The incidental disruption of dural integrity during spinal surgery is an anticipated complication of all spinal surgeries. Although there have been numerous reports on ID after spinal surgery, the reported incidence is highly variable (1.1%–17%).4–8,13,17,18,29,30,35–37,41,43 This variability relates in part to study designs and relatively small case series, with most being retrospective single-surgeon studies and a few being multisurgeon prospective studies with ID as a secondary measure. Because of the high variability of reported IDs in the literature, our a priori hypothesis in the present study was a “prospective determination of incidence.”

Incidental durotomy after spinal surgery: a prospective study in an academic institution

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Clinical article

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Object. Incidental durotomies (IDs) are an unfortunate but anticipated potential complication of spinal surgery. The authors surveyed the frequency of IDs for a single spine surgeon and analyzed the major risk factors as well as the impact on long-term patient outcomes.

Methods. The authors conducted a prospective review of elective spinal surgeries performed over a 15-year period. Any surgery involving peripheral nerve only, intradural procedures, or dural tears due to trauma were excluded from analysis. The incidence of ID was categorized by surgery type including primary surgery, revision surgery, and so forth. Incidence of ID was also examined in the context of years of physician experience and training. Furthermore, the incidence and types of sequelae were examined in patients with an ID.

Results. Among 3000 elective spinal surgery cases, 3.5% (104) had an ID. The incidence of ID during minimally invasive procedures (3.3%) was similar, but no patients experienced long-term sequelae. The incidence of ID during revision surgery (6.5%) was higher. There was a marked difference in incidence between cervical (1.3%) and thoracolumbar (5.1%) cases. The incidence was lower for cases involving instrumentation (2.4%). When physician training was examined, residents were responsible for 49% of all IDs, whereas fellows were responsible for 26% and the attending for 25%. Among all of the cases that involved an ID, 7.7% of patients went on to experience a neurological deficit as compared with 1.5% of those without an ID. The overall failure rate of dural repair was 6.9%, and failure was almost 3 times higher (13%) in revision surgery as compared with a primary procedure (5%).

Conclusions. The authors established a reliable baseline incidence for durotomy after spine surgery: 3.5%. They also identified risk factors that can increase the likelihood of a durotomy, including location of the spinal procedure, type of procedure performed, and the implementation of a new procedure. The years of physician training or resident experience did not appear to be a major risk for ID.

Key Words • academics • cerebrospinal fluid • incidental durotomy • spine

Incidental durotomy is commonly listed on consent forms as a potential complication; however, the actual impact on patient outcomes is unclear. Few studies have examined patient outcomes following an ID. There is wide variation in outcomes following IDs, ranging from no increased morbidity6,7,17,41 and simply an increase in operative time, blood loss, and duration of stay to a strong tendency for worsening outcomes including a tendency toward more reoperations, an increased incidence of neurological deficits, longer durations of inability to work, more back pain, and functional limitations related to back pain.30,43 Incidental durotomy has potential legal ramifications. In one report of neurosurgical malpractice cases, ID was listed as the second most common reported cause for bringing forward a malpractice complaint.41 A more
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recent report listed ID as the third most common cause after “subsequent treatment by another physician” and “wound infection.”

Commonly reported complications of an ID include symptoms of low-pressure headaches, the development of subdural hematomas, acquired Chiari malformation, egress of spinal fluid from the surgical site, development of a pseudomeningocele or palpable subcutaneous fluid collection, pain, sensory and motor dysfunction related to an associated nerve root injury, and delayed nerve root entrapment. Determining the incidence of each complication requires an analysis of a large number of IDs.

Various authors have examined potential repair strategies, including bed rest, epidural blood patches, percutaneous fibrin glue, prolonged Jackson-Pratt drainage, placement of temporary lumbar or cervical CSF diversionary drains, direct suturing of the dura matter with or without the addition of fibrin glue, the use of fat grafts or supplementation of the repair with a DuraGen graft. We report a standardized repair strategy in a large number of IDs to assist in defining a treatment protocol.

The significance of ID in relation to patient outcome and long-term care is one of the most important aspects of studying IDs. Our primary outcome measure was to establish a reliable overall incidence of IDs across all spinal surgery types in an academic institution. Our secondary measures included the rate of delayed CSF leakage following repair, the incidence and type of neurological deficit following ID, and the impact of training on the occurrence of ID.

