Title
Dural Tears in Adult Deformity Surgery: Incidence, Risk Factors, and Outcomes.

Permalink
https://escholarship.org/uc/item/7363p53x

Journal
Global spine journal, 8(1)

ISSN
2192-5682

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Publication Date
2018-02-01

DOI
10.1177/2192568217717973

Peer reviewed
Abstract
Study Design: Retrospective cohort study.
Objectives: Describe the rate of dural tears (DTs) in adult spinal deformity (ASD) surgery. Describe the risk factors for DT and the impact of this complication on clinical outcomes.
Methods: Patients with ASD undergoing surgery between 2008 and 2014 were separated into DT and non-DT cohorts; demographics, operative details, radiographic, and clinical outcomes were compared. Statistical analysis included t tests or χ² tests as appropriate and a multivariate analysis.
Results: A total of 564 patients were identified. The rate of DT was 10.8% (n = 61). Patients with DT were older (61.1 vs 56.5 years, P = .005) and were more likely to have had prior spine surgery (odds ratio [OR] = 2.0, 95% confidence interval [CI] = 1.2-3.3, P = .007). DT patients had higher pelvic tilt, lower lumbar lordosis, and greater pelvic-incidence lumbar lordosis mismatch than non-DT patients (P < .05). DT patients had longer operative times (424 vs 375 minutes, P = .008), were more likely to undergo interbody fusions (OR = 2.0, 95% CI = 1.1-3.6, P = .021), osteotomies (OR = 2.2, 95% CI = 1.1-4.0, P = .012), and decompressions (OR = 2.3, 95% CI = 1.3-4.3, P = .003). In our multivariate analysis, only decompressions were associated with an increased risk of DT (OR = 3.2, 95% CI = 1.4-7.6, P = .006). There were no significant differences in patient outcomes at 2 years.
Conclusions: The rate of DT was 10.8% in an ASD cohort. This is similar to rates of DT reported following surgery for degenerative pathology. A history of prior spine surgery, decompression, interbody fusion, and osteotomies are all associated with an increased risk of DT, but decompression is the only independent risk factor for DT.
Keywords
dural tears, durotomy, incidental durotomy, adult spinal deformity, complications, osteotomy

Introduction
Dural tears (DTs) are a relatively common complication in spine surgery. A number of studies have examined the incidence of incidental durotories in the lumbar spine in the setting of degenerative pathology.1-3 Rates of incidental durotomy in the literature range from 2% to 20%.2 Several risk factors for incidental durotomy have been identified, including prior lumbar surgery, older age, female sex, and spinal trauma.2,5 Similar investigations have also been performed in the cervical spine.7 Understanding these risk factors and anticipating and perhaps reducing the risk of durotomies is critical because

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these complications can have a substantial impact on cost and hospital resource utilization.\(^8\)

The incidence of DT and the risk factors for DT have been well described for lumbar, degenerative cases. There is, however, a paucity of literature reporting similar data in an adult spinal deformity (ASD) patient cohort. The only existing references are surveys of the Scoliosis Research Society (SRS) morbidity and mortality database.\(^9,10\) These studies report a rate of incidental durotomy of 2.9\% to 3.4\% in adult scoliosis surgery.\(^9,10\) Shaw et al also noted that DTs were the most common complication in patients over age 50.\(^8\) However, both of these studies were focused on all complications in scoliosis surgery and did not perform any analysis to determine risk factors for incidental durotomy. They were also limited by the fact that deidentified data was utilized and verification of the data could not be performed beyond the accuracy of SRS members’ retrospective data entry.

In order to address these shortcomings, we chose to survey our prospectively gathered, multicenter ASD database. The specific aims of this study were to (1) identify the rate of DTs in patients undergoing ASD surgery, (2) identify risk factors for DTs in ASD, and (3) compare clinical outcomes in patients with and without DTs.

