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Systematic Review

Spinal cord injury after open and endovascular repair of descending thoracic aneurysm and thoracoabdominal aortic aneurysm: an updated systematic review and meta-analysis

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Background: Spinal cord injury (SCI) is a rare but severe complication after open or endovascular repair of descending thoracic aneurysms (DTAs) or thoracoabdominal aortic aneurysms (TAAAs). This meta-analysis aims to provide a comprehensive assessment of SCI rates and factors associated with SCI.

Methods: A systematic literature search was performed in September 2022 looking for studies on open and/or endovascular repair of DTA and/or TAAA published after 2018, to update the results of our previously published meta-analysis. The primary outcome was permanent SCI. Secondary outcomes were temporary SCI, 30-day and in-hospital mortality, follow-up mortality, postoperative stroke, and cerebrospinal fluid (CSF) drain-related complications. Data were pooled as proportions using inverse-variance weighting.

Results: A total of 239 studies (71 new studies and 168 from our previous meta-analysis) and 61,962 patients were included. The overall pooled rate of permanent SCI was 3.3% [95% confidence interval (CI), 2.9–3.8%]. Open repair was associated with a permanent SCI rate of 4.0% (95% CI, 3.3–4.8%), and endovascular repair was associated with a permanent SCI rate of 2.9% (95% CI, 2.4–3.5%). Permanent SCI was 2.0% (95% CI, 1.2–3.3%) after DTA repair, and 4.7% (95% CI, 3.9–5.6%) after TAAA repair; permanent SCI rate was 3.8% (95% CI, 2.9–5.0%) for Crawford extent I, 13.4% (95% CI, 9.0–19.5%) for extent II, 7.1% (95% CI, 5.7–8.9%) for extent III, 2.3% (95% CI, 1.6–3.5%) for extent IV, and 6.7% (95% CI, 1.7–23.1%) for extent V TAAA aneurysms. The pooled rate of CSF drain related complications was 1.9% (95% CI, 0.8–4.7%) for severe, 0.4% (95% CI, 0.0–4.0%) for moderate, and 1.8% (95% CI, 0.6–5.6%) for minor complications.

Conclusions: Permanent SCI occurs after both endovascular and open DTA or TAAA repairs. Open repairs and TAAA repairs have higher risk of SCI compared with endovascular or DTA repairs. In particular, extent II aneurysms present the highest overall risk of SCI.

Keywords: Spinal cord injury (SCI); thoracoabdominal aortic aneurysm (TAAA); open; endovascular; cerebrospinal fluid drain

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Introduction

Spinal cord injury (SCI) after descending thoracic aneurysm (DTA) or thoracoabdominal aortic aneurysm (TAAA) repair is a devastating complication of aortic surgery, and has been affecting the outcomes of open aortic repair since its introduction in the 1950's (1) and persisting despite the introduction of less invasive endovascular aortic repair techniques in the contemporary era (2). Despite advancements in the preoperative, intraoperative, and postoperative care of DTA/TAAA repairs, postoperative SCI remains a source of major morbidity. The origin of SCI is likely multifactorial, resulting from factors such as occlusion of intercostal and lumbar arteries by the aortic graft or endovascular stent, perioperative hypotension, or embolic events. Postoperative SCI can either be temporary or permanent. The incidence of SCI has been reported to be between 2% and 10% (3-5) after open or endovascular repair, although estimating the general incidence rate (IR) is challenging as most of the data are from retrospective, single-center observational studies with major limitations of sample size, disparate surgical techniques, complex patient anatomy and pathology, and preexisting comorbidities. In this meta-analysis, we provide a comprehensive systematic review and an update of a meta-analysis previously published by our group on SCI, mortality, and cerebrovascular events after open or endovascular repair of DTA/TAAA.

Methods

Search strategy

A medical librarian (MD) performed a comprehensive search to identify randomized trials and observational cohort studies of TAAA and DTA repair from July 2018 to September 2022. Searches were run on September 13, 2022, in the following databases: Ovid MEDLINE (ALL; July 1, 2018, to September 13, 2022); Ovid EMBASE (July 1, 2018 to September 13, 2022); and The Cochrane Library (Wiley; July 1, 2018 to September 13, 2022). The full search strategy for each database is available in Table S1.