Methods

The institutional review board at the University of Miami Miller School of Medicine approved this study (University of Miami Institutional Review Boards, IRB No.: IRB00005622 [UM Medical IRB B]). We examined 3615 neurosurgical cases at a single academic institution with an Accreditation Council for Graduate Medical Education–approved neurosurgical residency and spine fellowship program approved by the Society of Neurological Surgeons. Data were prospectively collected over a 15-year period by the attending surgeon (A.D.L.) and entered daily into a computerized research database. Patients had a minimum of 4 months of clinical follow-up. Cases were excluded if they involved primarily peripheral nerve procedures, had an a priori intradural pathology, or were spinal cases in which dural tears were encountered due to a traumatic fracture. An ID included any disruption of dural integrity with egress of CSF that was recognized during the spinal procedure (102 cases). It also included any patient presenting with symptoms of CSF leakage following a recent spinal procedure (2 cases) without recognition of a durotomy at the time of surgery. Visualization of arachnoid and/or outpouching of arachnoid associated with a loss of dural integrity was not counted as an ID unless CSF was also visualized. Patients from an institution or neurosurgical service outside the attending neurosurgeon’s service were excluded. Incidental durotomies were examined in terms of spinal surgery location, type of spinal surgery performed, and physician years of training, as well as the failure rate of dural repair and the incidence of neurological deficits.

In cases with overlapping vertebral locations, classification was determined based on the greatest number of vertebrae involved. For example, a T10–L2 procedure was considered a thoracic case. In each case in which an ID was recognized, the surgeon who was primarily responsible for the ID was recorded. While each case had 2 surgeons scrubbed and the attending was always the responsible surgeon, the physician who held the operative instrument (Kerrison rongeur, curette, or drill) in hand at the time of the ID was recorded as the surgeon responsible for the durotomy. In some cases the ID appeared to be the result of a previous epidural injection, as CSF could be seen coming from a pinpoint opening after unroofing the lamina, without contact of an instrument to the dura. Physician years of training were calculated for residents (PGY1 to 7). Neurosurgical spine fellows and the attending (A.D.L.) were counted as a separate category. In 2 cases, the attending neurosurgeon was scrubbed with another neurosurgical attending during the ID. A neurological deficit following an ID included any neurological decline from the preoperative state, for example, numbness, weakness, or new onset of pain. The number of failed dural repairs was calculated based on the number of patients returning with symptoms of CSF leakage who had undergone a procedure involving a recognized ID and an initial repair.

The repair strategy in each case was to establish a watertight dural closure. The dura was repaired under high magnification using 5-0 or 6-0 Prolene continuous stitches to appose dural edges, and the repair was supplemented by a DuraGen patch (Integra LifeSciences Corp.; Fig. 1). The integrity of the closure was confirmed with a Valsalva maneuver. A Hemovac drain was placed, 6 hours of suction was followed by no suction, and the drain was pulled when the fluid output had diminished to less than 50 ml over 12 hours. Patients were placed on bed rest for 2 days. In laterally placed tears in the canal in which direct suture was not possible or in cases in which there was egress of CSF after a Valsalva maneuver, a DuraGen patch was supplemented with external CSF drainage for 5 days via either a lumbar or a cervical CSF drain. In the majority of cases, fibrin-based glues were not used. In durotomies with a dural defect, a muscle, fat, or cadaveric dural allograft was used and sutured to the host dura with a Prolene stitch. In minimally invasive cases, only a DuraGen graft was used, and patients were mobilized the day of surgery. Statistical comparisons were made using a chi-square test performed using a commercial software package (GraphPad Prism).

Results

Three thousand spinal surgery cases met the inclusion criteria. The total incidence of ID after spinal surgery was 3.5% (104 cases). The annual incidence over the 15-year data collection period varied from as little as 2% (Year 1) to as high as 5% (Year 7) without an appreciable learning curve effect. Cervical procedures constituted
1298 cases, thoracic procedures 227 cases, and lumbar procedures 1475 cases (Table 1). As calculated based on procedural location within the spine, the incidence during cervical procedures (1.3%) was substantially lower than for lumbar (4.9%) and thoracic (6.6%) procedures. Among the 3000 cases, 352 procedures were revisions, 271 were minimally invasive procedures, and 1717 involved instrumentation. The incidence of IDs for primary spinal procedures was 3.1% and for revision procedures was much higher, 6.5% (Table 2). Procedures involving instrumentation had the lowest incidence of IDs at 2.4%. Minimally invasive procedures had an incidence similar to the overall rate at 3.3%. The majority of IDs during minimally invasive procedures occurred early on in the surgical experience (Fig. 2), coinciding with the time that minimally invasive procedures were first adopted into the practice.