**Methods**

This study was a retrospective review of a prospectively collected multicenter ASD database maintained by the International Spine Study Group. Patients from 11 sites were enrolled if the following inclusion criteria were met: age \(\geq 18\) years and the presence of spinal deformity. Exclusion criteria included neuromuscular scoliosis, infection, and malignancy. Spinal deformity was defined as follows: scoliosis Cobb angle \(\geq 20^\circ\), sagittal vertical axis \(\geq 5\) cm, pelvic tilt \(\geq 25^\circ\), and/or thoracic kyphosis \(\geq 60^\circ\). Institutional review board approval was obtained prior to enrollment at each study site.

Patients were separated into 2 groups: (1) patients with DT and (2) patients without DT. Demographic data collected included patient age, gender, body mass index, American Society of Anesthesiologists (ASA) classification, history of previous infection, and previous spine surgery. Operative data collected included estimated blood loss, operative time, and intraoperative case details (such as osteotomy type, decompressions, interbody fusions, etc). Postoperative variables such as length of stay, intensive care unit stay, and complication data were also collected for all patients. Reporting of complication included the complication type (eg, neurologic, infectious, etc), the complication time (intraoperative vs postoperative), and complication severity (major vs minor). Complications were classified as major or minor similar to other studies in ASD.\(^11,12\) A complication was classified as major if it prolonged hospitalization, required reoperation or an invasive intervention, caused prolonged or permanent morbidity, or resulted in death. For example, proximal junctional kyphosis requiring revision surgery was classified as a major complication, while proximal junctional kyphosis not requiring surgery was classified as a minor complication. The list of minor and major complications was similar to a consensus list prepared by ASD surgeons and presented by Christiansen et al.\(^1\) Health-related quality-of-life (HRQOL) data collected at baseline, 6 weeks, and 2 years were analyzed; this included the Oswestry Disability Index (ODI), 36-item Short-Form Health Survey (SF-36; Physical Component Score and Mental Component Score), and the Scoliosis Research Society–22 questionnaire (SRS, subdomains: activity, pain, satisfaction, mental, appearance, and total).

**Statistical Analysis**

Statistical analysis was performed using an independent Student’s \( t \) test for continuous variables. Categorical variables were compared using the \( \chi^2 \) or Fisher exact test as appropriate; the \( P \) value derived from the Fisher exact test was used when cells had an expected count of less than 5. A \( P < .05 \) was considered significant. A binary logistic multivariate regression analysis was performed to identify preoperative and demographic risk factors, intraoperative techniques, and the risk of postoperative complications in patients with DTs. This regression analysis controlled for radiographic variables, age, gender, and ASA classification.

**Results**

**Overview**

In all 564 patients were identified. Two-year follow-up data was available for 270 patients out of 306 eligible (88.2\%). The mean age was 57.02 years (range 18-68), with 21.3\% male and 78.7\% female patients. The rate of DT in this patient population was 10.8\% (\( n = 61 \)). Of 61 DTs, 58 (95.1\%) were identified intraoperatively while the remaining 3 were identified in the perioperative or postoperative period. Most DTs (\( n = 58 \), 95.1\%) were categorized as minor complications while 3 were classified as major complications.

**Demographic and Radiographic Variables**

Univariate analysis revealed that patients with DT were older (61.1 vs 56.5 years, \( P = .005 \)) but with no differences in gender or body mass index (Table 1). A higher ASA grade was associated with an increased rate of DT (\( P = .031 \)) as was a history of prior spine surgery (OR = 2.0, 95\% CI = 1.2-3.3, \( P = .007 \)). Radiographically, patients who sustained incidental durotomies had more severe preoperative deformity (Table 2). DT patients had a higher pelvic tilt (PT; \( P = .012 \)), lower lumbar lordosis (LL; \( P = .006 \)), greater pelvic incidence–lumbar lordosis (PI-LL) mismatch (\( P = .007 \)), greater C7-S1 sagittal vertical axis (SVA; \( P = .011 \)), and greater T1-pelvis angle (T1PA; \( P = .003 \)). This difference was apparent even when patients were stratified based on Schwab classification; patients who sustained a DT were more likely to have higher Schwab modifiers for PT (\( P = .011 \)) and SVA (\( P = .04 \); Table 3). There was no difference between groups with regard
### Table 1. Patient Characteristics<sup>a</sup>.

