The use of lumbar drains in preventing spinal cord injury following thoracoabdominal aortic aneurysm repair: an updated systematic review and meta-analysis

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OBJECTIVE Paraplegia and paraparesis following aortic aneurysm repair occur at a substantially high rate and are often catastrophic to patients, their families, and the overall health care system. Spinal cord injury (SCI) following open thoracoabdominal aortic aneurysm (TAAA) repair is reported to be as high as 20% in historical controls. The goal of this study was to determine the impact of CSF drainage (CSFD) on SCI following TAAA repair.

METHODS In August 2015 a systematic literature search was performed using clinicaltrials.gov, the Cochrane Library, PubMed/MEDLINE, and Scopus that identified 3478 articles. Of these articles, 10 met inclusion criteria. Random and fixed-effect meta-analyses were performed using both pooled and subset analyses based on study type.

RESULTS The meta-analysis demonstrated that CSFD decreased SCI by nearly half (relative risk 0.42, 95% confidence interval 0.25–0.70; p = 0.0009) in the pooled analysis. This effect remained in the subgroup analysis of early SCI but did not remain significant in late SCI.

CONCLUSIONS This meta-analysis showed that CSFD could be an effective strategy in preventing SCI following aortic aneurysm repair. Care should be taken to prevent complications related to overdrainage. No firm conclusions can be drawn about the newer endovascular procedures at the current time.

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KEY WORDS aortic aneurysm; cerebrospinal fluid; endovascular; lumbar drain; spinal cord injury; vascular disorders

Paraplegia remains the most devastating complication in both open and endovascular repair of thoracic and aortic aneurysms. Permanent neurological deficit is a major cause of morbidity and leads to decreased long-term survival of patients with thoracoabdominal aortic aneurysm (TAAA) repair.13,46 the incidence of paraplegia has been reported to be as high as 20% in the early 1990s.36 Risk factors identified for developing spinal cord injury (SCI) following TAAA repair include aneurysm extent (related to the number of segmental arteries), location of the aneurysm (lumbar aneurysms have less robust collateral arteries), and prolonged aortic cross-clamping times. All of these risk factors point toward an ischemia/infarction model for the pathophysiology of SCI following TAAA repair.22 Anatomical work performed by Etz et al. resulted in a better understanding of the relationship between segmental and radicular arteries.20 This work has influenced our knowledge of ischemic injuries that occur during TAAA repair. A variety of measures to attenuate the ischemic pathophysiology have been investigated, such as elevation of mean arterial pressure, reattaching critical segmental arteries, and CSF drainage (CSFD).2,10,12,15,21,38,41 The introduction of CSFD and adjunctive neuroprotective therapies have reduced the risk of SCI to 4%–7% in the current literature.1,3,19,23,32,50 The first reports of CSFD as an adjunctive measure for reducing the risk of paraple-
gia following aortic aneurysm repair were from a seminal report on a canine model by Miyamoto et al. in 1960 and Blaisdell and Cooley in 1962. This topic has since been addressed by several prospective cohort studies and randomized controlled trials (RCTs), resulting in 2 systematic reviews that showed significant protective odds ratios (ORs) of 0.30 and 0.57 in 2004 and 2012, respectively. Neurosurgeons are often consulted for insertion and management of this adjunctive therapy. It is prudent for the neurosurgical community to understand the risks, benefits, and indications of this procedure as it relates to the natural history of this disease. This systematic review and meta-analysis was undertaken to provide an updated and thorough review about the use of CSFD in TAAA repair. The primary aim of this analysis was to determine if CSFD decreases SCI following TAAA repair.

Methods
This study was conducted using the “Assessment of Multiple Systematic Reviews” (AMSTAR) measurement tool, and reporting was conducted according to the “Preferred Reporting Items for Systematic reviews and Meta-Analyses” (PRISMA) measurement tool. AMSTAR is a tool designed to assess the methodological quality of systematic reviews and meta-analyses. PRISMA is a checklist and flow diagram that provides guidance on how to report systematic reviews and meta-analyses.

