Spine Deformity (2024) 12:1253–1260
https://doi.org/10.1007/s43390-024-00916-w

REVIEW ARTICLE

High incidence of dural tears with 3-column osteotomies: a systematic review of adult spinal deformity surgery literature for the past decade

Anna Martin[1,2] · Jamal Zahir[2] · Nathan Smith[3] · Oluwatodimu Raji[1,2] · David Nelles[1,2] · Dimitriy Kondrashov[1,2]

Received: 5 March 2024 / Accepted: 3 June 2024 / Published online: 24 June 2024

Abstract

Purpose Dural tear (DT) is a well-known complication of spinal surgery. We aimed to systematically review the literature from the past decade and determine the incidence and risk factors for DT in the adult spinal deformity (ASD) population to improve both the surgical strategy and counseling of patients undergoing ASD correction.

Methods A systematic review from 2013 to 2023 utilizing PRISMA guidelines was performed. The MEDLINE database was used to collect primary English language articles. The inclusion criterion for patients was degenerative ASD. Pediatric studies, animal studies, review articles, case reports, studies investigating minimally invasive surgery (MIS), studies lacking data on DT incidence, and articles pertaining to infectious, metastatic or neoplastic, traumatic, or posttraumatic etiologies of ASD were excluded.

Results Our results demonstrate that the incidence of DT in ASD surgery ranges from 2.0% to 35.7%, which is a much broader range than the reported incidence for non deformity surgery. Moreover, the average rate of DT during ASD surgery stratified by surgical technique was greater for osteotomy overall (19.5% +/− 7.9%), especially for 3-column osteotomy (3CO), and lower for interbody fusion (14.3% +/− 9.9%). Risk factors for DT in the ASD surgery cohort included older age, revision surgery, chronic severe compression, higher-grade osteotomy, complexity of surgery, rheumatoid arthritis (RA), and higher Anesthesiology Society of America (ASA) grade.

Conclusion To our knowledge, this is the first systematic review discussing the incidence of and risk factors for DT in the ASD population. We found that the risk factors for DT in ASD patients were older age, revision surgery, chronic severe compression, a greater degree of osteotomy, complexity of surgery, RA, and a higher ASA grade. These findings will help guide spine surgeons in patient counseling as well as surgical planning.

Keywords Adult spinal deformity · Spine · Dura · Durotomy · Osteotomy · Dural tear

Abbreviations

NS	Not specified
AS	Ankylosing spondylitis
ASA	American Society of Anesthesiologists
VCR	Vertebral column resection
APSO	Asymmetric pedicle subtraction osteotomy
XLIF	Extreme lateral interbody fusion
TLIF	Transforaminal lumbar interbody fusion
ALIF	Anterior lumbar interbody fusion
PLIF	Posterior lumbar interbody fusion
PSO	Pedicle subtraction osteotomy
SPO	Smith–Peterson osteotomy
3CO	Three-column osteotomy
RA	Rheumatoid arthritis
COPD	Chronic obstructive pulmonary disease
n	Total number

✉ Dimitriy Kondrashov
sfspine@gmail.com

[1] Department of Orthopaedic Surgery, San Francisco Orthopaedic Residency Program, St. Mary's Spine Center, 450 Stanyan St, San Francisco, CA 94117, USA

[2] The Taylor Collaboration Orthopaedic Biomechanics Laboratory, San Francisco, CA, USA

[3] Penn State College of Medicine, Hershey, PA, USA

Introduction

Dural tears are among the most common complications of ASD surgery. Its reported incidence is quite variable. According to the Scoliosis Research Society (SRS) morbidity and mortality database analysis, it ranges from approximately 2 to 4% [1, 2]. Other studies have indicated quite different rates [3–5].

The dura mater, the outermost meningeal layer enveloping the central nervous system, is approximately 380 µm thick and consists of fibroblasts and abundant collagen [6–8]. Cerebrospinal fluid (CSF) production occurs in the brain's choroid plexus via ependymal cells and reabsorption occurs via arachnoid granulations at the dural venous sinuses, with almost 125 mL of CSF circulating at any time in adult humans and a daily generation of approximately 500 mL [9].

