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Review Article

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

Nancy E. Epstein[1,2]

[1]Professor of Clinical Neurosurgery, School of Medicine, State University of New York at Stony Brook, [2]Chief of Neurosurgical Spine and Education, Winthrop NeuroScience, NYU Winthrop Hospital, Mineola, New York, USA

E-mail: *Nancy E. Epstein - nancy.epsteinmd@gmail.com
*Corresponding author

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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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Key Words: Abdominal aneurysm (T/TL-AAA) surgery, cerebrospinal fluid drainge (CSFD), complications, lumbar, spinal hematomas, subdural hematomas, TEVAR lumbar drain, thoracic

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 Not routine use CSFD	18 Patients SCI Preop CTA/MRA location of ICA-AKA	Average surgery 3 h 39 min Average aortic clamp 48 min	16 Aortic Cross Clamps Infrarenal 2 Suprarenal	Paraplegia Postop 6-20 h 5 received CSFD-no improvement
Jacobs 2000.[10]	TL-AAA Surgery 170 MEP Monitoring	Complications SCI Renal Failure Mesenteric Infarction	Protocol to decrease SCI: Hypothermia, CSFD	Protocols to decrease SCI: Left heart bypass MEP monitoring Reattach arteries	2.3% SCI risk
McHardy 2001.[15]	T-L AAA Case Study 63 year Male	Lumbar Drain/CSFD	Died 5 days after Type III TL-AAA	Subdural Hemorrhage	Fatal SDH
Jacobs 2002.[11]	TL-AAA 184 Patients Monitor MEPs	Protocol; Left heart Bypass CSFD IONM-MEPs	Intercostal-Lumbar arteries Grafted or Oversewn	183/184 MEP nl. 1 Plegic/MEP loss 4 Normal MEP/deficits; 2 Transient 2 Permanent	Neural deficit 2.7%
Dardik 2002.[8]	TL-AAA 230 Patients Preop CSFD	8 SDH (3.5%) Average age 60.6 SDH: Due to Over Drainage	Pressures for drain >5 mm H (2) 0; Drains Removed 3 Days	SDH Average CSF drainage: 690 cc No SDH; Average drainage 359 cc	6 SDH 9.3 Days Postop One-1.5 mos. One- 5 mos. 4 of 8 Died
Ackerman 2002.[1]	6 Cases TL-AAA 5 Delayed 12-40 h. Due to Hypotension	6th Patient: Acute Thrombus	Treatment; Raised BP over 70 mm HG	6 Treated CSFD: 4 Improved 2 Not improved	Duration CSFD 15-72 h. Pressure <10 mm Hg

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 Artery; MRA: Magnetic Resonance Angiography; CTA: Computed Tomographic Angiography; IONM: Intraoperative Neural Monitoring; AE: Adverse Events; MEPs: 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.[11] 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].[1,2,4-6,10-13,16,17]

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].[1,2,13,16] 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

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

Author reference year	Surgery# patients	Lumbar drain	Clinical history	Complications	Treatment outcome
Cheung 2003.[4]	162 TL-AAA Extracor-poreal circulation (ECC) CSFD Anti-Coagulation Avg. age 67	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]	TL-AAA 2286 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.[3]	Experimental 18 Canines	Descending Thoracic Aortic Occlusion	6 Cross Clamped 6 Preconditioned 6 CSFD before cross clamping	CSFD Group: Better 7 Day Tarlov Scores	CSFD: Faster Recovery SEP Monitoring
Bajwa 2008.[2]	Case TEVAR TL-AAA	Paraplegia	Reversed with CSFD	Case: Reversal paraplegia with CSFD	Case: Reversal paraplegia with CSFD
Martin 2009.[13]	TEVAR TL-AAA 261 Patients	CTA 2000-200	27 SCI (10%) 13 Reversed with CSFD 14 Stayed Plegic	>Risk SCI: Older, Male Emergency General Anesthesia	>Risk SCI: History of AAA Repaired/ unrepaired (39%-101/261)

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 reference year	Surgery# patients	Lumbar drain	Clinical history	Complications	Treatment outcome
Sinha 2010.[18]	TL-AAA Risks SCI	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.[9]	TL-AAA	CSFD Risks: Nerve Damage	CSFD Risks: Hematoma, Intracranial Bleed	CSFD Risks: Excessive Drainage/Clots	Risks infection
Matsuda 2010.[14]	TEVAR 60 Distal TL-AAA T7-L2	Intercostal Lumbar Artery to Adam kiewicz Artery ICA-AKA)	Ages 57-89 ICA-AKA using MRA or CTA Patient ICA-AKA after Identification Early Diagnosis SCI	Protection; IONM/MEPs Avoid Low BP Use CSFD	SCI 4-All Received CSFD: 3 Better 1 Stayed Plegic
Coselli 2016.[7]	Risks TL-AAA	Risks TL-AAA: Death Paraplegia Renal failure SCI	SCI Protection: Passive Hypothermia CSFD Left Heart Bypass Reimplant Crucial Intercostal/ Lumbar Arteries	Protection Hypothermia CSFD Bypass Reimplantation Critical Vessels	CSFD with Multiple Measures provide Increased Protection vs. SCI
Scott 2016.[17]	TL-AAA	Extensive Fenestrated Endovas-cular Aortic Grafts	Avoid SCI: CSFD Avoid Hypotension IONM Hypothermia	Avoid SCI: Staged Procedures- Increase Collaterals	Risks SCI 10% with CSFD Also Elevate BP
Khan 2016.[12]	Meta-analysis 10 Articles	Lumbar Drains-CSFD for TL - AAA	SCI with TL-AAA Without CSFD- 20% With CSFD -10%	Avoid Over-drainage with CSFD Increases Risks of Hematoma	SCI 20% without CSFD SCI 10% with CSFD

