Surgical Neurology International

OPEN ACCESS

SNI: Spine, a supplement to Surgical Neurology International

A review article on the diagnosis and treatment of cerebrospinal fluid fistulas and dural tears occurring during spinal surgery

Nancy E. Epstein

Clinical Professor of Neurological Surgery, Department of Neurosurgery, The Albert Einstein College of Medicine, Bronx, NY, 10461, and Chief of Neurosurgical Spine and Education, Department of Neurosurgery, Winthrop University Hospital, Mineola, NY, 11501

E-mail: *Nancy E. Epstein - nancy.epsteinmd@gmail.com
*Corresponding author

Received: 11 February 13 Accepted: 25 March 13 Published: 06 May 13

This article may be cited as:
Epstein NE. A review article on the diagnosis and treatment of cerebrospinal fluid fistulas and dural tears occurring during spinal surgery. Surg Neurol Int 2013;4:S301-17.
Available FREE in open access from: http://www.surgicalneurologyint.com/text.asp?2013/4/3/301/111427

Abstract

Background: In spinal surgery, cerebrospinal fluid (CSF) fistulas attributed to deliberate dural opening (e.g., for tumors, shunts, marsupialization of cysts) or inadvertent/traumatic dural tears (DTs) need to be readily recognized, and appropriately treated.

Methods: During spinal surgery, the dura may be deliberately opened to resect intradural lesions/tumors, to perform shunts, or to open/marsupialize cysts. DTs, however, may inadvertently occur during primary, but are seen more frequently during revision spinal surgery often attributed to epidural scarring. Other etiologies of CSF fistulas/DTs include; epidural steroid injections, and resection of ossification of the posterior longitudinal ligament (OPLL) or ossification of the yellow ligament (OYL). Whatever the etiology of CSF fistulas or DTs, they must be diagnosed utilizing radioisotope cisternography (RIC), magnetic resonance imaging (MRI), computed axial tomography (CT) studies, and expeditiously repaired.

Results: DTs should be repaired utilizing interrupted 7-0 Gore-Tex (W.L. Gore and Associates Inc., Elkton, MD, USA) sutures, as the suture itself is larger than the needle; the larger suture occludes the dural puncture site. Closure may also include muscle patch grafts, dural patches/substitutes (bovine pericardium), microfibrillar collagen (Duragen: Integra Life Sciences Holdings Corporation, Plainsboro, NJ), and fibrin glues or dural sealants (Tisseel: Baxter Healthcare Corporation, Deerfield, IL, USA). Only rarely are lumbar drains and wound-peritoneal and/or lumboperitoneal shunts warranted.

Conclusion: DTs or CSF fistulas attributed to primary/secondary spinal surgery, trauma, epidural injections, OPLL, OYL, and other factors, require timely diagnosis (MRI/CT/Cisternography), and appropriate reconstruction.

Key Words: Cerebrospinal fluid, dural sealants, fibrin sealants, fistulas, muscle grafts, reconstruction methods, spinal surgery, suture techniques

Access this article online
Website: www.surgicalneurologyint.com
DOI: 10.4103/2152-7806.111427
Quick Response Code:

ABBREVIATIONS

ACF Anterior Corpectomy and Fusion
BMP Bone Morphogenetic Protein
COPD Chronic Obstructive Pulmonary Disease
CSF Cerebrospinal Fluid

CT	Computed Axial Tomography
CTM	Computed Axial Tomography Myelography
DT	Dural Tears
FDA	Food and Drug Administration
FSE	Fast Spine Echo
JP	Jackson Pratt Drain
LP-shunt	Lumboperitoneal shunt
METRx	Medtronic MicroDiskectomy System
MIS	Minimally Invasive Surgery
MISS	Minimally Invasive Spine surgery
MR	Magnetic Resonance Imaging
MRSA	Methicillin Resistant Staphylococcus Aureus
Myelo-CT	Myelogram Computed Tomography
OPLL	Ossification Posterior Longitudinal Ligament
OYL	Ossification Yellow Ligament
PF	Posterior Fusion
PLIF	Posterior Lumbar Interbody Fusion
RIC	Radioisotope Cisternography
RIS	Radionuclide Cisternography
SIH	Spontaneous Intracranial Hypotension
SPORT	Spine Patient Outcomes Research Trial
3-D	Three Dimensional
TE/MR	Echo Time: Time After Excitation Pulses: Echo Time in Magnetic Resonance Imaging
TLIF	Transforaminal Lumbar Interbody Fusion
TR/MR	Relaxation Times on MR Scans (T1, T2 Weighted Studies)
WP-Shunt	Wound-Peritoneal Shunt

INTRODUCTION

Two major types of cerebrospinal fluid (CSF) fistulas/ dural tears (DTs) are encountered during spinal surgery [Table 1]. The first are deliberate dural incisions required to remove intradural pathology, including tumors or cysts, as well as those required for elective shunt placement (subarachnoid/lumbo-peritoneal [LP] shunt placement). The second are inadvertent dural lacerations encountered during surgery, either related to the initial traumatic dissection, or scarring attributed to prior surgery. There are multiple other etiologies that may contribute to the deliberate or inadvertent dural opening; dural pathology extending to/through the dura (occasional discs, synovial cysts, hypertrophy/ossification of the yellow ligament [OYL] or ossification of the posterior longitudinal ligament [OPLL]), and other factors.

The frequency and type of anticipated vs. traumatic CSF fistulas/DTs encountered during spinal surgery are reviewed, along with other etiologies of dural breach (e.g., with epidural steroid injection, spontaneous DT, others) The various operations/procedures that result in CSF leaks/DTs, the techniques utilized to diagnose fistulas, and their treatment with multiple adjunctive measures are assessed [Table 1].

INTENTIONAL OPENING OF THE DURA FOR INTRADURAL SPINAL TUMORS/ PATHOLOGY [VIDEOS 1-15]

Intentional (anticipated) opening of the dura may be required to remove intradural spinal tumors (intradural extramedullary meningiomas/neurofibromas, or intradural intramedullary tumors such as astrocytomas, ependymomas), to marsupialize arachnoid cysts, to place LP or cyst/syrinx peritoneal shunts along with other pathology. Deliberate opening and exposure to remove intradural pathology typically requires the sequential application of 7-0 Gore-Tex retraction sutures on the dural edges. As closure is performed, these retraction sutures may be flipped across the dural opening to allow the edges to come together. Everting the dural edges utilizing a Penfield forceps, allows for the placement of interrupted 7-0 Gore-Tex sutures at 3-5 mm intervals; the "gaps" are next filled in by medium (1.4 mm) microdural staples. If there is an absence/paucity of dura, or it is atretic, a bovine pericardial patch graft may be required. There may also be a dural defect secondary to resection of a meningioma that requires grafting. To further ensure adequate dural closure, it may be necessary to sew over the dural defect utilizing muscle patch grafts (e.g., once the dural defect is closed, keep the needle on the 7-0 Gortex suture and use it to directly sew in the overlying muscle graft). Once watertight closure is verified with Valsalva maneuvers, Duragen (Integra Life Sciences Corporation, Plainsboro, NJ) and fibrin sealant (Tisseel: Baxter Healthcare Corporation, Deerfield, IL) may be placed.