In spine surgery, most DTs and subsequent CSF leaks are iatrogenic [10]. Intraoperatively, DTs may present with leakage of CSF, which can subsequently subside even without watertight closure due to either depletion of CSF or plugging of the dural defect with nerve rootlets [11]. Prompt recognition and treatment are vital, and primary watertight suture closure is standard. Larger or irreparable tears necessitate augmentation with a dural patch or sealant [12].

Postoperatively, there may also be persistent leakage of clear fluid from the incision site. Patients may also develop a pseudomeningocele, which may be asymptomatic and can only be detected on subsequent imaging [13]. Postoperatively, a missed DT may become more difficult to diagnose and treat. Radiographic imaging can help make a definitive diagnosis; MRI and CT myelograms may provide useful diagnostic tools for identifying missed or persistent DTs postoperatively [14]. The constellation of signs (e.g. egress of clear fluid from incision site) and symptoms (e.g. positional headaches) of a dural tear and subsequent CSF leak is most essential for diagnosis and should warrant immediate evaluation and management [15]. However, small leaks may be obscured by postoperative changes, may only cause transient symptoms, and may not require surgical intervention [16]. Recognition and primary repair of DTs are paramount; therefore, identifying factors associated with DTs in high-risk surgical populations, such as those with ASD, may enable the identification of high-risk patients who require extra vigilance.

DTs due to ASD surgery, if not corrected, can result in numerous complications, such as infection, meningitis, spinal headache, nausea, vomiting, photophobia, persistent CSF leakage, chronic draining fistula, nerve root entrapment, and noncommunicating hydrocephalus. If not corrected, this can result in long-term sequelae such as ascending hygroma, subarachnoid hemorrhage, intraventricular hemorrhage, and subdural hematoma [11, 17, 18].

Herein, we aimed to determine the incidence and risk factors for DT during adult spinal deformity surgery. We hypothesized that a greater incidence of DT will be observed in ASD surgery involving higher-grade osteotomies, less experienced surgeons, and older patients [10, 19, 20]. This research addresses current gaps in understanding the incidence and risk factors specific to ASD surgery-related DTs.

Materials and methods

Literature search

A systematic review following PRISMA guidelines was performed [21]. A PubMed (MEDLINE) search of articles between 2013 and 2023 was performed: (((Lumbar) OR (Thoracic) OR (Spine) OR (Kyphosis) OR (Lordosis) OR (Scoliosis) OR (Deformity)) AND (Surgery)) AND ((dural tears) OR (dural tear) OR (Durotomy)). Unscreened articles via title alone were assessed through abstracts or full texts. Inclusions/exclusions involved two reviewers; disputes were settled by a third reviewer. The search and screening resulted in nine retrospective studies, one prospective study, and one case series, with a total of 65,227 patients among all studies.

Inclusion and exclusion criteria

Primary English-language articles from 2013 to 2023 reporting DT incidence in ASD surgery patients were included. Only patients with degenerative or idiopathic ASD etiologies were included, including iatrogenic deformity. The exclusion criteria were pediatric patients (< 17 years old), animal studies, reviews, case reports, minimally invasive surgery (MIS), studies not citing DT incidence, and ASD due to infection, neoplasm or trauma.

Data extraction

The primary author, type of study, publication date, number of patients, demographic characteristics of patients, ASD type and corrective surgery performed, management, vertebral level, dural repair, DT incidence, and complications were extracted, if available.

Bias management

Clearly defined inclusion and exclusion criteria, a comprehensive search strategy, and transparent reporting were utilized for control of bias.

Results

Study selection

First, the initial results yielded 1068 articles from 2013 to 2023, with 1002 studies remaining after duplicate removal. Second, 936 studies were excluded after title review, while

66 were retained. Third, 43 studies were further excluded after abstract screening, and 23 were retained. Finally, a full-text review excluded another 12 articles. Eleven articles were ultimately included in the systematic review (PRISMA flowchart Fig. 1).

