrospinal fluid drains in T/TL-AAA/TEVAR surgery (2003-2009)**

| Author reference year | Surgery\(^a\) patients | Lumbar drain | Clinical history | Complications | Treatment outcome |
|-----------------------|------------------------|-------------|-----------------|---------------|-------------------|
| Cheung 2003\(^{[4]}\)  | 162 TL-AAA Extracorporeal circulation (ECC) CSFD Anti- Coagulation | CSFD Placed L3-L5 Pressure 10-12 mmHg CSFD placed 153 min. Before Heparin | Intact Patients LD clamp 24 hrs. Removed 48 hrs. Plegic Patient: SCI drain kept > 24 h. | CSFD 135 TL-AAA 27 T-AAA Left heart bypass partial/ total arrest/+/- hypothermia | Paraplegic 4.9% (8 of 162) No hematomas 6 (3.7%) Adverse Events: 1-VI palsy 3-Retained catheter 2 Meningitis 1 Spinal headache Mortality 14.1% |
| Cheung 2005\(^{[5]}\)  | 75 Stents T-AAA with TEVAR Average Age 75 | Minimize Risk of SCI Early exam Postop SEP Increase BP CSFD | Maintain Mean BP >90 mm HG CSF Pressure <10 mm 23 CSFD 15 SEP | SCI Due to: 1 Bleed (retroperitoneal) 2 Prior AAA 1 Iliac injury 1 Embolism | SCI 6.6% (5 patients) 2 LE SEP Loss After Stent Placement 5 Paraplegic: 2 recovered >BP 3 recovered with >BP and CSFD |
| Coselli 2007\(^{[6]}\)  | 2286 TL-AAA Open Surgery 1662 (72.7%) Deg. aneurysms no dissection | 546 (23.9%) Chronic Dissection 78 (3.4%) Acute Dissection 139 (6.1%) Ruptured Aneurysms | Left heart bypass 30 days survival 2191 (95%) | 615 (26.9%) CSFD 87 (3.8%) SCI |
| Benicio 2007\(^{[2]}\)  | Experimental 18 Canines | Descending Thoracic Aortic Occlusion Paraplegia | 6 Cross Clamped 6 Preconditioned 6 CSFD before cross clamping Reversed with CSFD | CSFD Group: Better 7 Day Tarlov Scores CSFD: Faster Recovery SEP Monitoring | Case: Reversal paraplegia with CSFD Case: Reversal SEP Monitoring |
| Bajwa 2008\(^{[2]}\)   | Case TEVAR TL-AAA | CTA 2000-200 | 27 SCI (10%) 13 Reversed with CSFD 14 Stayed Plegic | >Risk SCI: Older, Male Emergency General Anesthesia | Paraplegia with CSFD CSFD: >Risk SCI: History of AAA Repaired/ unrepaird (39%-101/261) |
| Martin 2009\(^{[13]}\)  | TEVAR TL-AAA 261 Patients | CSFD Placed L3-L5 Pressure 10-12 mmHg CSFD placed 153 min. Before Heparin | Intact Patients LD clamp 24 hrs. Removed 48 hrs. Plegic Patient: SCI drain kept > 24 h. | CSFD 135 TL-AAA 27 T-AAA Left heart bypass partial/ total arrest/+/- hypothermia | Paraplegic 4.9% (8 of 162) No hematomas 6 (3.7%) Adverse Events: 1-VI palsy 3-Retained catheter 2 Meningitis 1 Spinal headache Mortality 14.1% |

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\(^{a}\) TEVAR: Thoracic Endovascular Aneurysm Repair; T/TL-AAA: Thoracic/Thoracolumbar Abdominal Aortic Aneurysm; SCI: Spinal Cord Injury; CSFD: Cerebrospinal Fluid Drainage; LD: Lumbar Drains; ICA-AKA: Intercostal-Lumbar Artery–Adamkiewicz; MRA: Magnetic Resonance Angiography; CTA: Computed Tomographic Angiography; IONM: Intraoperative Neural Monitoring; AE: Adverse Events; MEPs: Motor Evoked Potentials; ID: Identification; SEP: Somatosensory Evoked Potentials; BP: Blood Pressure; ECC: Extracorporeal Circulation; SDH: Subdural Hematoma; hrs: Hours; Avg: Average; min: Minutes; Deg: Degenerative; LE: Lower Extremity
Table 3: Risks/complications of cerebrospinal fluid drains in T/TL-AAA/TEVAR surgery (2010-2016)