| Variable                                      | Non–Dural Tear (n = 503) | Dural Tear (n = 61) | Odds Ratio (95% CI) | P Value |
|-----------------------------------------------|--------------------------|---------------------|---------------------|---------|
| Age<sup>b</sup>                               | 56.5 ± 15.8              | 61.1 ± 11.0         |                    | .005    |
| BMI                                           | 27.6 ± 9.3               | 28.6 ± 5.5          |                    | .401    |
| Gender (n = 545)                              |                          |                     |                    |         |
| Male                                          | 98 (19.5%)               | 18 (29.5%)          |                    | .067    |
| Female                                        | 388 (77.1%)              | 41 (67.2%)          |                    | .031    |
| ASA (n = 522)<sup>c</sup>                     |                          |                     |                    |         |
| I                                             | 47 (9.3%)                | 2 (3.3%)            |                    |         |
| II                                            | 235 (46.7%)              | 26 (42.6%)          |                    |         |
| III                                           | 172 (34.2%)              | 30 (49.2%)          |                    |         |
| IV                                            | 9 (1.8%)                 | 1 (1.6%)            |                    |         |
| History of prior spine surgery (n = 540)<sup>d</sup> | 218 (43.3%)          | 37 (60.7%)          | 2.0 (1.2-3.3)      | .007    |
| History of deep infection (n = 270)           | 9 (1.8%)                 | 2 (3.3%)            | 1.3 (0.4-4.6)      | .663    |

Abbreviations: Cl, confidence interval; BMI, body mass index; ASA, American Society for Anesthesiologists.
<sup>a</sup>For categorical variables, odds ratios are reported in addition to proportions. For some fields, data was not available for all patients analyzed. In these cases, the number of patients for whom valid data is available are listed. For example, data was available for ASA class on 522 patients.
<sup>b</sup>Significant differences noted (P < .05).

### Table 2. Radiographic Characteristics of Patients With and Without Dural Tears<sup>e</sup>.

| Variable | Preoperative |          |          | Two-Year Follow-up |          |          |
|----------|--------------|----------|----------|--------------------|----------|----------|
|          | Non-DT (n = 503) | DT (n = 61) | P        | Non-DT (n = 231) | DT (n = 27) | P        |
| SS       | 32.2 ± 12.1   | 29.2 ± 11.4 | .075     | 34.2 ± 10.6       | 29.6 ± 11.6 | .055     |
| PT       | 22.9 ± 10.9   | 26.7 ± 10.5 | .012     | 21.0 ± 10.2       | 23.4 ± 7.4  | .228     |
| PI       | 55.1 ± 12.6   | 55.9 ± 11.7 | .644     | 55.2 ± 12.4       | 53.0 ± 11.2 | .346     |
| PI-LL    | 4.9 ± 11.1    | 22.9 ± 23.3 | .007     | 3.3 ± 14.5        | 6.4 ± 15.8  | .318     |
| LL       | 40.3 ± 21.8   | 32.0 ± 22.8 | .006     | 51.9 ± 13.9       | 46.9 ± 17.0 | .090     |
| TK       | −35.4 ± 12.5  | −3.4 ± 20.1 | .469     | −47.6 ± 17.6      | −51.3 ± 19.0 | .316     |
| CL       | 9.3 ± 17.9    | 12.6 ± 16.3 | .244     | 8.9 ± 15.4        | 10.5 ± 22.2 | .742     |
| T1PA     | 27.1 ± 14.3   | 21.9 ± 13.4 | .009     | 17.1 ± 11.0       | 20.5 ± 9.9  | .124     |
| SVA      | 63.3 ± 75.8   | 90.5 ± 76.4 | .011     | 29.6 ± 55.1       | 47.8 ± 64.4 | .112     |

Abbreviations: DT, dural tear; non-DT, no dural tear; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence; PI-LL, pelvic incidence–lumbar lordosis mismatch; LL, lumbar lordosis; TK, thoracic kyphosis; T1PA, greater T1-pelvis angle; SVA, sagittal vertical axis.
<sup>e</sup>Patients who sustained a dural tear tended to have larger deformities and underwent larger corrections. There were no differences in radiographic characteristics between the 2 groups at 2-year follow-up.