OTHER ETIOLOGIES OF DURAL TEARS EXCLUDING SPINAL SURGERY

There are other etiologies of DTs, excluding those occurring during spinal surgery [Table 1].[2,4,6,37,51] Delayed DTs may occur when the dura becomes tethered over bony spikes in the lateral gutters following decompressive surgery/ laminectomies as in two patients from Brookfield *et al.* study.[6] In Berger *et al.* series involving 137,250 patients in labor undergoing epidural spinal analgesia, the frequency of inadvertent dural punctures ranged from 0.04% to 6%.[4] Other patients who develop spontaneous DT, as in the Balkan *et al.* study, may develop classical symptoms attributed to intracranial hypotension: throbbing, orthostatic headaches, meningeal symptoms (fever, CSF-documented pleocytosis, elevated CSF protein concentrations, but normal glucose levels, and negative cultures), lumbar puncture-documented low CSF pressure, and diffuse pachymeningeal enhancement on brain magnetic resonance imaging (MRI).[2] As in Suh *et al.*, another source of DTs/ CSF fistulas may include cervical/thoracic chiropractic manipulation. They treated a 36-year-old female with chiropractic manipulation following which she developed severe orthostatic headaches, nausea, and vomiting; a

Table 1: Titles and summaries of dural tears

Section	Summary
Intentional Opening of the Dura For Intradural Spinal Tumors/ Pathology	Summary: Intentional opening of the dura may be required to remove intradural or intradural/intramedullary spinal tumors, marsupialization of arachnoid cysts, placement of various shunts, along with other pathologies.
Other Etiologies of Dural Tears Excluding Spinal Surgery	Summary: Other etiologies of DT include postoperative tethering of dural edges by bony spikes, epidural spinal analgesia (0.04-6%), spontaneous fistulas, and those resulting from chiropractic manipulation.
Unintentional Dural Tears (DT) with Open Lumbar Surgery Frequency of DT with Primary Lumbar Stenosis Surgery	Summary: In the Cammisa *et al*. series, the incidence of DT for patients undergoing primary operations for lumbar spinal stenosis was 3.1%.[7] Of interest, 91% were discovered intraoperatively, and were directly repaired, and 9% that were found postoperatively required secondary open surgical repairs. The authors also noted that most CSF fistulas occurred during revision surgery.
Frequency of DT with Surgery for Degenerative Stenosis with/without Noninstrumented Fusions and/or Disc Herniations	Summary: Unintentional intraoperative DT occur in from 3.1% to 9.0% of patients undergoing primary or up to 15.9% for those undergoing revision surgery for degenerative lumbar stenosis.
Frequency of DTs with Lumbar Surgery for Spinal Stenosis with/without Fusion	Summary: In Desai *et al*., Spine Patient Outcomes Research Trial (SPORT), DTs occurred in 37 (9%) of 409 patients undergoing decompressive laminectomies (with/without fusion, without spondylolisthesis) for spinal stenosis and did not affect long-term outcomes.[12]
Frequency of Dural Tears for Degenerative Stenosis and Noninstrumented (In-Situ) Lumbar Fusion	Summary: In the Epstein's series, a 9.1% (10 patients) frequency of DT occurred in 110 patients undergoing multilevel laminectomies with noninstrumented fusions.[14] All 10 had marked OYL that in 3 cases extended to/through the dura. Five of the patients with DT had synovial cysts vs. 8% without DT, while 20% with DT had prior surgery vs. 10% without DT.
Frequency of Dural Tears for Stenosis Treated Predominantly with Instrumented Fusions	Summary: Out of 10,242 patients predominantly undergoing complex lumbar fusions for spondylolisthesis (DS) and isthmic spondylolisthesis (IS) in the Sansur *et al*. series, the frequency of complications overall was 7.9%; DTs was the most frequent complication encountered in 211 (2.1%) patients.[49]
Increased Frequency of DTs with Revision Lumbar Surgery	Summary: In the Khan *et al*. study, the frequency of traumatic/incidental DT occurring during primary lumbar surgery (typically for stenosis with/without fusion) was 7.6%, while the frequency increased to 15.9% for revision surgery.[32]
Frequency of Dural Tears with Minimally Invasive Surgery for Spinal Stenosis	Summary: In the Palmer *et al*. study, dural tears occurred in 3 (5.5%) of 54 patients undergoing minimally invasive lumbar surgery (METRx) for degenerative spinal stenosis.[46]
CSF Fistulas with Open vs. Minimally Invasive Diskectomy Incidence of Durotomy with Open Diskectomy	Summary: For patients undergoing open microdiskectomy, the frequency of DT in the Lee *et al*. study was a lower 6.67% vs. a higher 9.38% observed for those undergoing MIS tubular diskectomy.[38]
Incidence of Durotomy with Minimally Invasive Diskectomy	Summary: Ruban *et al*. documented a 9.4% incidence of traumatic surgical durotomy (53 of 563) for patients undergoing Minimally Invasive Surgery (MIS).[48] Of interest, 51 occurred during lumbar surgery, while only 2 occurred during posterior cervical procedures.
CSF Fistulas with Synovial Cysts Incidence of Dural Tears in Patients Undergoing Microsurgery for Juxtafacet cysts (Synovial Cysts/Ganglion Cysts)	Summary: Oertel *et al*. observed a 7.4% frequency of DT (2 of 27) following microsurgical decompression (partial hemilaminectomy) for the treatment of juxtafacet cysts.[45]
CSF Fistulas for Synovial Cysts Treated with Multilevel Laminectomy and Noninstrumented Fusion	Summary: Epstein noted that 10 of 110 patients developed intraoperative DT following lumbar decompressions with noninstrumented fusions. Five of the 10 patients had synovial cysts vs. only 8 of the remaining 100 patients.[14]
Cervical Spine Surgery and DT DT for Cervical Ossification of the Posterior Longitudinal Ligament (OPLL)	Summary: The frequency of dural tears attributed to cervical surgery for OPLL ranges from 6.1% to 6.3%.[13,16,31] Anterior cervical dural tears are variously managed with primary repairs (muscle/fascial grafts), wound-peritoneal, and/or lumbo-peritoneal shunts.[16]
DT with Craniocervical Fusions in Adults	Summary: DTs occur during the placement of transarticular screws in 0.3% of cases, but in from 0% to 4.2% of occipitocervical fusions.[36] The frequency is much higher (25-28%) when utilizing wires to perform the occipital portion of the occipital-cervical fusions.
DT With Occipital Screw Placement for Pediatric Posterior Cervical Fusions	Summary: In the Hwang *et al*. series, 2 of 20 pediatric patients developed DT while undergoing occipitocervical fusions while placing 114 bicortical screws.[28] Two others also developed marked venous bleeding, neurological deterioration, wound infection, pseudarthrosis, and transient dysphagia.