Study and patient characteristics

The included articles were all published between 2013 and 2023. The number of patients included in each study ranged from 14 to 52,818. Patients who underwent ASD surgery for pathologies such as idiopathic scoliosis, degenerative kyphosis, and ankylosing spondylitis (AS) with kyphotic deformity were included in this systematic review.

Dural tear rate and risk factors

The DT rate ranged from 2.0 to 35.7%, with a mean of 11.5%, among the selected studies (Table 1). The risk factors for DT in the ASD surgery population were older age, revision surgery, a greater degree of osteotomy, chronic severe compression, scar tissue, complexity of surgery, RA, and a higher ASA grade [1, 4, 17, 22–27].

The associations between the incidence of DT and surgical technique used in our selected studies are highlighted in Table 2. The incidence of DT was greatest in the asymmetric pedicle subtraction osteotomy (APSO) group (35.7%). Table 3 shows the average incidence of DT based on surgical technique. We found that the average DT incidence was greatest for 3CO (22.7% +/− 8.3%) and lowest for posterior column osteotomy (i.e., Smith Peterson or Ponte osteotomy) (12.1% +/− 0.5%), closely followed by interbody fusion (14.3% +/− 9.9%).

Previous studies have also identified various risk factors for DT in the ASD population, including older age, osteotomy, greater body mass index (BMI), revision surgery, increased surgical duration, and case start time after 4 pm [28–31].