 Patients with DT had a longer operative time (424 vs 375 minutes, P = .008) and were more likely to undergo interbody fusions (IBF; OR = 2.0, 95% CI = 1.1-3.6, P = .021) and decompressions (OR = 2.3, 95% CI = 1.3-4.3, P = .003; Table 4). When individual types of IBF were examined, posterior lumbar interbody fusion (PLIF) was the only IBF type that had a significant relationship with DT (OR = 2.9, 95% CI = 1.1-7.5, P = .021). Anterior lumbar interbody fusions (ALIF), transforaminal lumbar interbody fusions (TLIF), and extreme lateral lumbar interbody fusions (XLIF) did not increase the odds of sustaining a DT. Patients undergoing osteotomies were more likely to sustain DT (OR = 2.2, 95% CI = 1.1-4.0, P = .012). When we examined individual types of osteotomies, Smith-Peterson osteotomies (SPO; P = .088) and vertebral column resection (VCR; P = .759) did not affect the risk of DT. Pedicle subtraction osteotomies (PSO), however, significantly increased the likelihood of DT (OR = 2.8, 95% CI = 1.7-4.6, P < .001). Estimated blood loss was higher (2116 mL vs 1658 mL, P = .031) in the DT group, and patients with DT had a longer length of stay (9.8 vs 7.9 days, P = .039). In our multivariate analysis, only decompressions were linked to an increased risk of DT (OR = 3.2, 95% CI = 1.4-7.6, P = .006). Unsurprisingly, cases with DT were associated with a longer operative time (P = .035) in the multivariate analysis as well.

### Complications

Because most DTs were identified intraoperatively, DTs were associated with an increased rate of intraoperative complications (P < .001). However, DTs were also associated with an
increased rate of perioperative (\(P = .037\)) and postoperative (\(P = .019\)) complications. Specifically, patients with DT were more likely to have minor (\(P = .019\)) postoperative complications but not major (\(P = .367\)) postoperative complications (Table 5). Patients with DT were not more likely to sustain infectious (\(P = .055\)), neurologic (\(P = .066\)), or wound (\(P = .068\)) complications. While infectious complications included pneumonia, urinary tract infections, and other infections, there was no difference in the rate of deep infections between the DT and non-DT cohorts (\(P = .119\)). There was no association between DT and perioperative and postoperative complications in our multivariate regression model.

Patient Outcomes

DT and non-DT patients had similar HRQOL scores at baseline. Follow-up HRQOL scores were collected at 6 weeks and 2 years. At both these time points, there were no differences between groups in ODI, SF-36, or SRS-22 total scores and in any subdomains (Table 6).

Discussion

This article represents the first report on the incidence, risk factors, and outcomes of DTs in ASD surgery. We report a

| Table 3. Baseline Radiographic Classification Based on Schwab Classification. |
|---------------------------------------------------------------|
| Curve type (n = 542)                                         |
| DT (n = 503)         | Non-DT (n = 61) | \(P\) |
| N (no coronal curve) | 163 (32.4%)   | 19 (31.1%)   | .506 |
| T (thoracic only coronal curve)                             | 31 (6.2%)     | 2 (3.3%)     |      |
| L (lumbar only coronal curve)                               | 172 (34.2%)   | 19 (31.1%)   |      |
| D (thoracic and lumbar coronal curve)                       | 117 (23.3%)   | 19 (31.1%)   |      |
| PT modifier (n = 538)*                                      |              |
| Nonpathologic PT (PT < 20)                                  | 179 (35.6%)   | 15 (24.6%)   | .011 |
| Moderate deformity PT (20 < PT < 30)                         | 187 (37.2%)   | 20 (32.8%)   |      |
| Marked deformity PT (PT > 30)                               | 114 (22.7%)   | 23 (37.7%)   |      |
| SVA modifier (n = 533)*                                     |              |
| Nonpathologic global alignment (SVA < 4cm)                   | 205 (40.8%)   | 16 (26.2%)   | .04  |
| Moderate deformity global alignment (4cm < SVA < 9.5cm)      | 124 (29.2%)   | 18 (29.5%)   |      |
| Marked deformity global alignment (SVA > 9.5cm)             | 147 (29.2%)   | 23 (37.7%)   |      |
| PI-LL modifier (n = 538)                                    |              |
| Nonpathologic deformity PI-LL (PI-LL < 10)                   | 199 (39.6%)   | 18 (29.5%)   | .07  |
| Moderate PI-LL (10 < PI-LL < 20)                            | 99 (19.7%)    | 11 (18.0%)   |      |
| Marked PI-LL (PI-LL > 20)                                   | 182 (36.2%)   | 29 (47.5%)   |      |