Study selection and data extraction

The search strategy retrieved 6,176 studies. Following de-duplication, three reviewers (TA, LH, KRA) independently screened a total of 4,100 titles and abstracts. Any discrepancies were resolved by the senior author (MG). Titles and abstracts were reviewed against the prespecified inclusion/exclusion criteria. Studies were included if they were written in English, if they were randomized trials or observational studies reporting outcomes of endovascular and/or open repair of TAAAs and/or DTAs, due to either a degenerative process or post-chronic dissection. Studies were excluded if they were animal studies, abstracts only, case reports, commentary, conference presentations, editorials, expert opinions, studies reporting repair of other aortic pathologies (acute dissection, traumatic aneurysms, aortic ruptures, aortic ulcers), studies reporting less than 10 patients, and studies not clearly defining the strategy used or using hybrid procedures. Only the largest national registry databases from (US, Japan, and Italy) were included. Two hundred fifty-two [252] full text studies were evaluated to assess for eligibility. Reference lists for articles selected for inclusion in the study were also searched for relevant articles. The full Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (6) flow diagram outlining the study selection process is available in Figure S1.

All studies were reviewed by two independent investigators (TA, KRA), and disagreements were resolved by the senior author (MG). For studies with overlapping patient populations, the largest series were included. Seventy-one [71] studies were included for data extraction. Three investigators (TA, LH, KRA) performed data extraction independently. The following variables were included: study data (institution, country, study period, number of patients, study design) (Table S2), patient demographics [age, sex, comorbidities (diabetes, hypertension, smoking, coronary artery disease, chronic renal failure, and chronic obstructive pulmonary disease)] (Tables S3,S4). Aneurysm characteristics and procedural details (previous aortic surgery, aortic dissection, acute dissection, cerebrospinal fluid (CSF) drain use, use of left heart bypass, selective renal perfusion, circulatory arrest, sequential cross-clamping, or clamp-and-sew technique, and mean cross-clamp time) were reported in (Tables S3,S4). The quality of the included studies was assessed using the Newcastle-Ottawa Scale (NOS) for observational studies and the Cochrane risk-of-bias (RoB 2) tool for randomized trials (Tables S5,S6).

Outcomes

The primary outcome was the rate of permanent postoperative SCI. Secondary outcomes included temporary SCI, operative (30-day/in-hospital) mortality, follow-up mortality, postoperative stroke, and CSF drain-related complications using the individual studies' definitions. CSF drain-related complications were classified as severe (subdural hematoma, epidural hematoma, cerebellar hemorrhage, intracranial hemorrhage, subarachnoid hemorrhage, meningitis, and catheter/drainage-related neurologic deficit), moderate [spinal headache, CSF leak requiring intervention (i.e., blood patch or suturing), drain fracture requiring or not requiring surgical removal, cranial hypotension syndrome], or minor (puncture-site bleeding, bloody spinal fluid, CSF leak not requiring intervention, drain fracture left in place, and occluded/dislodged catheters, pale hemorrhagic discharge) based on a previous definition (7).

Meta-analysis

Short-term binary outcomes were reported and pooled as proportions (%) with 95% confidence interval (CI) using the generic inverse-variance method. Events were extracted from the individual studies or calculated based on the proportion of patients with the corresponding outcome among all patients treated. For follow-up mortality, IR with Poisson model with a constant event rate was used to account for different length of follow-up among studies with the total number of events observed within a group, calculated out of the total person-time follow-up for that group based on each study's follow-up. Random effect meta-analysis was performed, and heterogeneity was considered low (I^2=0–25%), moderate (I^2=26–50%), or high (I^2>50%). Publication bias assessment was carried out using funnel plot and Egger's test (Figure S2). Leave one-out analysis for the primary outcome was performed as a sensitivity analysis. Subgroup analyses were performed for DTAs, TAAAs, open and endovascular repair, Crawford extent of TAAAs, studies reporting on patients operated after the year 2000, CSF drain use, and studies with the highest NOS scores (eight or nine stars). Meta-regression was used to explore the effects of study period, publication year, hospital volume, age, sex, patient variables [coronary artery disease, chronic renal failure, chronic obstructive pulmonary disease, acute/chronic dissection, aneurysm type (TAAA/DTA)], and operative variables (open *vs.* endovascular repair, use of clamp-and-sew technique, use of CSF drain, and use of circulatory arrest or left heart bypass) on the primary outcome. Statistical significance was set at the two-tailed 0.05 level, without multiplicity adjustments. All statistical analyses were performed using R (version 4.2.1) within R Studio using "metafor" and "meta" packages (*Table 1*).