Taking into account physician training, the attending had the lowest percentage of IDs at 25%. Fellows and residents accounted for 26% and 49% of all IDs, respectively (Fig. 3). When residents were examined in terms of PGY level, the majority of IDs occurred during PGY5 to PGY7 (Fig. 4). This finding was anticipated since the amount of operative experience is disproportionately weighted to the later years of training, that is, PGY4 level and beyond.

The overall incidence for failed repair of an ID was 6.9% (7 of 102 cases). Note that only 102 cases of the 104 total IDs were included in this calculation because 2 cases had IDs that went undetected and thus were not repaired during the initial surgery in which the ID had occurred. To put this in perspective, when explaining the risks prior to surgery, only 7 (0.23%) of 3000 patients presented with delayed CSF leakage requiring additional surgical intervention. When the procedure type was assessed, primary procedure repairs failed 5% of the time (4 of 81 cases); however, revision procedures failed nearly 3 times as often, at a rate of 13% (3 of 23 cases). Patients presented with a host of symptoms, including low-pressure headaches, egress of CSF from the wound, and subcutaneous fluid collection. Two patients presented with headaches and a large subdural hematoma.32,45 Magnetic resonance imaging and/or myelography with a postmyelogram CT were critical in confirming the presence of a CSF leak and at times determining the site of leakage from the dural breach (Fig. 5).24 Meningitis was not encountered except for one case related to the prolonged use of a lumbar CSF drain. Patients referred for CSF leaks after spinal surgery or after unsuccessful attempts at repair (10 cases) did not form part of the analysis.

Neurological deficits following an ID occurred at a rate of 7.7% (8 of 104 cases). One revision procedure and one instrumented procedure resulted in a deficit, with the remainder of the neurological deficits occurring during primary surgical procedures. The severity of deficits

<table>
<thead>
<tr>
<th>Surgery Location</th>
<th>No. of IDs</th>
<th>Total No. of Cases</th>
<th>Incidence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cervical</td>
<td>17</td>
<td>1298</td>
<td>1.3</td>
</tr>
<tr>
<td>thoracic</td>
<td>15</td>
<td>227</td>
<td>6.6</td>
</tr>
<tr>
<td>lumbar</td>
<td>72</td>
<td>1475</td>
<td>4.9</td>
</tr>
</tbody>
</table>

TABLE 1: Incidence of ID by anatomical location of surgery in the spine

<table>
<thead>
<tr>
<th>Surgery Type</th>
<th>No. of IDs</th>
<th>Total No. of Cases</th>
<th>Incidence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>total</td>
<td>104</td>
<td>3000</td>
<td>3.5</td>
</tr>
<tr>
<td>primary</td>
<td>81</td>
<td>2648</td>
<td>3.1</td>
</tr>
<tr>
<td>revision</td>
<td>23</td>
<td>352</td>
<td>6.5</td>
</tr>
<tr>
<td>instrumented</td>
<td>41</td>
<td>1717</td>
<td>2.4</td>
</tr>
<tr>
<td>minimally invasive</td>
<td>9</td>
<td>271</td>
<td>3.3</td>
</tr>
</tbody>
</table>

TABLE 2: Incidence of ID by spine surgery type

Fig. 1. Intraoperative photographs showing a dural rent and its repair. A: Intraoperative incidental durotomy with herniation of the dorsal rootlet (dotted circle). B: Repair with figure of 8 5-0 Prolene sutures in a watertight fashion. C: Durotomy covered with a DuraGen graft patch.
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ranged from mild loss of sensation or numbness in a single dermatome to complete loss of function in multiple muscle groups (Table 3). One of the 2 patients with an unrecognized durotomy at the time of the original surgery presented with delayed pain and mild weakness in the L-5 distribution from nerve root herniation through the dural defect.12 No permanent spinal cord injuries were encountered. The incidence of neurological deficit with an ID (7.7%) was significantly higher (p < 0.0001) than in the absence (45 [1.5%] of 2896 cases) of an ID.