Contd...

Table 1: Contd...

Section	Summary
Dural Tears Following Thoracic Spine Surgery DT Following Thoracic Fusions in Patients with Ossification of the Posterior Longitudinal Ligament	Summary: The frequency of DTs in the Matsumoto *et al*. study was 9.2% (7 of 76) following fusions for thoracic OPLL (anterior, posterior, circumferential).[42]
DT Associated with Surgery for Thoracic Ossification of the Yellow Ligament (OYL)	Summary: Out of 266 patients undergoing thoracic surgery for OYL in the Sun *et al*. series, 32% (85 patients) developed DT; 25.2% of the 85 demonstrated clear dural ossification.[52] Repairs were unsuccessful in 65 patients, 58 of whom required additional prone positioning; sandbag pressure, and ultrasound aspiration, and additional surgery (7 patients).
Prudent to Avoid Use of BMP with Dural Tears During Spinal Surgery	Summary: In the Glassman *et al*. series of 1,037 patients undergoing decompression with posterolateral fusion, 58 (5.59%) patients exhibited DTs.[20] BMP, utilized to perform fusions even in those with DTs, did not clearly increase morbidity. Nevertheless, the authors concluded that it would be prudent to avoid BMP when DTs are present pending further investigations regarding potential morbidities.
Frequency of DTs During Epidural Analgesia for Patients in Labor	Summary: The incidence of inadvertent DTs in labor following various types of epidural/transforaminal procedures varies from 0.04% to 6%.[4,5,55]
Complications Associated with Dural Tears DT Contributing to Postoperative Infection	Summary: In Koutsoumbelis *et al*., DTs and multiple other factors contributed to the 2.6% risk of postoperative infection following posterior lumbar instrumented fusions in 3,218 patients.[34]
Frequency, Location, and Other Complications of DT	Summary: Of the 51 (3.84%) DTs occurring during 1,326 spinal procedures in Guerin *et al*. 94% (48 patients) involved thoracolumbar procedures.[21] Complications in 13 patients included; 7 persistent CSF leaks, 2 infections, 2 hematomas, 2 pseudomeningoceles, and 9 requiring reoperations.
DT: Frequency, Location, Attribution, Deficits, and Failure Rates for Closure	Summary: In 3,000 elective spinal procedures from the McMahon *et al*. study, DT occurred in 3.5% of primary and 6.5% of secondary procedures.[43] Residents contributed to 49% of DT, while fellows (26%) and attending surgeons (25%) contributed to a comparable number of DT. New neurological deficits were observed in 7.7% of patients with DT vs. only 1.5% without DT. Repair of DT failed in 6.9% of cases; 5% for primary but 13% for revision surgery.
Symptoms and Signs of DTs	Summary: Symptoms of DT most frequently include postural headaches, followed by nausea, vomiting, sterile or bacterial meningitic symptoms, and wound swelling (positive correlation with Valsalva maneuvers).
Neurodiagnostic Studies for Detecting CSF Fistulas/DTs Utility of Enhanced MR Studies, CT-Myelography or Radionuclide Cisternography	Summary: Following traumatic/spontaneous DT, enhanced MR studies, CT-Myelography, Digital Subtraction Myelography, 3D MR myelography, and/or Radionuclide Myelography/Cisternography may identify CSF fistulas, pseudomeningoceles, and indicate whether an infection is present.
CT-Myelography: Diagnosis of CSF Fistulas Utilizing CT/Intrathecal Metrizamide	Summary: In the Morris *et al*. study, CT-Myelography documented the locus of CSF fistulas/DT in five of six patients.[44]
Digital Subtraction Myelography for Diagnosing Spontaneous CSF Leaks	Summary: Hoxworth *et al*. utilized digital subtraction myelography to diagnose the site of thoracic CSF fistulas (six patients) vs. superficial siderosis (five patients) in patients with spontaneous intracranial hypotension (SIH).[25]
MRI, Myelo-CT (M-CT, and Radionuclide Myelography Demonstrating) Postoperative CSF Fistulas	Summary: Couture and Branch utilized MRI, CT, Myelo-CT, and occasionally, radionuclide myelography to evaluated postoperative spinal pseudomeningoceles and CSF fistulas/iatrogenic DT that occurred during posterior lumbar surgery.[9]
M-CT Superior to Radioisotope Cisternography (RIC) for Documenting Cervical/Thoracic Sites Responsible for SIH	Summary: Hashizume *et al*. found that M-CT was superior to RIC for documenting cervical/thoracic sites responsible for SIH.[23]
Detection of DT with Three-dimensional Fast Spin-echo MR myelography.	Summary: According to the Tomoda *et al*. study, CT-Myelography or M-CT studies, Digital Subtraction Myelography, MRI, Three-dimensional Fast Spin-echo MR myelography, Radionuclide Myelography/Cisternography are all capable of demonstrating DT or the site of origin of CSF fistulas.[53]
Repair of Dural Tears Open Surgical Repair Options for Full Thickens Tears	Summary: Full thickness dural tears are best treated with direct suturing techniques utilizing 7-0 Gore-Tex sutures (needle is smaller than the suture), followed by the application of muscle, fascial, or bovine pericardial grafts, microfibrillar collagen and fibrin sealants.
Muscle Patch vs. Pedicle Grafts for Open Repair of Full Thickness Tears	Summary: Muscle patch grafts may supplement repair of DT utilizing 7-0 Gore-Tex sutures (needle is smaller than the suture itself). Grafts must be harvested and compressed/tamped down so that they will not act as space occupying lesions. Once the graft is sewn in place (locally harvested, free muscle graft vs. pedicle graft), microfibrillar collagen and fibrin sealant may be applied.

Contd...

Table 1: Contd...