Fig. 1 PRISMA Flow Chart

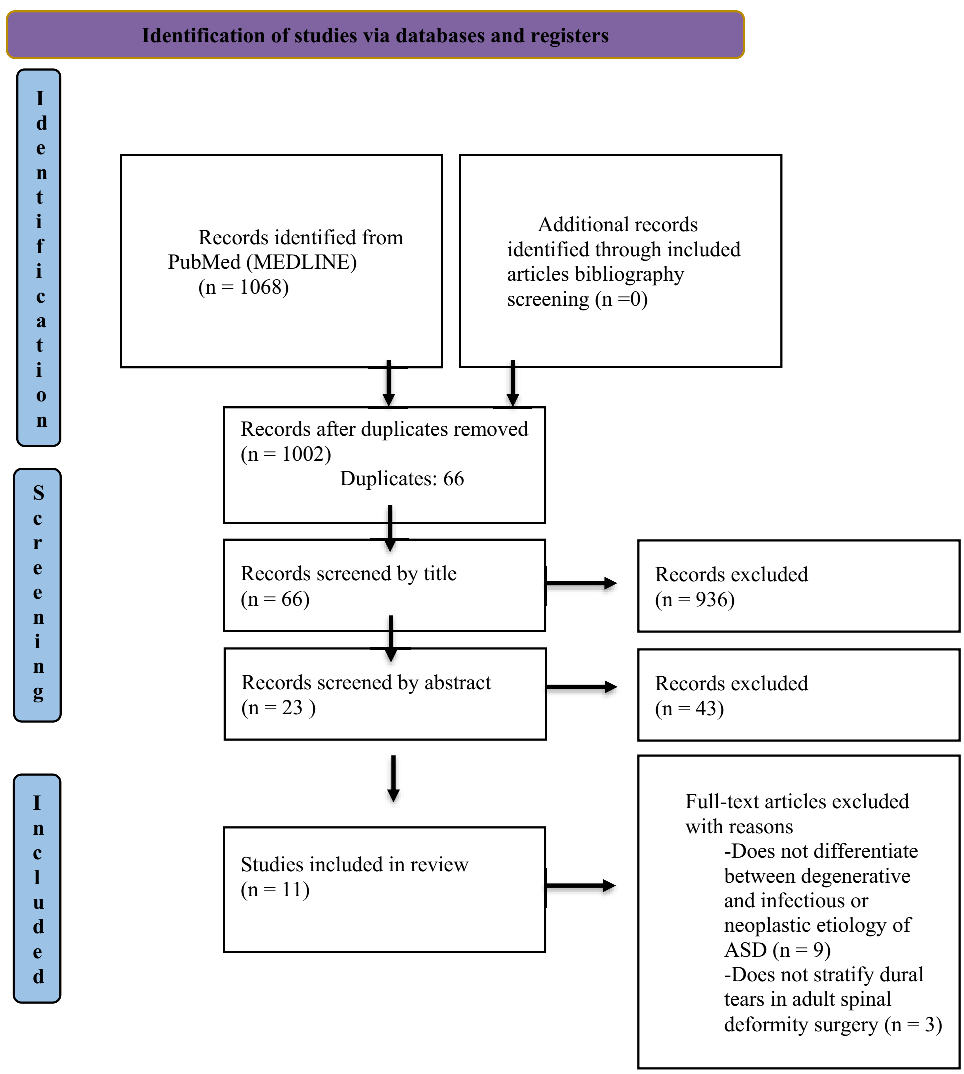

Table 1 Summary of Key Articles, DT Rate, and Risk Factors

Author & year	No. of patients	Procedure	Pathology	Durotomy rate	DT risk factors
Iyer et al. 2018	564	ALIF, TLIF, XLIF, PLIF, PSO, SPO, VCR	Scoliosis and kyphosis	10.8%	Prior spine surgery, decompression, interbody fusion, higher ASA grade, and osteotomy
Jo et al. 2015	87	PSO, SPO	AS with kyphotic deformity	17.2%	PSO, complexity of surgery, higher-grade osteotomy
Shaw et al. 2016	5,470	ALIF, PLIF, osteotomy	Idiopathic and degenerative scoliosis	3.4%	Older patients, especially over 50 years of age
Bernstein et al. 2018	52,818	Fusion type not specified	Scoliosis, kyphosis	4.0%	RA
Chen et al. 2020	97	PLIF	Degenerative scoliosis	2.0%	Free hand pedicle screw placement
Skovrlj et al 2015	5,117	Fusion type not specified	Scoliosis	3.4%	Surgeon experience not a significant risk factor
Smith et al. 2017	82	PSO, VCR	Scoliosis, kyphosis	20.7%	Operative technique
Chan et al. 2019	14	APSO	Scoliosis	35.7%	Scar tissue, revision surgery, prior instrumentation removal
Kwan et al. 2018	272	3CO	Scoliosis	15.8%	Older age, prior surgery, number of non neurological comorbidities, ASA grade
Elsamadicy et al. 2018	559	Fusion type not specified	NS	6.8%	No difference in COPD vs no COPD cohorts
Karikari et al. 2018	147	Posterior fusion	Scoliosis	6.8%	Osteophytic erosion, chronic severe compression, decompression

Table 2 Incidence of DT during ASD surgery in selected key articles

Author & year	Surgical technique	Incidence of DT stratified by surgical technique % (# of DT/total)
Iyer et al. 2018	Interbody fusion	XLIF: 10.4% (5/48)
		TLIF: 13.6% (20/147)
		ALIF: 16.4% (21/128)
		PLIF: 29.2% (7/24)
	Osteotomy	SPO: 11.7% (34/291)
		PSO: 25.8% (24/93)
		VCR: 16.0% (4/25)
Jo et al. 2015	Osteotomy	SPO: 12.5% (4/32)
		PSO: 20.0% (11/55)
Chen et al. 2020	Interbody fusion	PLIF: 2.0% (2/97)
Chan et al. 2019	Osteotomy	APSO: 35.7% (5/14)
Kwan et al. 2018	Osteotomy	3CO: 15.8% (43/272)
Karikari et al. 2018	Posterior	Laminectomy: 18.2% (10/55)

Discussion

Rate of dural tears in the ASD surgery population

DTs are among the most common, if not the most common, complications of spine surgery [20]. The Spine Patient Outcomes Research Trials (SPORT) study by Weinstein et al. revealed an overall DT rate of 4.0% for lumbar discectomy and 9.0% for decompressive laminectomy in a population without deformity [32, 33]. In comparison, we found a mean DT rate of 11.5% in ASD surgery—a somewhat greater incidence than in degenerative spine surgeries—especially given that ASD surgery does not always involve decompression or dural exposure.