Results

Study and patient characteristics

A total of 239 studies were included in the final analysis; 71 studies from the 252 studies that were retrieved for full-text review, and additional 168 studies were included from our group's previous meta-analysis (5), and one study (4) was excluded from the analysis due to overlapping patient population (Figure S1). The majority (84.1%) of the studies were retrospective (201/239), 15.5% (37/239) were prospective, and one was a randomized trial. Seventy-seven [77] studies were conducted in the United States, 29 in China, 29 in Japan, 21 in Italy, 11 in the United Kingdom, and 5 multi-national studies (Table S2). The quality of the included studies according to the NOS and the ROB 2 tool are provided in Tables S5,S6. Overall, 61,962 patients were included in the final analysis, and the patient population of each individual study ranged from 10 to 14,235. The mean age range was 36 to 86 years, and the percentage of male patients ranged from 28.6% to 94.3%. Patient demographics of individual studies are reported in Table S3.

Meta-analysis

Primary outcome

The overall pooled event rate of permanent SCI was 3.3% (95% CI, 2.9–3.8%). In subgroup analyses, the pooled rate of permanent SCI after open repair was 4.0% (95% CI, 3.3–4.8%), and 2.9% (95% CI, 2.4–3.5%) after endovascular repair (Figure S3). Permanent SCI rate was 2.0% (95% CI, 1.2–3.3%) for DTA repair and 4.7% (95% CI, 3.9–5.6%) for TAAA repair (Figure S4). For DTAs, open repair was associated with permanent SCI rate of 2.0% (95% CI, 1.0–4.3%), similar to the endovascular repair permanent SCI rate was 2.0% (95% CI, 1.1–3.8%) (Figure S5). TAAA repair was associated with a 5.6% SCI rate (95% CI, 4.4–7.2%) with the open technique and 3.9% (95% CI, 3.1–4.8%) with endovascular techniques (Figure S6). Pooled permanent SCI when stratified by aneurysm type (DTA and TAAA) showed no significant difference between open and endovascular repair (Figures S7,S8). In subgroup analysis based on TAAA Crawford extent, the pooled rate of permanent SCI was 3.8% (95% CI, 2.9–5.0%) for Crawford extent I, 13.4% (95% CI, 9.0–19.5%) for extent