Section	Summary
Muscle Patch Grafts and Free Flap Muscle Grafts Utilized for DT Repair	Summary: Muscle pedicle grafts, either vascularized in combination with fascia lata autograft (free graft) or muscle flaps may be utilized to repair complex cervical CSF fistulas.[1,29]
Open Surgical Repair Options for Partial Thickness Tears	Summary: Full thickness or partial, DT are best managed with direct repair techniques. These optimally include primary, interrupted suture repair with 7-0 Gore-Tex sutures, with or without the application of microdural staples to effect a watertight closure. If the dura is insufficient to cover the defect, either a muscle patch graft or bovine pericardial graft may be sutured in place. Fibrin sealant (Tisseel) and microfibrillar collagen are then typically added. Thicker mocrifibrillar collagen may also be sutured in place.
Minimally Invasive Alternatives for Dural Repair MIS Complete Repair of Full Thickness Dural Fistulas	Summary: Only 8 of Ruban and O'Toole's 46 cases involving full thickness dural tears could be repaired with primary suturing.[48] Unfortunately, the authors recommended utilizing a monofilament suture for repair, which is contraindicated as it typically loosens and the needle is larger than the suture itself thereby fostering continued leakage from the needle puncture sites.
MIS Incomplete Repair or Full Thickness DT	Summary: For the remaining 38 cases in Ruban and O'Toole MIS series, the dural defects could not be primarily repaired.[48] The authors utilized Gelfoam which, according to the product's insert, is not supposed to be left near neural tissues due to potential swelling leading to neural compression. The additional application of microfibrillar collagen, fibrin glue, and bed rest were also advocated, thus avoiding lumbar/subfascial drains.
Repair of Partial Thickness DT	Summary: The MIS techniques offered for repair of partial DT treated only with direct fibrin glue and bed rest succeeded in seven of Ruban and O'Toole's patients.[48] However, this technique, which should at least include microfibrillar collagen, often fails, and may typically require secondary complex direct/indirect closure maneuvers.
Alternative Methods for Repairing Dural Fistulas Excluding Direct Dural Repair Spontaneous Resolution of Pseudomeningoceles	Summary: Kumar *et al*. determined that patients with postoperative asymptomatic pseudomeningoceles might exhibit spontaneous resolution of these collections without intervention, but with only the utilization of protracted bed rest.[35]
Ultrasound Guided Blood Patch for Persistent CSF leaks After Spinal Surgery	Summary: Following decompressions/instrumented lumbar fusions, six patients in Clendenen *et al*. series with persistent CSF fistulas were successfully managed with 4-D ultrasound guided epidural blood patches.[8]
Low Pressure Headaches/Intracranial Hypotension Treated with Blood Patches	Summary: In the Hasiloglu *et al*. study, the authors reported two cases of spontaneous intracranial hypotension resulting from intradural osteophyte/disc in the thoracic region; both were successfully treated with epidural blood patches.[24]
Treatment of Pseudomeningocele with Epidural Blood Patch	Summary: In the Fridley *et al*. study, ultrasound guided aspiration combined with epidural blood patches may adequately treat postoperative pseudomeningoceles.[18]
Treatment of DT with Lumbar Drains	Summary: In the Kitchel *et al*. study, percutaneously placed lumbar drains utilized for 4 days in patients with postoperative CSF fistulas resulted in resolution of these leaks in 15 of 19 patients; 4 (21%) required reoperation, while another 2 (10.5%) developed infections warranting appropriate antibiotic therapy.[33]
DT Treated with Oversewing of Wounds or Lumbar Drains	Summary: In the Tosun *et al*. series, DT occurred in 3.2% of 360 patients undergoing thoracic/lumbar surgery.[54] Unrecognized postoperative CSF fistulas (seven patients) were successfully treated with oversewing of the wounds, while pseudomeningoceles (five patients) were managed with lumbar drains.
Management of Giant Pseudomeningoceles	Summary: According to Weng *et al*., repair of giant pseudomeningoceles requires wound revision, direct dural repair, and subarachnoid fluid drainage.[56]
Treatment of DT with Lumbo-Peritoneal (LP) Shunts	Summary: Yadav *et al*. observed that LP shunts might be utilized to treat persistent CSF spinal fluid fistulas.[57] Risks included infections, CSF leaks, over drainage, and the potential for acquired Chiari malformations.
Lumbo-peritoneal and Pseudomeningocele-Peritoneal Shunts for Treating Postoperative CSF Fistulas	Summary: Hughes *et al.* managed 16 dural fistulas in 184 patients with placement of subfascial Jackson Pratt (JP) drains.[26] Eight patients were discharged home with drains left in place for a total of 10-17 days. Despite the absence of major sequelae, including the absence of infection, this management strategy poses significant risks that include pneumocephalus, subdural hematoma, and other factors.
Treatment of Persistent Lumbar CSF fistulas with Two Shunts: Lumbar Subarachnoid-Peritoneal, and Pseudomeningocele-Peritoneal Shunts.	Summary: Treatment of refractory CSF fistulas following lumbar spinal surgery was effectively accomplished by Deen et al. utilizing both subarachnoid-peritoneal, and pseudomeningocele-peritoneal shunts.[11]

Contd...

Table 1: Contd...

Section	Summary
Lumbar DT Repair with Aneurysm Clip	Summary: In the Beier *et al*. study, five patients with recurrent CSF fistulas following failed primary repair of DT utilizing sutures were successfully managed with aneurysm clips.[3]
Use of Shunts for Cervical DT Anterior Cervical DT Treated with Wound-Peritoneal and Lumbo-Peritoneal Shunts	Summary: The incidence of durotomies attributed to anterior cervical spinal surgery varies from 3.1% to 12.5%, the latter specifically attributed to OPLL.[7,16,17,22] Five (6.1%) of the 82 patients with CSF fistulas following OPLL surgery in the Epstein's series required wound-peritoneal and lumboperitoneal shunts in addition to bovine pericardial grafts, microfibrillar collagen, and Tisseel.[16]
Anterior Cervical CSF Fistula Treated with Sternocleidomastoid Muscular Flap	Summary: Lien *et al*. performed sternocleidomastoid muscular flaps to prevent persistent CSF leaks following durotomies occurring during anterior cervical procedures.[40]
Contraindications for Using Gelfoam As Adjunct to Closure of DT	Summary: Gelfoam's insert documents warn that it should not to be left in contact with or near neural tissue as swelling may contribute to neural compression and neurological deficits. Although recombinant thrombin is now available for utilization with Gelfoam, no longer posing the risk of viral transmission, the contraindications for its use with Gelfoam near neural structures remains.
Two Clinical Studies Documenting Neurological Deficits with Gelfoam	Summary: Two clinical studies, one involving the cervical (myelopathy), the other, the lumbar spine (cauda equina syndrome), documented increased neurological deficits attributed to the utilization of Gelfoam near neural tissues.[17,19] There are multiple contraindications to utilizing Gelfoam near neural tissues including increased neurological deficits due to compression of neural tissues (brain/spinal cord), fever/infections/abscess, giant-cell granuloma, immunologic reactions/encapsulation, hematoma, fibrosis, toxic shock, and hearing loss.
Use of Fibrin Sealants and Fibrin Glues in Spinal Surgery	Summary: One of the two fibrin sealants, DuraSeal, although FDA approved, resulted in two cases of spinal paralysis in the literature. The second fibrin sealant, BioGlue is clearly identified in its insert as neurotoxic, and is not FDA approved for spinal use. Despite their lack of FDA approval, both fibrin sealants have been safely/effectively utilized, although Tisseel has been more prominently reviewed in the clinical literature.[17]
Tisseel Safe and Effective: In Vivo Porcine Laboratory Studies	Summary: In a porcine skull base model, de Almeida *et al*. documented that Tisseel increased the biomechanical strength of dural repair.[10] Those utilizing fibrin glue also exhibited greater graft adherence and higher burst pressures without demonstrating increased inflammatory responses.
Efficacy of Fibrin Glues vs. Sealants: In Vivo Dog Durotomy Model	Summary: Hutchinson *et al*. assessed the efficacy of Evicel Fibrin Sealant (Human) vs. Tisseel (fibrin sealant) and DuraSeal (synthetic polyethylene glycol [PEG] hydrogel sealant) to avoid CSF leaks following 2.0-cm durotomies in a mongrel dog model.[27] Although all three sealants produced 100% intraoperative repair of CSF leaks (15 mmHg), only the two fibrin sealants were 100% effective postoperatively, and DuraSeal failed.
Clinical Efficacy of Tisseel in Chiari Malformation Type I Repairs in Children	Summary: Parker *et al*. reviewed the high incidence (3-40%) of complications attributed to performing duraplasty for Chiari I malformations (CM-I).[47] Complication rates for tissue sealants were 14.8% for no sealant, 18.7% for Tisseel, and 50% for DuraSeal.
Fibrin Sealant (Tisseel) For Closing DT in Spinal Surgery Tisseel Safety/Efficacy with Anterior Cervical Surgery	Summary: Two studies documented the safety/efficacy of Tisseel when utilized for anterior cervical dural repair.[16,58] In the Yeom *et al*. study, Tisseel reduced the volume of drainage (47 vs. 98 mL), its duration (< 20 cc at 17 and 24 hours), and the length of stay (1.2 vs. 2.1 days).[58] In Epstein's study, 5 of 82 patients undergoing average 2.6 level anterior corpectomy/fusion for OPLL developed CSF fistulas successfully managed with dural grafts, microfibrillar collagen (DuraGen), Tisseel, and both wound-peritoneal and lumboperitoneal shunts.[16]
Tisseel Safety and Efficacy in Spine Surgery Fibrin Sealant Supplementing DT Closure in Lumbar Surgery: Comparable Rate of Persistent CSF Fistulas with/without Tisseel	Summary: Following 4,835 lumbar procedures, 11.3% of patients (547 patients) developed CSF fistulas.[30] Although 50.8% of patients underwent repair with fibrin sealant, ultimately the utilization of fibrin sealant did not alter the incidence of persistent CSF leaks (those continuing over 90 postoperative days not reversed with bed rest/oversewing). Of interest, prior surgery increased the risk of CSF fistulas 2.8-fold.