Search Strategy
The systematic search strategy involved a search through multiple electronic databases, bibliographies of relevant articles, and consultation with the senior author (L.M.M.). We electronically searched clinicaltrials.gov, The Cochrane Library, PubMed/MEDLINE, and Scopus to find English-language articles—excluding gray literature—with no timeframe restrictions in August of 2015.

The following terms in various combinations were used: aortic aneurysm, cerebrospinal fluid, endovascular, lumbar drain, paraplegia, paraparesis, and spinal cord ischemia. Three independent researchers (Z.S., C.L.N., and S.L.L.) conducted 3 separate independent literature searches with the help of librarians at the University of Tennessee Health Science Center. If there was any question as to the eligibility of an article, consensus was reached through discussion with the senior author. When necessary, additional contact was made with the authors of the articles we included to confirm data.

Inclusion Criteria, Data Extraction, End Points, Definitions
The goals of the search were to find articles that met the following inclusion criteria: 1) described a group of adult patients (> 18 years of age) with surgical repair of a TAAA treated with CSFD; 2) described a control group not treated with CSFD; 3) had the use of CSF diversion as the main treatment difference between the 2 groups; and 4) reported the number of patients and number of neurological deficits for each group. Thus, noncomparison studies, case reports, and pediatric reports were excluded.

Three separate individuals (Z.S., C.L.N., and S.L.L.) screened all potential articles and extracted data independently. The data extracted from each article included: 1) information regarding the timeframe and drainage parameters for CSF diversion; 2) the total number of participants, in both treatment and control groups; 3) early and late postsurgical neurological deficits (i.e., paraparesis, paraplegia); 4) complications related to the use of CSF diversionary procedures; and 5) length of follow-up. The level of evidence for each study was evaluated using the Oxford Centre for Evidence Based Medicine (OCEBM) guidelines (http://www.cebm.net/cebm-levels-of-evidence/). Study quality (i.e., assessment of bias within individual studies) was determined using the Jadad scale for RCTs and the Newcastle-Ottawa Scale (NOS) for quality assessment of controlled observational cohort studies. Disagreements among any of the above data points were resolved through discussion among the authors.

Meta-Analysis
For each study, the numbers of neurological deficits (early and late) in patients treated with CSF diversion were identified and a relative risk (RR) was calculated. The overall risk ratio was computed using the method of DerSimonian and Laird. Analysis was performed using Review Manager software (version 5.3, Cochrane Collaboration 2014).

A random effects meta-analysis was performed on selected studies. A random effects model, in contrast to a fixed effects model, does not assume that the relative risk is the same across studies and yields a more conservative estimate of effect. Heterogeneity between studies was assessed by the Cochran Q test and I² statistic. Heterogeneity is calculated by taking a weighted sum of the squared differences between individual study effect sizes and the overall pooled effect estimate. The greater the difference, the more likely it is that significant methodological and clinical differences exist between the included studies. Heterogeneity was considered statistically significant when the p value derived from the Cochran Q test was less than 0.1. For the qualitative interpretation of heterogeneity, I² values of at least 50% are usually considered to represent substantial heterogeneity, while values of at least 75% indicate considerable heterogeneity according to the Cochrane Handbook.

Publication bias (i.e., assessment of bias across studies) was graphically evaluated using a funnel plot. The theory of a funnel plot is that smaller studies should have more variation in effect sizes compared with larger studies with more robust data. A plot measuring the log of the standard error (correlated to the size of the study) and overall effect should yield a symmetric funnel-shaped diagram in the absence of publication bias.