Table 1 Summery of outcomes

Outcomes	Studies	Patient number	Effect estimate (%) (95% CI)	Heterogeneity (I^2) (%)	$P_{interaction}$
Permanent spinal cord injury	214	60,602	3.3 (2.9–3.8)	81.1	–
DTA	22	2,714	2.0 (1.2–3.3)	40.8	0.002
TAAA	107	37,202	4.7 (3.9–5.6)	86.4	
Open	80	20,498	4.0 (3.3–4.8)	83.0	0.02
Endo	134	40,104	2.9 (2.4–3.5)	73.2	
DTA open	13	1,413	2.0 (1.0–4.3)	43.0	0.01
TAAA open	53	11,270	5.6 (4.4–7.2)	88.0	
DTA endovascular	9	1,301	2.0 (1.1–3.8)	42.0	0.06
TAAA endovascular	54	25,932	3.9 (3.1–4.8)	68.0	
DTA open	13	1,413	2.0 (1.0–4.3)	43.0	0.98
DTA endovascular	9	1,301	2.0 (1.1–3.8)	42.0	
TAAA open	53	11,270	5.6 (4.4–7.2)	88.0	0.03
TAAA endovascular	54	25,932	3.9 (3.1–4.8)	68.0	
Extent I	10	1,280	3.8 (2.9–5.0)	0.0	<0.001*
Endo	2	21	15.2 (3.4–47.4)	64.0	0.06
Open	8	1,259	3.7 (2.8–4.8)	0.0	
Extent II	15	1,686	13.4 (9.0–19.5)	70.6	<0.001*
Endo	4	79	21.5 (13.8–31.9)	0.0	0.05
Open	11	1,607	11.8 (7.6–17.9)	66.0	
Extent III	12	1,012	7.1 (5.7–8.9)	0.0	<0.001*
Endo	3	93	5.4 (2.3–12.3)	0.0	0.50
Open	9	919	7.3 (5.8–9.1)	2.0	
Extent IV	12	1,031	2.3 (1.6–3.5)	0.0	<0.001*
Endo	5	174	2.3 (0.9–6.0)	0.0	0.98
Open	7	857	2.3 (1.5–3.6)	0.0	
Extent V	3	30	6.7 (1.7–23.1)	0.0	<0.001*
Endo	–	–	–	–	–
Open	3	30	6.7 (1.7–23.1)	0.0	–
CSF drain 100% patients	24	3,577	3.5 (2.5–4.9)	58.1	0.23
CSF drain 0% patients	8	362	1.5 (0.3–5.7)	0.0	
CSF drain ≥75% patients	53	9,189	3.8 (3.0–4.9)	82.9	0.62
CSF drain <75% patients	61	18,437	3.6 (3.0–4.3)	68.3	
CSF drain ≥50% patients	76	12,748	3.9 (3.2–4.6)	79.1	0.33
CSF drain <50% patients	38	14,878	3.3 (2.5–4.4)	77.1	

Table 1 (*continued*)

Table 1 (*continued*)

Outcomes	Studies	Patient number	Effect estimate (%) (95% CI)	Heterogeneity (I^2) (%)	$P_{interaction}$
30-day/in-hospital mortality	210	65,067	4.8 (4.1–5.6)	86.8	–
Late mortality	141	–	6.1 (5.3–7.1)	93.0	–
Stroke	183	50,186	2.9 (2.3–3.6)	82.6	–
Temporary spinal cord injury	114	22,597	3.1 (2.5–3.8)	73.7	–
Studies with highest NOS ratings					
Permanent spinal cord injury	115	28,273	3.2 (2.7–3.9)	78.1	
Operative mortality	111	21,339	4.6 (3.7–5.8)	85.1	
Late mortality	90	–	6.7 (5.6–8.0)	93.5	
Stroke	96	19,481	2.9 (2.0–3.9)	84.9	

*, $P_{interaction}$ for Crawford extents. CI, confidence interval; DTA, descending thoracic aneurysm; TAAA, thoracoabdominal aortic aneurysm; CSF, cerebrospinal fluid; NOS, Newcastle-Ottawa Scale.

II, 7.1% (95% CI, 5.7–8.9%) for extent III, 2.3% (95% CI, 1.6–3.5%) for extent IV, and 6.7% (95% CI, 1.7–23.1%) for extent V (Figure S9A-S9E).