Discussion

We report an overall ID incidence of 3.5%, which is in the midrange of values published in previous studies.4–8,17,18,29,30,35,36 Unlike those previous studies, the present study benefits from 15 years of prospectively collected data with the a priori hypothesis of establishing an incidence for durotomies. Prospectively collecting ID data ensures that even the smallest of durotomies are counted, and thus we did not have to rely on the accuracy of dictated operative reports or coders.

Classifying ID incidence by location of spinal surgery, we found that thoracic procedures accounted for the highest incidence at 6.6%, whereas cervical procedures had the lowest incidence at 1.3%. This represents the largest number of thoracic cases (227) analyzed in a single-surgeon series, as most published data focus on the lumbar or cervical spine. At least part of the explanation for a high incidence of ID in thoracic cases relates to the fact that many of these cases involved tumors, ossification of the ligamentum flavum, or calcified thoracic discs in which the pathology was intimately involved with the dura. Ossification of the posterior longitudinal ligament is a pathology in which the dura and ligament can be fused together.2 It is most commonly encountered in anterior approaches to the cervical spine. Many such cases in the present study were treated via a posterior approach, limiting the observed cervical incidence of ID.

Procedure type has been reported to have an effect on ID, with revision procedures specifically having an increased overall rate.43 We also found that revision procedures have an increased incidence (6.5%) of durotomy as compared with primary procedures. The absence of normal anatomical landmarks and the presence of dense adhesions between dura and surrounding scar tissue account for this finding. More importantly, the repair of a dural tear during a revision procedure is 3 times more likely to fail than during a primary procedure. One of the most important reasons for the higher failure rate relates to the fact that the dural tube is less pliable in a revision
procedure, and watertight dural closure becomes more difficult to achieve. In that regard, many of the revision dural repairs were supplemented by external CSF drainage.

The rate of ID during minimally invasive procedures was similar to the overall ID rate (3.3%) and slightly higher than the overall rate for primary procedures (3.1%). Almost all minimally invasive procedures were primary cases. The ID rate was significantly higher during the first 2 years of data acquisition, when minimally invasive procedures were first adopted and probably related to the learning curve of the procedure. One distinct advantage of minimally invasive approaches is that minimal dead space is created by the tubular retractors. When the retractors are removed, the muscles that have been simply pushed to the periphery immediately fill the dead space. We believe this helps to tamponade the area of CSF leakage. None of the patients who had undergone minimally invasive surgery had a direct suture repair, and despite early mobilization, no patients returned with symptoms of CSF leakage. We believe that early mobilization and the absence of a delayed CSF leak represent several of the major advantages of minimally invasive surgical approaches. One can use newly developed minimally invasive U-clips through a retractor system in an attempt to obtain a more direct dural closure. Interestingly, the use of spinal instrumentation lowered the risk of ID. We attribute this to the fact that in some instrumented cases (for example, scoliosis correction and percutaneous screw fixation), the placement of instrumentation does not require unroofing the spinal canal and exposing the dura, and thus reduces the potential for ID.

The most common instrument leading to ID is the Kerrison punch followed by the curette and then the drill. The most common surgical scenarios for the creation of ID are when transitioning a dissection between normal dura and scar tissue, Kerrison bites in the lateral gutters especially in areas of critical lateral recess stenosis, and medial bites during tubular surgery. There are a wide variety of dural defects, from pinpoint to major rents with nerve root exposure. Meticulous attention to technique with adequate visualization of the interface between instrument and dura is critical at all times to prevent ID. Early closure of the defect will prevent blood ooze from epidural veins that have lost the tamponade effect of CSF pressure transmitted via the dural sac. In certain cases, permitting CSF to spill from the dural sac allows plication of the dural tube to ultimately obtain a watertight dural closure.