Results
Search Results and Included Articles
After a comprehensive search of PubMed/MEDLINE, Cochrane/Ovid, Scopus, and clinicaltrials.gov, we identified 3478 unique titles. Of these titles, 93 articles were identified for abstract review after excluding articles not in English (n = 624) and articles not directly pertinent to the use of CSFD in TAAA repair (n = 2761). Of these 93 arti-
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articles, 27 were identified for full-text review after excluding case reports (n = 29), case series (n = 19), commentaries and nonsystematic reviews (n = 12), animal studies (n = 4), and articles with no aortic aneurysms in the study population (n = 2). Of these 27 articles, 17 met inclusion criteria; however, 8 had data from the same research groups with overlapping dates and were excluded. Two articles were excluded because they selected only patients at high risk of SCI for CSFD, thus no utility between lumbar drains preventing SCI could be meaningfully assessed.7,26 Additionally, a single article was identified after mining the bibliographies of included articles, leaving a final total of 10 included articles comprising 1319 patients receiving lumbar drainage and 784 control patients (Fig. 1). There were 3 RCTs and 7 cohort studies. The overall quality of the evidence for the included observational studies was moderate. The average number of stars using the NOS was 5.5 ± 2.1 out of a maximum of 9 stars. Each of the 3 RCTs11,13,47 received 3 points using the Jadad criteria.30 Table 1 lists the characteristics of each study included in this analysis.

Overall SCI Following TAAA Repair

A total of 10 studies had sufficient information to extract overall rates of both transient and permanent SCI. All but 1 study4 showed a protective benefit against SCI when using CSFD compared with a control group.5,11,13,27,28,37,40,47,48 The OR was 0.42 with a 95% confidence interval (CI) of 0.25–0.70 (p = 0.0009; Fig. 2). A funnel plot was used to assess publication bias (Fig. 3). There was moderate, but not significant (p = 0.11), heterogeneity as indicated by an I² statistic of 37%. The absolute risk reduction was 7% with a number needed to treat (NNT) of 14.

FIG. 1. Flow diagram of the search strategy used in the study.
<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>OCEBM Grade of Evidence (Jadad score)</th>
<th>Study Type</th>
<th>Endo vs Open</th>
<th>Indications for LD</th>
<th>CSF Pressure &amp; Drainage Targets, Vol Drained (total)</th>
<th>Length &amp; Location of LD</th>
<th>Co-intervention</th>
<th>Complication (Early, Late)</th>
<th>SCI</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crawford et al., 1991</td>
<td>2 (3/5)</td>
<td>RCT Open Random</td>
<td>None</td>
<td>10–15 mmHg, 24–120 mL (median 52.5)</td>
<td>Removed immediately postop, L3–4 or L4–5 inserted 5–10 cm depth</td>
<td>None</td>
<td>NES; “headache &amp; infection did not occur”</td>
<td>14/46 (LD), 17/52 (Control)</td>
<td>10/46 (LD), 11/52 (Control)</td>
<td>4/36 (LD), 6/41 (Control)</td>
</tr>
<tr>
<td>Hollier et al., 1992</td>
<td>4</td>
<td>Retro Open NES</td>
<td>≤10 mmHg, up to 500 mL</td>
<td>Removed POD 1–3, L-2 or L-3, depth NR</td>
<td>Permissive hypothermia (32–34°C), intercostal artery reattachment, nimodipine, steroids, mannitol</td>
<td>NR</td>
<td>0/42 (LD), 6/108 (Control)</td>
<td>0/42 (LD), 3/108 (Control)</td>
<td>0/42 (LD), 3/108 (Control)</td>
<td>NES; 30-day mortality</td>
</tr>
<tr>
<td>Murray et al., 1993</td>
<td>4</td>
<td>Retro Open</td>
<td>Types I, II, III TAAAs &amp; descending thoracic aneurysms</td>
<td>≤15 mmHg 3–150 ml (median 33 ml)</td>
<td>CSFD group, permissive hypothermia (34°C)</td>
<td>NR</td>
<td>4/47 (LD), 4/45 (Control)</td>
<td>2/47 (LD), 3/45 (Control)</td>
<td>2/47 (LD), 1/45 (Control)</td>
<td>NES; &gt;96 hrs, 30-day mortality</td>
</tr>
<tr>
<td>Svensson et al., 1998</td>
<td>2 (3/5)</td>
<td>RCT Open Random</td>
<td>≤7 to 10 mm Hg, 12–1157 ml (mean 447 ml)</td>
<td>Removed after 2-60 hrs (mean 40 hrs), L3-4 &amp; L4–5, depth NR</td>
<td>Permissive hypothermia (29°–31°C), CSFD group, intrathecal papaverine</td>
<td>NR</td>
<td>2/17 (LD), 7/16 (Control)</td>
<td>NR</td>
<td>NR</td>
<td>3 yrs</td>
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</table>
### Table 1. Characteristics of studies included for analysis