| Author            | Surgerya patients | Lumbar drain | Clinical history | Complications | Treatment outcome |
|-------------------|-------------------|--------------|------------------|---------------|------------------|
| Sinha 2010.[18]   | TL-AAA            | Higher Risk: Open Surgery Prior AAA Hypotension | Reduce Risks: CSFD Increase BP | Reduce Risks: Reattach Segmental Arteries | Early Detection of SCI with IONM Early exam |
| Fedorow 2010.[6]  | TL-AAA            | CSFD Risks: Nerve Damage | CSFD Risks: Hematoma, Intracranial Bleed | CSFD Risks: Excessive Drainage/Clots Protection; IONM/MEPs Avoid Low BP Use CSFD | SCI 4-All Received CSFD: 3 Better 1 Stayed Plegic CSFD with Multiple Measures provide Increased Protection vs. SCI |
| Matsuda 2010.[14] | TEVAR             | Intercostal Lumbar Artery to Adam kiewicz Artery ICA-AKA) | SCI Protection: Passive Hyperthermia CSFD Left Heart Bypass Reimplant Crucial Intercostal/ Lumbar Arteries | SCI Protection; Hypothermia CSFD Bypass Reimplantation Critical Vessels | Avoid SCI: Staged Procedures- Increase Collaterals |
| Coselli 2016.[7]  | Risks TL-AAA      | Extensive Fenestrated Endovas-cular Aortic Grafts | Avoid SCI: CSFD Avoid Hypotension IONM Hypothermia | Avoid Over-drainage with CSFD Increases Risks of Hematoma | SCI 20% without CSFD SCI 10% with CSFD |
| Scott 2016.[17]   | TL-AAA            | Lumbar Drains-CSFD for TL - AAA | SCI with TL-AAA Without CSFD: 20% With CSFD -10% | SCI with TL-AAA | SCI 10% with CSFD |

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**TEVAR:** Thoracic Endovascular Aneurysm Repair; TL/TL-AAA: Thoracic/Thoracolumbar Abdominal Aortic Aneurysm; SCI: Spinal Cord Injury; CSFD: Cerebrospinal Fluid Drainage; IONM: Intraoperative Neural Monitoring; AE: Adverse Events; MEPS: Motor Evoked Potentials; ID: Identification; SEP: Somatosensory Evoked Potential Monitoring; BP: Blood Pressure; ECC: Extracorporeal Circulation; T-AAA: Descending Thoracic AAI-AAA: Abdominal Aortic Aneurysm; SDH: Subdural Hematoma

Immediate placement of lumbar drainage/CSFD: unfortunately, none recovered. In 2002, Ackerman and Traynelis found 5 patients who developed the delayed (12 and 40 hours) onset of SCI after TL-AAA surgery again without CSFD [Table 1].[11] Placement of CSFD 15–72 hours postoperatively (e.g. after patients became paraplegic), maintaining lumbar CSF pressures under 10 mm Hg, and elevating their systemic blood pressures (mean of >70 mmHg) reversed deficits in just 4 of 6 patients. In 2008, Bajwa et al. reversed paraplegia following TEVAR for TL-AAA (infra renal) utilizing CSFD [Table 2].[2] For Martinez et al. (2009), 10% (27 patients) of 261 patients undergoing TEVAR without CSFD developed SCI; 13 (48%) recovered with CSFD, while 14 (52%) did not [Table 2].[13]

**Reduction of SCI with preoperative placement of CSFD for T/TL-AAA/TEVAR**

The placement of CSFD prior to T/TL-AAA/TEVAR surgery reduced the postoperative incidence of SCI to 2.5–10% [Tables 1-3].[14][12] In 2003, Cheung et al. utilized CSFD (e.g. lumbar drains placed at L3-L5 levels; CSF pressures maintained between 10 and 12 mmHg) along with extracorporeal circulation ([ECC]/left heart bypass) for 135 patients undergoing 98 TL-AAA and 27 T-AAA [Table 1].[4] The time between lumbar drain insertion and full anticoagulation (e.g. to avoid creating spinal/subdural hematomas) was 155 minutes. Postoperatively, for intact patients, drains were clamped at 24 hours, and removed at 48 hours; for plegic patients (e.g. with SCI) drainage was maintained for over 24 hours. SCI occurred in 4.9% (8 of 162) of the patients in this series, while another 6 (3.7%) had catheter-related complications including 1 transient VI nerve palsy (over drainage), 2 retained catheters, 1 retained catheter/meningitis, 1 meningitis alone, and 1 spinal headache. In a second study (2005), Cheung et al. evaluated 75 patients (averaging 75 years of age) undergoing distal T-AAA [Tables 1 and 2].[1] SCI occurred in 5 patients (6.6%); 2 recovered by just increasing the BP, whereas 3 required both raising the BP and placing CSFD. When Coselli et al. evaluated 2256 conventional open TL-AAA repairs (2007), 615 had prophylactic CSFD; SCI occurred in 3.8% patients (87 of 2286) [Table 2].[7] After Matsuda et al. (2010) utilized CSFD in all 60 patients undergoing TEVAR, 3 of 4 (6.6%) who developed SCI recovered with additional adjunctive measures, while one remained plegic [Table 2].[14] In a meta-analysis of 10 studies involving T/TL-AAA/TEVAR, Khan et al. (2016)
observed the 20% incidence of SCI occurring without CSFD, and noted the reduction of this number to 10% with CSFD [Table 3].[12]