Contd...

Table 1: Contd...

Section	Summary
Attenuation of Epidural Cervical and/or Lumbar Hemorrhage with Tisseel	Summary: Tisseel, a fibrin sealant, effectively reduces postoperative blood loss following decompressive cervical and/or lumbar surgery, and facilitates the reduction in volume and duration of drainage, while decreasing the length of stay.[50,58]
Tisseel Minimizes Intraoperative Bleeding and Limits Postoperative Drainage	Summary: Tisseel is safe and effective whether utilized clinically to minimize intraoperative bleeding, or to limit postoperative drainage. Additionally utilizing Tisseel to supplement closure by occluding/limiting epidural bleeding limits the risk for significant postoperative symptomatic seroma/hematoma.
Conclusion	Summary: Early recognition of DT, utilizing clinical and radiographic correlation, is critical to limit short and long-term complications. DT repair may utilize a multitude of adjunctive reparative measures, including lumbar drains, and wound-peritoneal/lumboperitoneal shunts.

thoracic MRI revealed a traumatic CSF leak, that was successfully treated with an epidural blood patch.[51]

UNINTENTIONAL DURAL TEARS WITH OPEN LUMBAR SURGERY

Frequency of DTs with primary lumbar stenosis surgery

The majority of unintentional DTs occur during spinal surgery, particularly in revision/secondary procedures [Table 1]. Cammisa *et al*. retrospectively assessed the incidence of traumatic durotomy occurring during 2,144 spinal operations performed over a 10-year period (followed for 22.4 months), finding: 66 (3.1%) had traumatic dural fistulas, most frequently occurring during revision surgery.[7] Of interest, 60 fistulas were discovered intraoperatively, and were directly repaired, while 6 (0.28%) fistulas not recognized at the primary surgery (five with pseudomeningoceles), failed to respond to conservative measures, and required additional surgery.

Frequency of DTs with surgery for degenerative stenosis with/without noninstrumented fusions and/or disc herniations

Unintentional dural fistulas occur with varying frequencies in patients undergoing lumbar surgery for spinal stenosis vs. disc disease [Table 1]. Intraoperative inadvertent CSF fistulas occur in from 3.1% to 15.9% of patients undergoing primary or revision surgery addressing degenerative lumbar stenosis.[7,12,32] The rate of DTs ranged from 3.1% to 9.0% for primary procedures, but increased to 15.9% for secondary/revision surgery (largely attributed to scar).[7,12,32] For predominantly geriatric patients undergoing multilevel laminectomies with noninstrumented fusions, Epstein found that DTs occurred in 9.1% of patients; all had severe OYL, and 50% had synovial cysts.[14] Lee *et al*. observed a 6.7% incidence of DTs attributed to open diskectomy vs. a higher 9.4% for those having minimally invasive surgery (MIS) tubular diskectomy.[38] In the Ruban *et al*. study, a 9.4% incidence of DTs occurred during minimally invasive diskectomy.[48]

Frequency of DTs with lumbar surgery for spinal stenosis with/without fusion

Utilizing the data from the Spine Patient Outcomes Research Trial (SPORT), Desai *et al*. evaluated whether durotomy occurring during surgery for spinal stenosis impacted outcomes [Table 1].[12] The study included 409 patients undergoing initial open laminectomies with/without fusion, and without spondylolisthesis; patients were followed an average of 43.8 months. Thirty-seven (9%) patients exhibited traumatic intraoperative dural fistulas that, interestingly, did not clearly correlate with clinical variables (sex, race), comorbidities (diabetes, hypertension), or other surgical variables (the number of levels decompressed, or the additional levels fused). Those with DTs exhibited no increased frequency of nerve root injuries, mortality, the need for more operations, or poorer primary outcomes (Short Form-36 Bodily Pain or Physical Function scores or Oswestry Disability Index). Repair of DTs did, however, require longer operative times, resulted in greater intraoperative blood loss, and longer lengths of stay (LOS). Despite the latter observations, the authors concluded that intraoperative durotomy during spinal surgery did not affect long-term outcomes.

Frequency of dural tears for degenerative stenosis and noninstrumented (*in-situ*) lumbar fusion

Epstein *et al*. noted a 9.1% (10 patients) frequency of DTs in 110 predominantly geriatric individuals undergoing multilevel laminectomies with noninstrumented posterolateral fusions followed over one postoperative year [Table 1].[14] Patients who developed DTs were typically older (averaging 74 years of age with fistulas vs. averaging 69 years of age without fistulas), included more females (90% vs. 76%), and had somewhat more extensive laminectomies (5.5 vs. 5.0 levels) and noninstrumented fusions (1.8 vs. 1.6 levels). Three other major factors appeared to contribute to DTs including OYL, synovial cysts, and prior surgery/scar.[14] All 10 patients in Epstein's series exhibited marked OYL that, in 3 patients, clearly extended to/through the dura; the remaining 100 patients without DT had moderate OYL (57 patients), while only 22 exhibiting marked OYL. In the same series, synovial cysts were observed in 50% of patients with DTs (5 of 10 with DTs) vs. 8% without DTs (8 of 100 patients). Prior surgical scar was found in a slightly higher number of patients with DTs (2 of 10 patients) vs. without DT (10 of 100 patients).