On the other hand, the SRS morbidity and mortality database indicated a lower occurrence of DT (2.9–3.4%) during ASD surgery than our mean DT rate of 11.5% [1]. The lower DT rates in the SRS morbidity and mortality database may be because SRS members are typically some of the most experienced deformity surgeons worldwide. Moreover, the SRS morbidity and mortality database may be subject to recall bias, as it is a retrospective database of annual voluntary data input by select participating surgeons.

Risk factors for dural tears

Considering our results, one should be particularly vigilant for DTs in patients undergoing 3COs, higher-grade osteotomy, older patients, and revision surgery (Table 1). Identifying high-risk patients is of particular importance because

Table 3 Incidence of DT based on surgical technique for ASD correction

Surgical Approach	Average	Standard deviation	Range
Any interbody fusion (PLIF, TLIF, ALIF, XLIF)	14.3%	9.9%	2.0–29.2%
Any osteotomy (PSO, APSO, SPO, VCR, 3CO)	19.5%	7.9%	11.7–35.7%
3-column osteotomy (PSO, APSO, VCR, 3CO)	22.7%	8.3%	15.8–35.7%
Posterior-column osteotomy (SPO)	12.1%	0.5%	11.7–12.5%

DTs can often be managed promptly and in a relatively straightforward fashion intraoperatively.

Other recognized risk factors for DT in ASD surgery include female sex, late case start time (after 4 pm), and greater BMI [4, 20, 26, 28–31, 34].

Osteotomy

Numerous studies have individually emphasized the increased DT risk associated with osteotomy in general, especially 3CO (e.g., APSO, PSO, and VCR). We found an average DT risk of 19.5% +/− 7.9% with osteotomy overall, which is higher than that reported in the literature during ASD surgery [4, 17, 24, 25].

Our results clearly demonstrated that more invasive procedures (e.g., 3CO) yielded a greater average DT incidence (22.7% +/− 8.3%), while relatively less invasive procedures such as interbody fusion yielded a lower average DT incidence (14.3% +/− 9.9%), which is in line with previous studies [4, 17]. Figure 2 clearly shows that osteotomy, especially 3CO, is one of the greatest risk factors for DT in the ASD surgery population.

Notably, 3COs (e.g., PSO and VCR) are more invasive than posterior-column osteotomies (e.g., SPO), necessitating multiple rounds of passing sharp osteotomes and curettes around the exposed dura, which likely explains the greater incidence of DTs. Increased osteotomy angles and the resulting greater manipulation of the dura may further increase the chances of DT. Importantly, most DT patients did not experience long-term complications during subsequent follow-up.

A study conducted by Smith et al. revealed 17 cases of DT during 3CO, resulting in an incidence rate of 20.7% - nearly six times the rate reported in SRS database studies and twice the rate reported with laminectomy in the SPORTS trial. This value approaches the 1 in 3 rate of DT reported by Chan et al. for APSO. Although likely underpowered, the study's findings indicated that the likelihood of DT was primarily associated with surgical factors rather than patient age [24].

In contrast, the study by Mills et al. revealed that there was no statistically significant difference in DT occurrence between 3-level single-column osteotomy and single-level 3CO for degenerative spinal pathology [35]. This indicated a cumulative DT risk with even lower-grade osteotomies.