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>Grade of Evidence (Jadad score)</th>
<th>Study Design</th>
<th>Endo vs Open</th>
<th>Indications for LD</th>
<th>Length &amp; Location of LD</th>
<th>Co-intervention</th>
<th>Compl</th>
<th>Overall</th>
<th>Early</th>
<th>Late</th>
<th>FU</th>
<th>Conclusions</th>
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</thead>
<tbody>
<tr>
<td>Tefera et al., 2000</td>
<td>4</td>
<td>Retro Open</td>
<td>NES</td>
<td>≤10 mm Hg, (mean 116 ml)</td>
<td>&quot;Typically&quot; removed POD 2, L1–2 inserted 6-cm depth</td>
<td>Intercostal artery reattachment &amp; permissive hypothermia (32°–34°C); CSFD group, naloxone</td>
<td>NR</td>
<td>5/150 (LD), 12/67 (Control)</td>
<td>NR</td>
<td>NR</td>
<td>NES</td>
<td>&quot;In our experience, CSF drainage and naloxone use has shown significant spinal cord protection, significantly reducing neurologic complications.&quot;</td>
</tr>
<tr>
<td>Coselli et al., 2002</td>
<td>2 (3/5)</td>
<td>RCT Open</td>
<td>Random</td>
<td>≤10 mm Hg, 10–250 ml during op (mean 64 ml) &amp; 40–864 ml (mean 261 ml) after op</td>
<td>Removed POD2, continued if SCI present; L-3 or L-4, depth NR</td>
<td>Lt heart bypass, permissive hypothermia, heparinization, reattachment of intercostal &amp; lumbar arteries T7-L2</td>
<td>Cather occlusion (2), catheter dislodged (1), infections (0), CSF leaks (0)</td>
<td>2/82 (LD), 9/74 (Control)</td>
<td>1/82 (LD), 7/74 (Control)</td>
<td>1/82 (LD), 2/74 (Control)</td>
<td>NES; 30-day mortality</td>
<td>&quot;Perioperative CSFD reduced the rate of paraplegia after repair of extent I and II TAAAs.&quot;</td>
</tr>
<tr>
<td>Safi et al., 2003</td>
<td>3 or 4</td>
<td>Retro Open</td>
<td>NES</td>
<td>≤10 mm Hg, vol of drainage NR</td>
<td>Removed POD3, L-3 or L-4, depth NR</td>
<td>CSFD group, distal aortic perfusion &amp; permissive hypothermic</td>
<td>NR</td>
<td>18/741 (LD), 18/263 (Control)</td>
<td>18/741 (LD), 18/263 (Control)</td>
<td>NR</td>
<td>NES; 30-day mortality</td>
<td>&quot;These long-term results indicate that cerebrospinal fluid drainage and distal aortic perfusion are safe and effective adjunct for reducing morbidity and mortality following thoracic and thoracoabdominal aortic repair.&quot;</td>
</tr>
<tr>
<td>Authors &amp; Year</td>
<td>OCEBM Grade of Evidence (Jadad score)</td>
<td>Study Type</td>
<td>Endo vs Open</td>
<td>Indications for LD</td>
<td>CSF Pressure Targets, Vol Drained (total)</td>
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<tr>
<td>Arnaoutakis et al., 2014</td>
<td>3 or 4</td>
<td>Retro Endo TEVAR for included lesions ≤10 mm Hg intraop; &lt;15 mm Hg postop, NR Placed day before op &amp; replaced preop if malfunctioning, clamped POD1, removed POD2, L-3 or L-4 interspace</td>
<td>CSFD group, 12 had IT subclavian artery bypass NR</td>
<td>2/60 (LR), 1/30 (Control)</td>
<td>NR</td>
<td>0/56 (LD), 5/65 (Control)</td>
<td>NR</td>
<td>NES; 30-day &amp; 1-yr mortality</td>
<td>“Preoperative CSF drain placement allows for rapid, intensive therapy for SCI and should be considered when clinically feasible.”</td>
<td></td>
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<td></td>
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<tr>
<td>Hnath et al., 2008</td>
<td>4</td>
<td>Retro Endo TEVAR for included lesions ≤15 mm Hg intraop; &lt;10 mm Hg postop, “no set limit on volume”</td>
<td>Clamped 12 hrs postop, continued if SCI present, L2–4</td>
<td>None</td>
<td>NR</td>
<td>0/56 (LD), 5/65 (Control)</td>
<td>NR</td>
<td>NES; ICU for &gt;24 hrs</td>
<td>“Perioperative CSF drainage with augmentation of systemic blood pressures may have a beneficial role in reducing the risk of paraplegia in patients undergoing endovascular thoracic aortic stent graft placement.”</td>
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<td></td>
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<tr>
<td>Bisdas et al., 2015</td>
<td>3</td>
<td>Retro Endo TEVAR for included lesions NR, (mean 64 ml) Continued for LE weakness, NR</td>
<td>Cranial hypotension syndrome (4), EVD required (2) 12/78 (LD), 11/64 (Control) Immediate: 5/78 (LD), 5/64 (Control); &lt;24 hrs: 6/78 (LD), 5/64 (Control)</td>
<td>&gt;24 hrs: 1/78 (LD), 1/64 (Control)</td>
<td>NES; 30-day mortality data</td>
<td>“Prophylactic use of CSFD could not reduce the SCI rate and was associated with 6% adverse events.”</td>
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<td></td>
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</table>