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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].[1] 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 (infrarenal) utilizing CSFD [Table 2].[2] For Martian *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 2.3–10% [Tables 1-3].[4-6,12] 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 153 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].[5] 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 2286 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/TAVER, 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 risks factors for SCI occurring after TL‑AAA//TEVAR [Tables 1‑3].[5,6,13,14,17,18] 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/intraaxial 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 63‑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.

REFERENCES

1. Ackerman LL, Traynelis VC. Treatment of delayed‑onset neurological deficit after aortic surgery with lumbar cerebrospinal fluid drainage. Neurosurgery 2002;51:1414‑21; discussion 1421‑2.
2. Bajwa A, Davis M, Moawad M, Taylor PR. Paraplegia following elective endovascular repair of abdominal aortic aneurysm: Reversal with cerebrospinal fluid drainage. Eur J Vasc Endovasc Surg 2008;35:46‑8.
3. Benício A, Moreira LF, Mônaco BA, Castelli JB, Mingrone LE, Stolf NA. Comparative study between ischemic preconditioning and cerebrospinal fluid drainage as methods of spinal cord protection in dogs. Rev Bras Cir Cardiovasc 2007;22:15‑23.
4. Cheung AT, Pochettino A, Guvakov DV, Weiss SJ, Shanmugan S, Bavaria JE. Safety of lumbar drains in thoracic aortic operations performed with extracorporeal circulation. Ann Thorac Surg 2003;76:1190‑6; discussion 1196‑7.
5. Cheung AT, Pochettino A, McGarvey ML, Appoo JJ, Fairman RM, Carpenter JP, *et al*. Strategies to manage paraplegia risk after endovascular stent repair of descending thoracic aortic aneurysms. Ann Thorac Surg 2005;80:1280‑8; discussion 1288‑9.
6. Coselli JS, Bozinovski J, LeMaire SA. Open surgical repair of 2286 thoracoabdominal aortic aneurysms. Ann Thorac Surg 2007;83:S862‑4; discussion S890‑2.
7. Coselli JS, de la Cruz KI2Preventza O, LeMaire SA, Weldon SA. Extent II Thoracoabdominal Aortic Aneurysm Repair: How I Do It. Semin Thorac Cardiovasc Surg 2016;28:221‑37.
8. Dardik A, Perler BA, Roseborough GS, Williams GM. Subdural hematoma after thoracoabdominal aortic aneurysm repair: An underreported complication of spinal fluid drainage? J Vasc Surg 2002;36:47‑50.
9. Fedorow CA, Moon MC, Mutch WA, Grocott HP. Lumbar cerebrospinal fluid drainage for thoracoabdominal aortic surgery: Rationale and practical considerations for management. Anesth Analg 2010;111:46‑58.
10. Jacobs MJ, Meylaerts SA, de Haan P, de Mol BA, Kalkman CJ. Assessment

of spinal cord ischemia by means of evoked potential monitoring during thoracoabdominal aortic surgery. Semin Vasc Surg 2000;13:299-307.
11. Jacobs MJ, de Mol BA, Elenbaas T, Mess WH, Kalkman CJ, Schurink GW, *et al*. Spinal cord blood supply in patients with thoracoabdominal aortic aneurysms. J Vasc Surg 2002;35:30-7.
12. Khan NR, Smalley Z, Nesvick CL, Lee SL, Michael LM 2nd. The use of lumbar drains in preventing spinal cord injury following thoracoabdominal aortic aneurysm repair: An updated systematic review and meta-analysis. J Neurosurg Spine 2016;25:383-93.
13. Martin DJ, Martin TD, Hess PJ, Daniels MJ, Feezor RJ, Lee WA. Spinal cord ischemia after TEVAR in patients with abdominal aortic aneurysms. J Vasc Surg 2009;49:302-6; discussion 306-7.
14. Matsuda H, Ogino H, Fukuda T, Iritani O, Sato S, Iba Y, *et al*. Multidisciplinary approach to prevent spinal cord ischemia after thoracic endovascular aneurysm repair for distal descending aorta. Ann Thorac Surg 2010;90:561-5.
15. McHardy FE, Bayly PJ, Wyatt MG. Fatal subdural haemorrhage following lumbar spinal drainage during repair of thoraco-abdominal aneurysm. Anaesthesia 2001;56:168-70.
16. Rosenthal D. Spinal cord ischemia after abdominal aortic operation: Is it preventable? J Vasc Surg 1999;30:391-7.
17. Scott DA, Denton MJ. Spinal cord protection in aortic endovascular surgery. Br J Anaesth 2016;117(Suppl 2):ii26-ii31
18. Sinha AC, Cheung AT. Spinal cord protection and thoracic aortic surgery. Curr Opin Anaesthesiol 2010;23:95-102.