Frequency of dural tears for stenosis treated predominantly with instrumented fusions

Sansur *et al*. performed a retrospective analysis of 10,242 patients, under 65 or over 65 years of age, undergoing surgery for degenerative lumbar spondylolisthesis (DS) and isthmic spondylolisthesis (IS) of varying grades [Table 1].[49] Surgical procedures included; decompressions without fusion, anterior, anterior/posterior, posterior without instrumentation, posterior with instrumentation, and interbody fusion. There were 945 complications (9.2%) observed in 813 patients (7.9%). The most common included; DTs (2.1%; 211 patients), wound infections, implant complications, and neurological complications (range 0.7-2.1%).[49] Of interest, the mortality rate was 0.1%. Higher complication rates correlated with the diagnosis of DS (8.5%) vs. IS (6.6%), higher-grade spondylolisthesis (22.9% vs. 8.3%), and being over 65 years of age. Prior surgery did not have a negative impact on the frequency of complications.

Increased frequency of DTs with revision lumbar surgery

Khan *et al*. observed a higher frequency of intraoperative traumatic DTs occurring among 3,183 revision procedures consisting of decompressions and/or fusions [Table 1].[32] A 7.6% incidence of DT (153 of 2,024 patients) followed primary lumbar surgeries, but was increased to 15.9% for secondary operations (185 of 1,159 patients). Those observed intraoperatively were repaired with 4-0 silk sutures (7-0 Gore-Tex is now preferred due to the needle size being smaller than the suture and less reactive than silk); only six patients required additional surgery (four primary, two revisions).

Frequency of dural tears with minimally invasive surgery for spinal stenosis

Palmer *et al*. assessed the frequency of DTs occurring in 54 consecutive patients (77 levels decompressed) averaging 67 years of age, undergoing minimally invasive surgery (MIS) for degenerative spinal stenosis without spondylolisthesis [Table 1].[46] Patients had bilateral decompressions performed through a unilateral approach utilizing the Medtronic MicroDiskectomy (METRx) system (Medtronic, Memphis, TN, USA); eight patients also had disc herniations, and four had synovial cysts. Three (5.5%) of the 54 patients developed traumatic DTs; 2 were immediately recognized and treated, while the third DT was not; the latter patient subsequently required a secondary operation for repair/exploration of a pseudomeningocele.

CSF FISTULAS WITH OPEN VS. MINIMALLY INVASIVE DISKECTOMY

Incidence of durotomy with open diskectomy

Lee *et al*. analyzed 109 patients undergoing single level open (45 patients) vs. MIS tubular diskectomy (64 patients) [Table 1].[38] In this series, intraoperative DTs were somewhat less frequent; they occurred in three patients (6.67%) undergoing open diskectomy vs. a higher six (9.38%) having tubular diskectomy. Tubular diskectomy was, therefore, associated with an increased rate of durotomy, nerve root injury, wound complications, and recurrent disc herniations that were more likely to require additional surgery.

Incidence of durotomy with minimally invasive diskectomy

Ruban and O'Toole documented a 9.4% (53 patients) incidence of incidental durotomies occurring out of 563 patients undergoing MIS diskectomy [Table 1].[48] Of interest, 51 occurred during lumbar operations, while only 2 involved posterior cervical procedures. Following repair, no patients developed recurrent fistulas and/or pseudomeningoceles. Intraoperative CSF fistulas were also more likely to occur in patients with previous surgery at the same level. Additionallly, those with DTs had somewhat longer LOS, averaging 52 hours following decompressions, and 106 hours after fusions.

CSF FISTULAS WITH SYNOVIAL CYSTS

Incidence of dural tears in patients undergoing microsurgery for juxtafacet cysts (synovial cysts/ganglion cysts)

Oertel *et al*. evaluated the results of microsurgical decompressions (partial hemilaminectomy) for 27 patients (average age 61) with symptomatic juxtafacet cysts [Table 1].[45] At six postoperative weeks, 93% of patients improved; 83% demonstrated good to excellent results. Two (7.4%) of 27 patients sustained small asymptomatic DTs, and a slight temporary increase of the preoperative paresis. One cyst recurred 4 months later, and a second operation was warranted.[45]

CSF fistulas for synovial cysts treated with multilevel laminectomy and noninstrumented fusion

Synovial cysts are also typically associated with a higher incidence of traumatic DTs.[14,48] In Epstein's series, 10 (9.1%) of 110 patients undergoing multilevel laminectomies with noninstrumented fusions had DTs; five of 10 with DTs had synovial cysts, while only 8 of 100 patients without DTs had cysts [Table 1].[14]

CERVICAL SPINE SURGERY AND DURAL TEARS

Dural tears for cervical ossification of the posterior longitudinal ligament

Epstein and Hollingsworth discussed the rare efficacy of focal micro-dural repair of a DT following anterior cervical surgery for OPLL [Table 1].[13] Following a C3-C7 anterior corpectomy/fusion (ACF) (later followed by a C3-T1 posterior fusion (PF)), an anterior 5-mm CSF fistula at the C4-C5 level was directly repaired with a small (<1 cm) bovine pericardial graft. This was performed under an operating microscope, utilizing multiple interrupted 7-0 Gore-Tex sutures, 1.4-mm microdural staples, fibrin glue, and both wound-peritoneal (WP) and LP shunts. The patient was asymptomatic until the end of the first postoperative year when she presented with headaches attributed to a small, nonsurgical, intracranial, subdural hematoma; the LP shunt was removed, and her symptoms resolved.

Epstein further discussed the utilization of WP shunts to treat patients with DTs following anterior cervical OPLL surgery.[16] The series included 82 patients with MRI and computed axial tomography (CT) documented OPLL (averaging 2.6 levels) contributing to multilevel anterior cord compression. As all patients demonstrated significant kyphosis, they underwent multilevel anterior corpectomy/fusion (ACF) with simultaneous PF (average 6.6 levels). Five (6.1%) patients developed intraoperative DTs that positively correlated with CT-documented single-layer signs in two patients (large central mass), and double-layer signs in three patients (hyperdense/hypodense/hyperdense layers). All five patients were managed with complex dural repairs (sheep pericardial grafts, fibrin sealant, microfibrillar collagen) and shunts (WP and LP); fistulas resolved in all cases.

Joseph *et al*. reported a 6.3% incidence (9 patients) of anterior cervical DTs occurring in a series of 144 patients with OPLL.[31] Anterior dural defects (10-75 mm) were variously treated with on-lay muscle/fascia grafts, a gelatin sponge, and 5 days of bed rest with lumbar subarachnoid drainage. They too noted that subsequent secondary surgery was not required.