Compl = complications; Endo = endovascular; FU = follow-up; IP = intrathecal papaverine; LD = lumbar drainage; LE = lower extremity; NES = not explicitly stated; NR = not reported; POD = postoperative day; Random = randomized; Retro = retrospective.
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Early SCI Following TAAA Repair

A total of 6 studies had sufficient information to extract early rates of transient and permanent SCI. One study showed an increase in early SCI when using CSFD and the remaining 5 showed a protective benefit. The OR was 0.48 with a 95% CI of 0.30–0.76 (p = 0.002; Fig. 4). There was mild heterogeneity as indicated by an I² statistic of 15%. The absolute risk reduction was 4.3% with an NNT of 23.

Late SCI Following TAAA Repair

A total of 5 studies had sufficient information to extract late rates of transient and permanent SCI. One study showed an increase in late SCI when using CSFD and the remaining 4 showed a protective benefit. The OR was 0.73 with a 95% CI of 0.29–1.81 (p = 0.49; Fig. 5). A funnel plot was used to assess publication bias. There was minimal heterogeneity as indicated by an I² statistic of 0%.

Subgroup Analysis of RCTs

A total of 3 RCTs were included in the subgroup analysis. Two studies showed a protective benefit when using CSFD in preventing SCI and 1 did not. Using a fixed-effects meta-analysis, the OR was calculated to be 0.48 with a 95% CI of 0.25–0.92 (p = 0.03). There was moderate (p = 0.09) heterogeneity as indicated by an I² statistic of 59% (Fig. 6).

Complications of CSFD

Of the 10 studies that met criteria, only 3 reported complications when using lumbar drainage for CSFD. Bisdas et al. reported a requirement of 2 external ventricular drains and 4 episodes of intracranial hypotension. Coselli et al. reported 2 catheter occlusions/dislodgements. Svensson et al. reported a persistent CSF leak requiring an epidural blood patch.

Publication Bias and Heterogeneity

Publication bias was assessed graphically using funnel plots. As shown in Fig. 3 there is a paucity of studies in the right lower quadrant. This quadrant represents small studies that showed increased rates of SCI. There was minimal heterogeneity as detected by the I² statistics and correlating p values.