One factor commonly considered in ID is physician years of training and experience. Studies have documented an inverse relation between the years of attending experience and the rate of durotomy. With respect to attending experience in the present study, the rate of ID did not vary over time. Laminectomy is a standard procedural skill to be mastered early on during residency training. At a teaching institution, residents and fellows, under the supervision of the attending, participate in the surgical care of the patient. While the degree of surgical responsibility would be expected to increase linearly with the time of training, most experience is obtained in the latter years and by those who obtain fellowship training. While in each case a responsible surgeon was noted for every ID, each procedure was completed by a primary and an assistant surgeon. The roles can change several times during an individual procedure, with the resident as the primary and then the attending, and the roles can reverse several times during a case. The assistant who fails to provide adequate visualization, because of insufficient suctioning, retraction, or dural dissection, can be equally responsible, even if the surgeon holding the causative instrument is registered as the surgeon of record for the ID. Residents and fellows as a whole accounted for 75% of all durotomies. There is a significant increase in operating time and increased responsibility in the last 2 years of training. The number of durotomies increases steadily until the 6th and 7th year of training; the rate stabilizes at the level of fellows and attending physicians. These findings seemed to indicate that the level of training does not have a significant impact on the incidence of durotomy and that when time in the operating room and supervision are roughly equal, there is a baseline rate of durotomies, unrelated to years of training.

The clinical effect of durotomies on patient outcomes is poorly understood, with some studies reporting poorer outcomes and others documenting no significant effects. But this may be one of the most important aspects of durotomies to classify accurately, not only because it affects patient care but also because it can allow more appropriate counseling as regards the risk of surgery. In the present study, 7.7% of the 104 reported durotomies had a concurrent neurological deficit. One nerve root deficit was permanent and one neurological deficit (nerve root herniation into a meningocele) required further surgical intervention to correct. The hypothesized reason for an increased risk of neurological deficit after CSF leakage is that since the dura is juxtaposed with the spinal cord and nerve roots, an unanticipated breach of the dura during surgery may put the nerve root or spinal cord at increased risk of associated injury. While each individual case of intraoperative nerve or spinal cord injury is unique, there seems to be an association between neurological injury and ID (7% vs 1.5%), with the risk of neurological deficit being almost 5 times higher in the presence of ID.

One of the limiting factors of this study is the reli-

### Table 3: Neurological deficits by type of surgery and type of deficit

<table>
<thead>
<tr>
<th>Immediate Neurological Deficit</th>
<th>Type of Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>numbness of rt toes</td>
<td>instrumentation</td>
</tr>
<tr>
<td>lt leg weakness 2/5</td>
<td>revision</td>
</tr>
<tr>
<td>lt: ADF 4/5 &amp; EHL 3/5</td>
<td>primary</td>
</tr>
<tr>
<td>lt: ADF 4/5 &amp; EHL 1/5</td>
<td>primary</td>
</tr>
<tr>
<td>lt: HF, quadriceps &amp; ADF 0/5</td>
<td>primary</td>
</tr>
<tr>
<td>rt: deltoid &amp; biceps 0/5</td>
<td>primary</td>
</tr>
<tr>
<td>lt triceps 4/5</td>
<td>primary</td>
</tr>
<tr>
<td>leg pain only</td>
<td>primary</td>
</tr>
</tbody>
</table>

* ADF = ankle dorsiflexors; EHL = extensor hallucis longus; HF = hip flexor.
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ance on a single institution as well as a single surgeon’s experience, resulting in selection bias in the types of patients and the procedures performed. Patients could have been lost to follow-up, and thus the current results would underestimate the rate of missed intraoperative CSF leaks and failed repairs—but not the overall incidence of ID recognized during surgery, which represents the majority of cases. The results may not generalize to a community-based neurosurgical practice. The strengths of this study include the prospective data collection, significant period of time during which data were gathered, assessment of an academic institution with its educational nuances, and significant number of total spine cases analyzed. These factors helped to balance some of the limitations.

Conclusions

In this study we established a reliable baseline rate of IDs that can be expected during spinal procedures: 3.5%. We also identified risk factors that can increase the likelihood of a durotomy: location of the spinal procedure (cervical, thoracic, or lumbar), type of spinal procedure performed (revision, primary procedure, or placement of instrumentation), and implementation of a new procedure such as minimally invasive spine surgery. The years of physician training or resident experience do not appear to be a major risk for ID. The rate of failed dural repair increases with revision surgery. By recognizing patients with an increased risk, based on the factors identified in this study, surgeons can be more vigilant in monitoring for dural tears and potentially avoid them altogether.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: Levi. Acquisition of data: Levi. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Statistical analysis: all authors. Administrative/technical/material support: McMahon, Dididze. Study supervision: Levi.

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