Risk factors for SCI with TL-AAA/TEVAR surgery
Several studies cited risk factors for SCI occurring after TL-AAA/TEVAR [Tables 1-3].[5,6,7,14,17,18] These included; older age, male sex, more emergencies, general anesthesia, a history of prior aortic surgery, a history of prior diagnosis of AAA, open surgery, intraoperative hypotension, and more extensive/lengthy aneurysm surgery (e.g. Crawford Type II).

Measures to prevent SCI
Multiple measures utilized to prevent SCI following TL-AAA/TEVAR included; prophylactic placement of CSFD, increasing the mean arterial blood pressure (>80–90 mmHg), mild passive hypothermia, early neurological assessment postoperatively to detect the onset of paraparesis/paraplegia, evaluation of preoperative MRA/CTA to determine the necessity of reimplanting intercostal/lumbar arteries, staging surgical procedures to promote collateral circulation, identifying the vascular supply to the artery of Adamkiewicz, and the use of intraoperative neural monitoring (IONM/SEP/MEP) [Tables 1-3].[7,14,17,18]

Intraoperative neural monitoring limits paraplegia following TL-AAA surgery
Following TL-AAA/TEVAR surgery, the acute/subacute onset of SCI was typically attributed to reduced spinal cord perfusion (e.g., decreased collateral circulation/perfusion of the artery of Adamkiewicz, hypotension), resulting in increased spinal cord ischemia/edema/reperfusion injury, and increased intraspinal pressures [Table 1].[1,10,11] In 2000, Jacobs et al. noted in 170 patients undergoing TL-AAA surgery that the incidence of SCI was reduced to just 2.3% using a combination of CSFD plus; motor evoked potential monitoring (MEP), hypothermia, distal aortic perfusion, and revascularization of segmental arteries [Table 1].[10] Following 184 TL-AAA in 2002, Jacobs et al. (2002) again limited the incidence of postoperative SCI to 2.7% utilizing CSFD. IONM/MEPs, revascularization (e.g. of intercostal/lumbar arteries for MEP amplitude loss of >25%), plus left heart bypass [Table 1].[11] Of the 5 patients with new postoperative neurological deficits, just one lost all MEP (MEP remained normal in 183); 2 of the remaining 4 without significant MEP changes exhibited transient, whereas the other 2 exhibited permanent paraplegia.

Multiple adverse events still result from CSFD utilized in T/TL-AAA/TEVAR surgery
Many adverse events were still attributed to utilizing CSFD to avoid SCI for patients undergoing T/TL-AAA/TEVAR [Tables 1 and 3].[8,9,15] These included; direct neural injury, epidural/intraxial spinal hematomas, intracranial bleeds/subdural hematomas (e.g., due to excessive drainage), and infection [Table 3].[9]

Subdural Hematomas (SDH) resulting from CSFD
Nine acute SDH were reported in two studies.[8,15] McHardy et al. (2001) reported a 65-year-old male who received a prophylactic CSFD for a Crawford Type III TL-AAA: he expired 5 days later from an acute SDH [Table 1].[15] For 230 patients in Dardik’s study (2002) where CSFD were routinely placed preoperatively, 8 (3.5%) developed acute SDH; 50% died [Table 1].[8] In the latter study, patients averaged 60.6 years of age, and those who developed SDH drained nearly twice the amount of CSF (e.g. 690 cc with SDH vs. 359 cc) as those without SDH.

CONCLUSIONS
Without CSFD, patients undergoing T/TL-AAA/TEVAR sustained up to a 20% risk of SCI, while with CSFD, SCI were reduced to a minimum of 2.3% [Tables 1-3]. Most vascular surgeons now prophylactically place CSFD prior to T/TL-AAA/TEVAR surgery. Nevertheless, complications of CSFD still include; spinal/cranial subdural hematomas, VI nerve palsies, retained catheters, meningitis/infection, and spinal headaches.

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Conflicts of interest
There are no conflicts of interest.

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