Discussion

Spinal cord injuries following TAAA repair are significant complications to patients, their families, providers, and the overall health care system. The cardiothoracic literature is mixed when evaluating adjuncts such as CSFD in preventing SCI. Some studies show a benefit, while others do not. This study focuses on nontraumatic SCI in the setting of TAAA repair.

A systematic review performed in 2004 by Cina et al. demonstrated a protective benefit when using CSFD. This study contained 8 included articles and 2 of their studies may have overlapping patient recruitment periods from the same groups of authors. The article by Safi et al. in 2003 in our study contains the same group of patients as these 2 studies with longer follow-up durations and larger sample sizes. Thus, our review contains 4 unique articles not presented in their review after more than a decade has elapsed. A Cochrane review in 2012 by Khan et al. looked...
only at RCTs and found 3 included articles\textsuperscript{11,13,47} that are also included in the current study. Khan et al. concluded that there is limited data supporting the role of CSFD in thoracic and TAAA surgery and further studies are needed.\textsuperscript{31} Two of the 3 RCTs of open aortic aneurysm repair included in this study showed benefit when using CSFD.\textsuperscript{11,47} The study by Svensson et al. in 1998 was stopped early by the institutional review board because the interim results show a significant benefit in favor of CSFD and intrathecal papaverine, thus limiting the size of their trial.\textsuperscript{47} In the second trial by Coselli et al. in 2002\textsuperscript{11} the rates of SCI significantly decreased from 12.2\% to 2.7\% (\(p = 0.03\)), although the observers rating neurological deficit were not blinded. The RCT by Crawford et al. in 1991 did not show a benefit in preventing SCI in those who received CSFD compared with those who did not.\textsuperscript{13} The Crawford study had several important shortcomings. The amount of CSF drained was limited to 50 ml and the CSFD pressure was only reduced to less than 10 mm Hg in less than half of the participants. Thus, this trial may not have adequately increased spinal cord perfusion pressure to prevent neurological deficit and answer the hypothesis posed by their study.\textsuperscript{13} Our subgroup fixed-effects meta-analysis shows the same results as described by the Cochrane Review in 2012.\textsuperscript{31}

Our study contains 7 articles pertaining to open aortic aneurysmal repair and 3 newer endovascular studies. In the overall analysis we showed a significant protective benefit with moderate but not significant heterogeneity. The overall NNT was 14 with an absolute risk reduction of 7\%, which is slightly more modest than the systematic review performed over a decade ago by Cinà et al. that showed an NNT of 11 with an absolute risk reduction of 9\%.\textsuperscript{8} This benefit continued when analyzing early SCI but did not continue when analyzing late SCI. Late neurological deficits may be more a manifestation of a reperfusion type injury and not as directly responsive to increasing spinal cord perfusion pressure by CSFD.

The literature is heterogeneous when evaluating the 3 included endovascular studies. The study by Bisdas et al. showed no improvement in SCI following endovascular repair when prophylactically performing CSFD. However, their protocol for prophylactic versus selective CSFD placement was not uniform and the validity of their results is questionable.\textsuperscript{5} Arnaoutakis et al. did not show a difference when placing a CSF drain compared with the control group, however, both patients who developed SCI responded to CSFD and the authors concluded that the “use of adjunctive procedures for TEVAR [thoracic endovascular aortic repair] demonstrated better SCI results compared with prior reports.”\textsuperscript{4} Hnath et al. showed a statistically significant benefit when using prophylactic CSFD despite having higher rates of prior TAAA repair, left subclavian artery coverage, increased aortic coverage, and perioperative vasopressors in the CSFD group.\textsuperscript{27} Additional higher quality studies will be needed prior to making any formal recommendations on the use of CSFD in endovascular repair of aortic aneurysms.