DTs with craniocervical fusions in adults

Lall *et al*. evaluated the frequency of complications including DTs occurring during craniovertebral junction (occiput/upper cervical spine) fusions in adults [Table 1].[36] The best-quality 22 studies showed that the most common perioperative complications included: instrumentation failure (nonunion with rates up to 7% for occipitocervical fusion, and 6.7% for atlantoaxial fusion), vertebral artery injury (1.3-4.1% mostly with C1-C2 transarticular screws and a high-riding vertebral artery), wound infection, and DTs. The incidence of DTs was 0.3% for patients undergoing transarticular screw placement, but 0% to a higher 4.2 for those undergoing occipitocervical fusions; where the latter utilized wire-based constructs, the rate of DTs increased to 25-28%. CSF fistulas were typically treated by leaving the screw in place if it occluded the leak, primary suturing, placing drains, and/or wound revisions.

Dural tears with occipital screw placement for pediatric posterior cervical fusions

Hwang *et al*. found that 2 of 20 pediatric patients developed DTs while undergoing occipitocervical fusions that involved placing 114 bicortical screws.[28] Patients averaged 7.7 years of age (range 10 months to 16 years). In addition to the two DTs, two other patients exhibited "vigorous venous bleeding, worsening of quadriparesis, wound infection, radiographic pseudarthrosis, and transient dysphagia."[28] The authors concluded that bicortical occipital screw fixation in the pediatric population is associated with an increased fusion rate but a high complication rate.

DURAL TEARS FOLLOWING THORACIC SPINE SURGERY

Dural tears following thoracic fusions in patients with ossification of the posterior longitudinal ligament

Matsumoto *et al*. evaluated the incidence of DTs and outcomes of fusions performed in 76 patients with thoracic OPLL treated with posterior decompression fusion/anterior decompression fusion, anterior decompression from a posterior approach, or circumferential approaches [Table 1].[42] Complications observed in 31 patients (40.8%) included; 7 (9.2%) DTs, 20 increased neurological deficits, 5 epidural hematomas, and 4 respiratory complications, along with 10 others.

Dural tears associated with surgery for thoracic ossification of the yellow ligament

Sun *et al*. assessed how often DTs occurred in 266 patients with thoracic OYL, and how they were managed [Table 1].[52] Dural ossification was the primary reason for DTs; DTs were observed in 32% (85 patients) of patients, 25.2% of whom exhibited dural ossification. Repairs utilized combinations of "gelatin sponge, muscle/fascia (grafts), artificial dura, silk suture, and fibrin glue." These repairs were not successful in 65 cases; patients exhibited combinations of continued CSF leakage, pseudocysts, wound dehiscence, and meningitis. Of these 65, 58 were successfully treated with prone positioning, sandbag pressure, and ultrasound aspiration, while only seven required additional surgery.

Prudent to avoid use of BMP with dural tears during spinal surgery

Glassman *et al*. in 2011 investigated whether the presence of DTs occurring during lumbar surgery was a contraindication to utilizing BMP/INFUSE (Medtronic, Memphis, TN, USA) due to its increased risks (e.g., ectopic bone formation, swellling, edema, scarring) [Table 1].[20] Proinflammatory effects were observed when BMP/INFUSE was used in the cervical spine, and resulted in increased swelling and edema. Recent animal studies documented that intrathecal diffusion of BMP in the presence of a DT could lead to activation of "a signaling cascade in all major CNS cell types, which may increase glial scarring and impact neurologic recovery."[20] Their study included 1,037 consecutive patients undergoing decompressions and posterolateral lumbar spine fusions utilizing rhBMP-2 with an absorbable collagen sponge (2003 to 2006); 58 patients (5.59%) developed intraoperative DTs. Notably, outcomes were comparable in both the DTs and non-DTs groups. The authors concluded that if the DTs can be repaired this is not a direct contraindication to using BMP with posterolateral fusions. However, avoiding the use of BMP/INFUSE in the presence of a DT would be prudent until further data are available regarding its safety in this setting.

Frequency of DTs during epidural analgesia for patients in labor

DTs also inadvertently occur during the placement of epidural/transforaminal lumbar catheters for epidural analgesia during labor [Table 1]. Manchikanti *et al*.'s prospective, nonrandomized series of 10,000 patients included those undergoing the following epidural procedures; 39% caudal epidurals, 23% cervical interlaminar epidurals, 14% lumbar interlaminar epidurals, 13% lumbar transforaminal epidurals, 8% percutaneous adhesiolysis, and 3% thoracic interlaminar epidural procedures.[41] DTs were encountered in 0.5% of patients; 1% following cervical, 1.3% following thoracic, 0.8% following lumbar interlaminar epidurals, and 1.8% after adhesiolysis.

In the Botwin *et al*. series, 157 patients received 345 cervical epidural steroid injections performed under fluoroscopy, utilizing an interlaminar technique at the C7-T1 or C6-C7 levels (18-gauge or 9-mm Tuohy needle).[5] Patients received 2 mL of 1% lidocaine (Xylocaine) and 80-mg of triamcinolone acetonide (Kenalog). There was an overall 16.8% complication rate that included a 0.3% incidence of DTs.

In the Berger *et al*. and Webb *et al*. studies, the risk of inadvertent DTs for those in labor varied from 0.04% to 6%.[4,55] The Berger *et al*. series involved 137,250 deliveries; epidural blood patches utilized to treat DT failed in 86% of cases, with 44% experiencing persistent headaches.[4] In the Webb *et al*. study, those with DTs experienced a 70-80% incidence of postural headaches that persisted in 28% of patients.[55]

COMPLICATIONS ASSOCIATED WITH DURAL TEARS

Dural tears contributing to postoperative infection

Koutsoumbelis *et al*. evaluated the medical records of 3,218 patients undergoing posterior lumbar instrumented fusions over a 6-year period; major complications and/or infections occurred in 84 (2.6%) patients [Table 1].[34] Factors contributing to the risk of perioperative infections included; DTs, obesity, greater blood loss, 10 or more people in the operating room, diabetes, chronic obstructive pulmonary disease (COPD), coronary heart disease, and osteoporosis. The most significant risk factors were obesity and COPD, and the most prevalent infectious organism was Methicillin-Resistant *Staphylococcus Aureus* (MRSA) (34.5%).

Frequency, location, and other complications of DTs

Guerin *et al*. retrospectively reviewed the incidence of durotomy/DTs occurring during 1,326 spinal procedures (37-month follow-up) [Table 1].[21] Fifty-one DTs (3.84%) involved the following spinal levels; 1 anterior cervical, 1 posterior cervical, 1 anterior retroperitoneal, and 48 posterior thoracolumbar procedures. Thirteen patients required 9 reoperations for complications that included: 7 persistent CSF leaks, 2 infections, 2 hematomas, and 2 pseudomeningoceles.