Abbreviations: DT, dural tear; non-DT, no dural tear; PT, pelvic tilt; SVA, sagittal vertical axis; PI-LL, pelvic incidence–lumbar lordosis mismatch.

*Significant differences noted (\(P < .05\)).

| Table 4. Case Details for the Dural Tear and Non–Dural Tear Cohorts*. |
|---------------------------------------------------------------|
| Non-DT (n = 503)         | DT (n = 61) | OR (95%CI) | \(P\) |
| Operating room time (minutes)*                                | 375 ± 132 | 424 ± 147 | .008 |
| EBL (mL)*                                                      | 1658 ± 1551 | 2116 ± 1533 | .031 |
| Interbody fusion (n = 334)*                                   | 289 (57.5%) | 45 (73.8%) | .021 |
| ALIF (n = 128)                                                | 107 (21.3%) | 1 (34.4%) | .230 |
| PLIF (n = 24)*                                                | 17 (3.4%)   | 7 (11.5%)   | .021 |
| TLIF (n = 147)*                                               | 127 (25.2%) | 20 (32.8%) | .990 |
| XLIF (n = 48)                                                 | 43 (8.5%)   | 5 (8.2%)    | .488 |
| Decompression (n = 342)*                                     | 294 (58.4%) | 48 (78.7%) | .003 |
| Osteotomy (any) (n = 376)*                                   | 326 (64.8%) | 50 (82.0%) | .012 |
| VCR (n = 25)                                                  | 21 (4.2%)   | 4 (6.6%)    | .759 |
| PSO (n = 93)*                                                 | 69 (13.7%)  | 19 (39.3%)  | <.001 |
| SPO (n = 291)                                                 | 257 (51.1%) | 34 (55.7%) | .088 |
| Length of stay (days)*                                       | 7.9 ± 4.9 | 9.8 ± 6.7 | .039 |
| SICU stay                                                     | 324 (64.4%) | 47 (77.0%) | .179 |

Abbreviations: DT, dural tear; non-DT, no dural tear; OR, odds ratio; CI, confidence interval; EBL, estimated blood loss; ALIF, anterior lumbar interbody fusion; PLIF, posterior lumbar interbody fusion; TLIF, transfemoral lumbar interbody fusion; XLIF, extreme lateral lumbar interbody fusion; VCR, vertebral column resection; PSO, pedicle subtraction osteotomy; SPO, Smith-Peterson osteotomy; SICU, surgical intensive care unit.

*Odds ratios are reported for categorical variables. For some fields, data was not available for all patients analyzed. In these cases, the number of patients for whom valid data is available are listed. For example, data was available for osteotomy versus no osteotomy on 556 patients.

*Significant differences noted (\(P < .05\)).
10.8% rate of DTs in ASD and identify several potential risk factors for DT that might help inform discussions between patients and surgeons. Our multivariate analysis revealed that decompression was the only independent risk factor for DT in ASD surgery. However, in addition to decompression, we identified several potential risk factors based on our univariate analysis. These include IBF, specifically, PLIF, and the use of PSOs. Other findings of note include the fact that patients with DT had larger preoperative deformity and were more likely to have undergone a prior spine procedure.

The rate of DT reported in this article is higher than the rate of DTs in ASD and identify several potential risk factors for DT that might help inform discussions between patients and surgeons. Our multivariate analysis revealed that decompression was the only independent risk factor for DT in ASD surgery. However, in addition to decompression, we identified several potential risk factors based on our univariate analysis. These include IBF, specifically, PLIF, and the use of PSOs. Other findings of note include the fact that patients with DT had larger preoperative deformity and were more likely to have undergone a prior spine procedure.