Secondary outcomes

Temporary SCI was reported in 114 studies with a total of 22,597 patients, with the pooled rate at 3.1% (95% CI, 2.5–3.8%; Figure S10). The 30-day/in-hospital mortality was reported in 210 studies with 65,067 patients, with the pooled rate at 4.8% (95% CI, 4.1–5.6%; Figure S11). Follow-up mortality at a weighted median follow-up of 3.9 years was 6.1% (95% CI, 5.3–7.1%; Figure S12). The pooled rate of postoperative stroke from 183 studies and 50,186 patients was 2.9% (95% CI, 2.3–3.6%; Figure S13) (*Table 1*: summary of outcomes). CSF drain-related complications were reported in 13 studies (*Table 2*), with a total of 986 patients undergoing CSF drain placement. The pooled rate of severe complications was 1.95% (95% CI, 0.75–4.67%), moderate complications was 0.38% (95% CI, 0.03–3.97%), and minor complications was 1.81% (95% CI, 0.57–5.56%; Figure S14; Table S7). The pooled permanent SCI rate in the studies that reported CSF drain in ≥50% of the patient when compared to the studies that reported ≤50% of patients was not different, at 3.9% (95% CI, 3.2–4.6%) *vs.* 3.3% (95% CI, 2.5–4.4%, P=0.33; Figures S15-S17). Leave one-out analysis for the primary outcome was performed as a sensitivity analysis (Figure S18). We also noticed that there are no changes in permanent SCI over the last five years (Figure S19).

Meta-regression

Meta-regression showed an association between DTA repair, endovascular repair, and clamp and saw technique with lower rate of permanent SCI (beta =–0.009, P=0.05), (beta =–0.336, P=0.02), (beta =–0.020, P=0.04), respectively (*Table 3*).

Discussion

This study is an updated meta-analysis of one previously conducted by our group (5), which includes all relevant studies published from July 1, 2018 to September 13, 2022. The final analysis consists of a total of 239 studies and 61,962 patients. The overall pooled rate of permanent SCI after TAAA or DTA repair was 3.3% including both endovascular and open surgeries, with the permanent SCI rate being numerically higher after open repair compared with endovascular repair. Furthermore, the rate of SCI was found to be numerically higher after TAAA repair (4.7%, 95% CI, 3.9–5.6%) than DTA repair (2.0%, 95% CI, 1.2–3.3%; P=0.002). Of note, the highest rate of permanent SCI was observed in patients who underwent Crawford extent II repair, with a rate of 13.4% (95% CI, 9.0–19.5%).

Due to the anatomical and pathological complexity of the disease, in addition to the complicated patient population and surgical procedures, the current literature has reported varying IRs of SCI. Our data compares similarly to large contemporary national registry studies

Table 2 Complications related to cerebrospinal fluid drain use

Study*	No. of patients with drain	Severe complications									Moderate complications				Minor complications		Total		
		Subdural hematoma	Subarachnoid bleeding	Epidural hematoma	Cerebellar hemorrhage	Intracranial bleeding	Meningitis	Para-lumbar infection	Intraspinal hematoma and subsequent paraplegia	Neurological symptom of bilateral thighs	Spinal headache	Persistent CSF leak	Fractured catheter	Cranial hypotension syndrome	Bleeding at spinal puncture side	Pale hemorrhagic discharge	Minor	Moderate	Severe
Abdelbaky 2021	100	2	NR	NR	NR	NR	NR	NR	NR	NR	5	7	NR	NR	NR	3	8	7	2
Andersen 2014	9	1	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	0	0	1
Bisdas 2015	64	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	4	NR	NR	4	0	0
Dias 2015	64	2	3	1	NR	NR	2	1	NR	NR	NR	NR	NR	NR	NR	NR	0	0	9
Ferreira 2008	11	NR	NR	NR	NR	NR	NR	1	NR	NR	NR	NR	NR	NR	NR	NR	0	0	1
Hicks 2017	137	NR	NR	NR	NR	NR	NR	NR	NR	NR	4	NR	NR	NR	NR	NR	4	0	0
Hiraoka 2018	55	NR	NR	NR	NR	NR	NR	NR	1	NR	NR	NR	NR	NR	NR	NR	0	0	1
Katsargyris 2015	144	2	NR	NR	NR	NR	NR	NR	NR	NR	1	NR	NR	NR	2	NR	2	1	2
Kitpanit 2021	78	NR	2	NR	1	NR	NR	NR	NR	NR	2	NR	1	NR	7	NR	20	0	6
Marcondes 2023	22	NR	NR	NR	NR	1	1	NR	NR	NR	NR	NR	NR	NR	NR	NR	1	0	0
Sugiura 2017	78	1	NR	NR	NR	NR	1	NR	NR	1	13	NR	1	NR	NR	3	3	14	3
Van Calster 2019	197	NR	NR	NR	NR	NR	NR	NR	NR	NR	8	NR	NR	NR	NR	NR	0	8	0
Yunoki 2015	27	1	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	0	0	1

*, see Supplementary references. CSF, cerebrospinal fluid; NR, not reported.