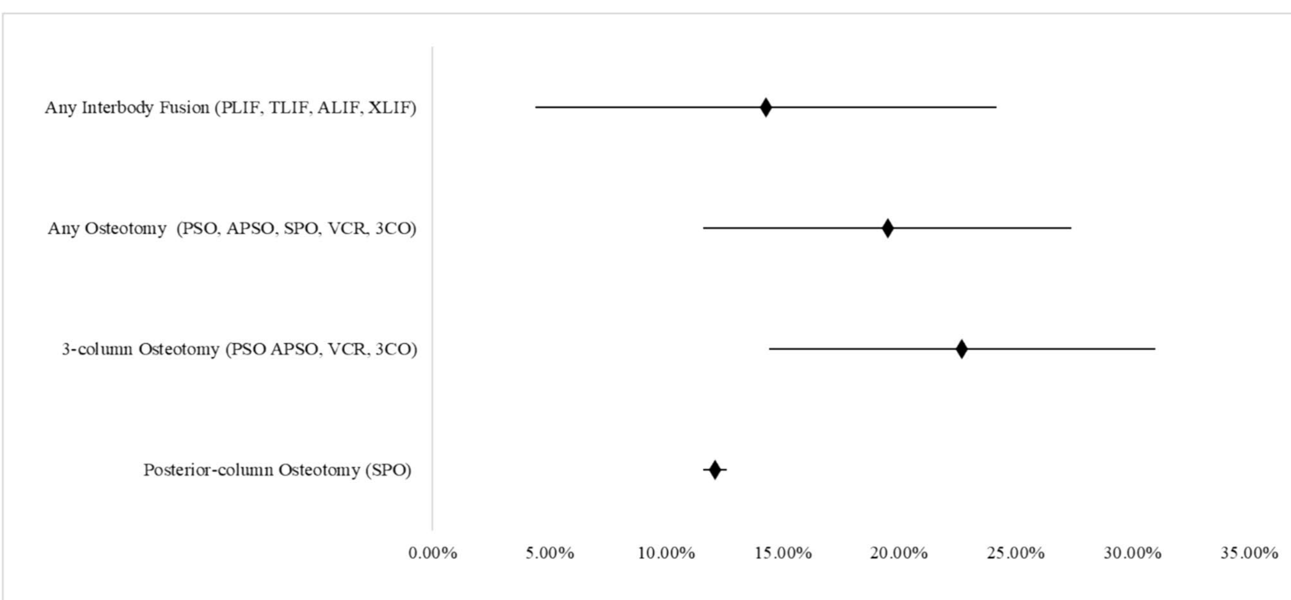

Fig. 2 DT Rate Among Our Key Articles Stratified by Surgical Technique (+/ − 1 standard deviation)

Revision surgery and prior spine surgery

Our analysis demonstrated that revision spine surgery was a risk factor for DTs (Table 1). Prior spine surgery may result in epidural fibrosis and peridural scar tissue, thus increasing the risk of DT. This makes intuitive sense and is supported by evidence from previous studies [36–38]. To illustrate this point, a prospective cohort study by Smorgick et al. revealed that DT risk was significantly greater in patients with a prior history of spine surgery ($p < 0.001$).

In fact, a prospective cohort study by Baker et al. revealed that among other risk factors, revision surgery was the strongest risk factor for DT, with a relative risk (RR) of 2.2 ($p < 0.001$) [39].

In cases involving previous decompression at the three-column osteotomy level and the presence of dural scar tissue, some surgeons opt to resect the dural scar to minimize dural buckling during sharp angular correction, which could further increase the risk of DT. A retrospective review by Khan et al. revealed that the resection of peridural scar tissue and fibrosis due to previous spine surgery increased the risk of DT [40].

Older age

Our analysis also revealed that age was one of the risk factors for DT (Table 1). This phenomenon may be attributed to higher rates of spinal stenosis in older patients. In fact, the study by Alshameeri et al. found that patients with spinal stenosis had significantly higher rates of incidental durotomy [1, 26, 36, 37].