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have identified revision surgery (prior spine surgery) as a possible risk factor for incidental durotomy.4-6,13 Unfortunately, we were unable to ascertain if the patients’ prior surgeries were at the same levels as their current procedure. However, because these patients all underwent long fusions for ASD, it is likely that the location of the prior surgery was encountered during our procedures. Similarly, other authors have identified TLIF5 and PLIF17 as risk factors for incidental durotomy. Perhaps not coincidentally, these series report a much higher rate of durotomy (~14%) compared to other series in the literature. Our findings corroborate these results. We showed that interbody fusion and PLIF, in particular, results in an increased risk of DT. Patients with DT had a longer length of stay in our study, which is also similar to other series in the literature.3,16,18,19

In addition to corroborating the data from existing literature, we provide specific insights that might be of particular interest for deformity surgeons. For instance, we show that patients undergoing osteotomies were at higher risk for DT. When subgroup analysis was performed, we showed that PSOs increased the risk of DT. Surprisingly, VCRs were not found to increase the risk of DT. However, this finding must be interpreted with caution given the small number of VCRs performed in our series (n = 25). The fact that techniques such as PSO are associated with a higher risk of DT is in line with our finding that patients with DT have larger sagittal deformities preoperatively. Our study also showed that decompressions were an independent risk factors for DT in ASD patients. In this context, the value of our study is particularly apparent as surgeons who anticipate performing a decompression can guide patients about the increased risk for DTs.

Finally, we showed that DT had no impact on functional outcomes. In our series, patients with DT had no difference in early (6 week) or late (2 year) functional outcomes. While we were not surprised by the fact that DT did not affect late outcomes, it was reassuring to learn that DT had no impact on early functional outcomes in adult patients despite an increased incidence of complications and a longer length of stay in this patient cohort. In that regard, our data allows us to reassure adult patients who have sustained a DT that their long-term outcome is not likely to be affected by this complication.

There are some important limitations to acknowledge. Perhaps the most significant limitation of our study is that we do not have data on how the DT in these patients were repaired. Different strategies for repair such as primary repair, dural patches, and/or the presence of irreparable tears could conceivably have a large impact on both the length of stay and the likelihood of other complications (return to the operating room or lumbar drainage, for example). Unfortunately, the retrospective nature of this database and the time frame over which cases were collected (2008-2014) preclude us from performing a detailed review of the DT repair strategies and the resultant complications. In general, however, the senior authors attempt to perform a primary repair of DT in all cases and augment the repair with dural patches or sealant if necessary. In cases of irreparable tears, dural sealant is used over the spinal canal to prevent cerebrospinal fluid leakage.

The retrospective design of this trial also prevents us from inferring causation and leads to the possibility of underreporting complications. However, the rate of DT reported by this study is similar to other prospective studies, which supports the validity of the auditing methods used by our database. While the ability to study granular questions (such as the impact of specific techniques such as PSO, VCR, etc) in a deformity surgery setting is a unique strength of this study, it is important to note that certain subgroups are necessarily small and limits the statistical power of this investigation. It is possible, for instance, that some trends noted in this article (gender-related changes, for example) would be significant if more patients can be examined. Despite that limitation, to our knowledge, this is the largest series of deformity patients that can examine questions that pertain to preoperative, intraoperative, and postoperative variables in the detailed manner presented above.

In summary, we report an overall rate of DTs of 10.8% in an ASD cohort. We report several risk factors that are in line with currently reported literature but also highlight specific techniques relevant to deformity surgeons (PSO) that might increase the risk of DT. Decompression performed in the setting of deformity surgery was an independent risk factor for DT.

Declaration of Conflicting Interests
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding
The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was conducted with funding support provided to the International Spine Study Group Foundation (ISSGF) from DePuy Synthes Spine, K2M, NuVasive, Innovasis, Biomet, Orthofix, as well as individual donations.

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