Table 3 Univariable meta-regression for permanent spinal cord injury

Variable	Regression coefficient (beta) ± SD	P value
Study period	0.002±0.011	0.86
Publication year	0.011±0.017	0.54
Hospital volume	−0.0001±0.0004	0.74
Age	0.014±0.008	0.08
Male gender	−0.003±0.005	0.56
Coronary artery disease	0.004±0.005	0.412
Diabetes	0.008±0.010	0.45
Chronic renal failure	0.008±0.005	0.10
Chronic obstructive pulmonary disease	−0.002±0.001	0.11
Acute dissection	−0.004±0.003	0.16
Chronic/subacute dissection	0.008±0.004	0.10
DTA repair percent	−0.009±0.005	0.05*
Endovascular repair (*vs.* open)	−0.336±0.138	0.02*
Clamp-and-sew technique	−0.020±0.010	0.04*
Circulatory arrest	−0.002±0.006	0.75
Left heart bypass	0.007±0.004	0.13
Cerebrospinal fluid drain use	0.004±0.003	0.12

*, significant results. SD, standard deviation; DTA, descending thoracic aneurysm.

reporting on SCI injury after both open and endovascular procedures. Hoshina *et al.* (8), using data from the Japanese Committee for Stentgraft Management's national registry, reported a 3.7% paraplegia rate in 13,235 patients after endovascular repair of TAAA; similarly Scali *et al.* (9) using the Vascular Quality Initiative (VQI) database, reported a 2.1% permanent SCI after 6,529 thoracic endovascular aortic aneurysm repairs. In a population-based study using propensity-score matching including 664 patients, Rocha *et al.* (10) reported similar permanent paraplegia rates in patients with open *vs.* endovascular TAAA repair (4.1% *vs.* 4.6%; P>0.99). In the largest observational study of open TAAA repair comprising of 3,309 patients, including 1,066 patients with extent II repair, Coselli *et al.* (3) reported an SCI rate of 9.6%, whereas Gambardella *et al.* (11) and Girardi *et al.* (4) reported an SCI rate of 2.9% and 2.6%, respectively, after open DTA/TAAA repair. Rocha *et al.* (12) in a meta-analysis of eight comparative observational studies reported lower SCI after endovascular TAAA repair compared to open repair [relative risk (RR), 0.65; 95% CI, 0.42–1.01; P=0.05; I^2=28%]. In a more recent meta-analysis including 71 studies, 24 endovascular repairs and 47 open repairs of TAAA, Rocha *et al.* (13) reported higher SCI rates after endovascular repair 13.5% (95% CI, 10.5–16.7%) *vs.* open repair 7.4% (95% CI, 6.2–8.7%; P<0.01). In our group's previous meta-analysis including 169 studies and 22,634 patients, we reported a pooled overall permanent SCI rate of 4.5%, 3.5% for DTA and 7.6% for TAAA, 5.7% for open repairs and 3.9% for endovascular repairs. A pooled meta-analysis of 43 studies and 7,168 patients by Dijkstra *et al.* (14) reported a permanent SCI of 2.2% after endovascular repair of DTA and TAAA. In another meta-analysis of 46 studies and 4,936 patients, Wong *et al.* (15) reported an overall SCI rate of 3.9% in patients who underwent endovascular TAAA repair. A pooled SCI rate of 8.3% after open TAAA repair was reported in a meta-analysis of 30 articles and a total of 9,963 patients by Moulakakis *et al.* (16).