The rate of complications related to CSFD was marginal in the included studies. There were reports of nonclinically significant subdural hematoma and external ventricular drain placement. However, there are a multitude of case reports\textsuperscript{9,14,24,25,29,33,34} in the literature citing CSFD

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Study or Subgroup & Lumbar Drain & Control & Odds Ratio & & \\
& Total & Total & M–H, Fixed, 95\% CI & & \\
& Events & Total & Total & & \\
\hline
Bisdas 2015 & 7 & 78 & 5 & 64 & 10.0\% & 0.81 [0.22, 2.92] & \\
Coselli 2002\textsuperscript{11} & 1 & 76 & 1 & 69 & 14.1\% & 0.12 [0.01, 0.99] & \\
Crawford 1991 & 4 & 36 & 6 & 41 & 45.0\% & 0.73 [0.19, 2.82] & \\
Hollier 1992 & 0 & 42 & 3 & 108 & 17.7\% & 0.35 [0.02, 7.01] & \\
Murray 1993 & 2 & 47 & 1 & 45 & 8.8\% & 1.96 [0.17, 22.35] & \\
\hline
Total (95\% CI) & 279 & 327 & & & 100.0\% & 0.73 [0.29, 1.81] & \\
Total events & 8 & 13 & & & & & \\
Heterogeneity: Chi\textsuperscript{2} = 1.02, df = 4 (\(p = 0.91\)); I\textsuperscript{2} = 0\% & & & & & & & \\
Test for overall effect: Z = 0.69 (\(p = 0.49\)) & & & & & & & \\
\hline
\end{tabular}
\caption{Forest plot of all studies with their respective RRs and 95\% CIs, events (late SCI), and overall RR.}
\end{table}
linked to the development of subdural hematoma following aortic aneurysm repair; I report even directly links this complication to the death of the affected patient. A study by Youngblood et al. looking at a series of 504 patients over 5 years receiving CSFD for TAAA repair reported that the rate of intracranial hemorrhage was 2.8%, with the majority being subdural hematomas (72%), and the postprocedural headache rate was 9.7%. At our own institution we follow a protocol of CSF pressure targeting to 10 mm Hg but do not allow greater than 30 ml of CSF to be drained in a single hour to prevent these types of complications.

Limitations and Strengths
Limitations of our meta-analysis are related to the quality of the included studies. A systematic review and meta-analysis is only as robust as the articles of which it is composed. With only 3 RCTs, the majority of the included data are based on combining prospective and retrospective cohort studies. The quality of the evidence was moderate using objective grading scales. Any selection bias inherent to these nonrandomized studies would be perpetuated in the current analysis. Authors defined neurological deficit heterogeneously. Some authors used sensitive grading scales that likely identified more subtle deficits while others did not. Surgical technique and approach was heterogeneous. To account for heterogeneity in the overall analysis we used a random, instead of a fixed-effects, meta-analysis and formal statistical testing found minimal overall heterogeneity among studies in the outcome of interest. While publication bias may exist, the Cochrane Collaboration recommends against testing for it when a meta-analysis is composed of 10 or fewer studies because when there are fewer studies the power of the tests is too low to distinguish chance from real asymmetry. Until a large, multinstitutional, prospective RCT is performed, the current meta-analysis represents the highest level of evidence supporting CSFD in TAAA repair.

Conclusions
Neurosurgeons are often asked to perform CSFD for other consulting services at their discretion. It is prudent for the neurosurgical community to understand the risks, benefits, and indications of this procedure as it relates to the natural history of this disease. Based on moderate quality evidence, the use of CSFD in open TAAA repair may be beneficial with appropriate spinal cord perfusion pressure targeting and appropriate neurological monitoring, but care should be taken to prevent complications related to overdrainage. No firm conclusions can be drawn on the endovascular population at the current time.

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References

FIG. 6. Forest plot of RCTs with their respective RRs and 95% CIs, events (SCI), and overall RR.


Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions
Conception and design: Khan. Acquisition of data: Michael, Khan, Smalley, Nesvick. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: Michael, Khan, Lee. Approved the final version of the manuscript on behalf of all authors: Michael. Statistical analysis: Khan. Study supervision: Michael.

Correspondence