Older patients typically have a greater amount of chronic nerve compression and stenosis and possibly have had a greater number of prior interventions, including epidural injections and laminectomies, which would result in greater peridural scar formation and DT risk [41]. Of note, the retrospective study by Labaran et al. found that patients aged 65–85 years old undergoing lumbar discectomy had a significantly higher likelihood of sustaining a dural tear if they received a lumbar epidural steroid injection within 3-6 months [42]. The retrospective study by Shakya et al. also demonstrated a significantly increased risk of dural tear during lumbar discectomy within 3 months of an epidural injection [43]. The exact relationship between recent epidural steroid administration and durotomy is somewhat unclear, though it is possible that epidural steroid administration may result in some degree of peridural scar formation.

Du et al. noted a link between lower Hounsfield Units (indicative of osteoporosis) and DT ($p = 0.023$), suggesting that osteoporosis was a risk factor for DTs, which might explain the greater risk of DT in older patients [27].

Similar to our results, other studies have also revealed that older age was significantly associated with DT risk [34, 37]. One of those studies was by Yoshihara et al., who reported that the DT risk significantly increased in patients aged 45–64 years ($p < 0.001$) and patients aged 65–84 years ($p < 0.001$).

Evaluation of additional risk factors

Chen et al. demonstrated a lower rate of DT in the robotics group than in the free-hand group, which suggests that robotics may decrease the risk of DT during ASD surgery [44]. This may be due to the greater precision of robotics compared to the free-hand anatomic technique.

Additional significant risk factors for DT include treatment at a hospital with a higher case load than at a hospital with a lower case load ($p = 0.044$), as demonstrated in the database study by Yoshihara, et al. [34]. The higher incidence of DTs in higher case load hospitals is likely due to those institutions handling more complex and more challenging revision cases and possibly greater magnitude of deformity. Those institutions are also likely dealing with sicker and older patients.

Interestingly, our results demonstrated that increasing ASA grade was associated with an increased risk of durotomy [4, 26]. The study by Somani et al. found that increasing ASA grade was independently associated with a significantly increased risk of any complication in spinal deformity surgery in adults [45]. Patients with higher ASA grade are typically older, have more comorbidities, and have more challenging anesthesia requirements, which we hypothesize may lead to difficulty in optimal patient positioning and altered tissue quality, possibly leading to unintended dural tears. Further expanding on the subject of comorbidities, the retrospective study by Elsamadicy found that there were no statistically significant differences in elderly patients with and without chronic obstructive pulmonary disease undergoing spinal deformity surgery [46]. This is interesting considering that prior studies found a significant association between comorbidities and incidence of dural tear.

Limitations

Limitations of this study are those inherent to retrospective reviews. Moreover, this paper did not evaluate the incidence and risk factors of dural tear in the cervical spine which is a topic for future research. Another limitation of this paper is that some of the data was extracted from database studies, which limited the granularity of data. Of note, many studies do not report DTs as a complication. Hopefully, future studies will routinely include dural tears as a complication.

Conclusion

In our analysis, the DT incidence in ASD surgery patients ranged from 2.0–35.7%, with a mean of 11.5%, which was higher than the current DT incidence reported in recent SRS morbidity and mortality database analyses. Higher-grade osteotomy (e.g. 3CO), previous spine surgery, and older age were the top risk factors for DT in the ASD surgery population. Our findings revealed several other risk factors for DT, including, chronic severe compression, surgical complexity, RA, and higher ASA grade. Understanding the influence of these factors will allow surgeons to better plan ASD surgery and recovery protocols, as well as to appropriately counsel patients preoperatively.

Author contributions Anna Martin, Jamal Zahir, Nathan Smith, Oluwatodimu Raji, David Nelles and Dimitriy Kondrashov : Data curation. Investigation. Writing original draft, review & editing. Approved version to be published. Agree to be accountable for all aspects of the work. Conceptualization and Principal Investigator. Formal Analysis. Methodology.

Funding The authors did not receive financial nor nonfinancial support from any organization for the submitted work.

Data availability The raw data used for the statistical analysis is available upon request.

Declarations

Conflict of Interest No financial nor nonfinancial conflicts of interest to disclose.

Ethical approval The CommonSpirit Health Research Institute has designated this study as "IRB exempt".

Informed Consent No human subjects were included in the study, so no informed consent was required.

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