The decision to use a CSF drain in DTA/TAAA repairs is based on individual patient factors, such as prior aortic surgery, aneurysm size, stent or graft length, hypogastric artery patency, as well as reimplantation and occlusion of intercostal and lumbar vessels. While CSF drain use is common, there is limited evidence to support its effectiveness in preventing SCI (17). Coselli *et al.* (18) in a randomized clinical trial of 145 patients who underwent extent I or II TAAA open repair, found that prophylactic CSF drainage was associated with a significantly lower SCI rate when compared with no prophylactic CSF drainage (2.6% *vs.* 13%, P=0.03). Similarly, Cinà *et al.* (19) in a meta-analysis of three randomized trials and 11 cohort studies reporting effectiveness of CSF drainage after thoracic aneurysm and TAAA open repairs, found that patients with CSF drain have a pooled odds ratio of 0.35 (95% CI, 0.12–0.99; P=0.05) for paraplegia development. However, Wong *et al.* (15) in a meta-analysis of the effect of preoperative CSF drainage in patients who underwent thoracic endovascular aneurysm repair, including 46 studies and 4,936 patients, reported SCI rate of 3.2% in patients with routine prophylactic CSF drain placement and 3.5% in patients with no CSF drain placement. Gaudino *et al.* (5) in our group's previous meta-analysis reported nonsignificant difference in SCI rate in studies reporting greater use of CSF drain compared to studies with lower use of CSF drain (4.8% *vs.* 5.5%, P=0.58). In this study, CSF drain use was reported in 13 studies and a total of 986 patients had a CSF drain placed; permanent SCI in the studies that reported CSF drain use in ≥50% of the patients was not significantly different when compared with the SCI rate in studies reporting drain use in ≤50% of patients [3.9% (95% CI, 3.2–4.6%) *vs.* 3.3% (95% CI, 2.5–4.4%); P=0.33]. This noted difference in the effectiveness of CSF drain might be explained by differences in the surgical approach, as Coselli *et al.* (18) and Cinà *et al.* (19) included only open procedures, while Wong *et al.* (15) and Gaudino *et al.* (5) included both open and endovascular repair in their meta-analyses. As open repairs are more invasive, more physiologically stressful, and are associated with greater blood loss and greater risk for intraoperative hypotension, the benefit of prophylactic CSF drainage may be more pronounced in patients undergoing open repair compared with endovascular repair.

In this analysis, we also reported the pooled rate of severe, moderate, and minor CSF drain complications as 1.95%, 0.38%, and 1.81%, respectively, which is lower than our group's previously published meta-analysis (5) that reported 5.0% for severe, 4.0% for moderate, and 4.0% for minor complications. In another recent meta-analysis, Rong *et al.* (7) reported the pooled CSF drain-related complications were 2.5%, 3.7%, and 2.0%, respectively. These lower rates of complications in this study might be due to the low number of studies that reported the complications, with fewer reported events which can be potentially due to underreporting.

Limitations

Although this is a comprehensive summary of current evidence on the incidence of SCI after DTA/TAAA repairs, it is important to interpret our analysis with caution due to methodological limitations intrinsic to pooled analyses of single-armed observational studies, and from the use of aggregated data, such as the ecological fallacy for meta-regression results (20). Moreover, the heterogeneity of the patient population, pathological and anatomical disease characteristics, presence of genetic connective tissues disorders, previous aortic surgical interventions, differences in surgical techniques, use of different types of endovascular grafts (fenestrated, branched, physician modified), variability in operators' volume and experience, and differences in perioperative and postoperative care protocols, all could impact surgical decision-making and outcomes. Even though our analysis showed low-to-moderate levels of heterogeneity among the included studies, not all primary and secondary outcomes were reported in all studies, which might have influenced the power of the subgroup analysis and the results of meta-regression.

Conclusions

After analyzing 239 current studies and a total of 61,962 patients, we found that open repairs and TAAA repairs appear to be at higher risk of SCI compared with endovascular or DTA repairs. Notably, extent II aneurysms present the highest overall risk of SCI. Given the complexity of the disease and the surgical methods involved, as well as the scarcity of randomized controlled trials, more advanced and meticulous prospective data gathering, or ideally randomized controlled trials, should be undertaken to shed light on some of the unresolved issues.

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Footnote

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