DTs: Frequency, location, attribution, deficits, and failure rates for closure

McMahon *et al*. performed a prospective review of the frequency of DTs occurring in 3,000 elective spinal cases performed over 15 years; the frequency of DTs was 3.5% (104 cases) for primary, but a higher 6.5% for secondary/revision procedures [Table 1].[43] DTs were attributed to the following individuals; 49% to residents, 26% to fellows, and 25% to attendings performing these procedures. DTs involved the cervical spine in 1.3% of cases vs. the thoracolumbar spine in 5.1% of procedures. New neurological deficits were attributed to DTs in 7.7% of patients vs. a 1.5% incidence of new deficits in patients without DTs. Failed attempts at dural repair occurred in 6.9% of cases; this was 3-fold greater (13%) for those undergoing revision (secondary) vs. initial operations (5%).

SYMPTOMS AND SIGNS OF DT

For patients with DTs, whether traumatic or spontaneous, orthostatic headaches typically lead the list of symptoms, followed by nausea, and vomiting [Table 1]. Although patients may exhibit findings that mimic meningitis, cultures are often negative reflecting a sterile inflammatory response. Other patients with recent surgery may develop wound swelling that may increase with Valsalva maneuvers. Swollen wounds may be directly tapped or tapped under ultrasound or CT-guidance. For those with open CSF fistulas, direct wound cultures are preferably obtained from a percutaneous puncture of the wound rather than from cultures obtained from draining fluid on the skin, as the latter can be secondarily contaminated by skin organisms.

NEURODIAGNOSTIC STUDIES FOR DETECTING CSF FISTULAS/DURAL TEARS

Utility of enhanced MRI studies, CT-myelography or radionuclide cisternography

For both traumatic and spontaneous DTs, enhanced MRI studies help document whether there is an underlying pseudomeningocele [Table 1]. MRI studies often directly demonstrate the site of communication with the CSF pathways, help to differentiate the collection from a seroma by showing direct communication with the dura/subarachnoid space, and offer more evidence as to whether an infection is present. If there is no infection, CT-Myelography (CTM), (Myelo-CT (M-CT) studies, Digital Subtraction Myelography, Three-dimensional (3D) Fast Spin echo (FSE) MRI myelography, and/or Radionuclide Myelography/Cisternography may document CSF fistulous sites.

CT-Myelography: Diagnosis of CSF fistulas utilizing CT/intrathecal metrizamide

Morris *et al*. utilized CT combined with intrathecal metrizamide to document the locus of CSF fistulas/DTs (contrast material extruding from the subarachnoid space) in five of six patients.[44] In one case, the DT had healed, and contrast material was confined to a focal meningocele.

Digital subtraction myelography for diagnosing spontaneous CSF leaks

Hoxworth *et al*. utilized digital subtraction myelograms to diagnose and pinpoint the origin of spontaneous intracranial hypotension (SIH) attributed to thoracic CSF fistulas (six patients) vs. superficial siderosis (five patients) [Table 1].[25] For the 11 patients in this study, although MRI examinations demonstrated extradural fluid collections spanning an average of 15.5 vertebral levels, only the postmyelographic CT studies with digital subtraction myelography documented the site of origin of these fistulas in 9 of 11 patients; they were all located between the T3 and T11 levels.

MRI, Myelo-CT, and radionuclide myelography demonstrating postoperative CSF fistulas

Couture and Branch evaluated postoperative spinal pseudomeningoceles and CSF fistulas that were iatrogenic DTs occurring during posterior lumbar surgery [Table 1].[9] Symptoms included: low-back pain, headaches, orthostatic hypotension, and occasionally nerve root entrapment manifesting radicular complaints.[9] Diagnostic studies utilized to confirm DTs included MRI, CT, M-CT, and occasionally, radionuclide myelography.

Myelo-CT superior to radioisotope cisternography for documenting cervical/thoracic sites responsible for spontaneous intracranial hypotension

Hashizume *et al*. retrospectively analyzed the use of radioisotope cisternography (RIC) vs. the M-CT (CTM) for detecting the site of CSF leak in 12 patients who developed SIH [Table 1].[23] Direct signs of paraspinal RIC accumulation occurred in 8 patients (67%), but in 100% of patients utilizing CTM primarily (in the cervical and thoracic regions).

Detection of DTs with three-dimensional fast spin echo MR myelography

Tomoda *et al*. documented that a large number of CSF leaks/small DTs can be visualized utilizing 3D FSE MR-myelographic images vs. radionuclide cisternography (RIS) [Table 1].[53] Of the 67 patients who were symptomatic with CSF hypovolemia, the 27 with positive indium-111 RIS were isolated. Twenty-two of these patients (81.5%) exhibited positive MR myelographic scans (16 definite, 6 possible, utilizing 3D FSE sequences TR/TE 6000/203 ms: lumbar spine). The authors concluded that MR-myelography was successful in a large number of cases of CSF hypovolemia/hypotension, and that RIS should be reserved for those that are more difficult to define and diagnose.

REPAIR OF DURAL TEARS

Open surgical repair options for full thickens tears

Full thickness DTs are best treated with direct suturing techniques (if feasible with/without micro dural staples), followed by the application of muscle patch grafts, fascia grafts, or commercially available bovine pericardial grafts [Table 1]. Direct suturing techniques, under the microscope, require 7-0 Gore-Tex sutures that have the advantage in that the needle is smaller than the suture itself. Interrupted sutures are preferred, as running sutures may loosen or break, disrupting the entire repair. Avoiding monofilament sutures is critical, as these tend to loosen, slide, and unfurl, compromising the repair site. Once the primary repair is performed, and a Valsalva maneuver has documented a watertight closure, then fibrin sealant, microfibrillar collagen, and a drain above the repair may be placed (e.g., it will help draw fibroblasts into the microfibrillar collagen, making the closure more water-tight). If the wound is relatively dry and the repair tenuous, one may choose not to use a drain.

Muscle patch vs. pedicle grafts for open repair of full thickness tears

If a primary repair with sutures is not considered watertight, it may be supplemented with a muscle patch graft [Table 1]. During the placement of the primary interrupted sutures, keeping the single needle still attached to the individual sutures, allows you to use these same sutures/needles to apply the muscle patch graft. Free muscle may be harvested locally. Muscle pedicle grafts are largely avoided as contractions of this "appendage" may disrupt the repair. Once the separated segment of muscle is harvested, tamping it down between two sheets of gauze will allow flattening of the graft so that it will not act as a space-occupying lesion. Once the muscle graft is in place, repeating the Valsalva maneuver will allow one to assess the adequacy of the closure, and then proceed with the application of fibrin sealant and microfibrillar collagen. With difficult repairs, a two-layer closure utilizing fibrin sealant, the soft microfibrillar collagen, another layer of fibrin sealant, and the suturable heavier-duty microfibrillar collagen (that can be sewn into place with 7-0 Gortex sutures) may be performed. This may be followed by the placement of an epidural drain if indicated.

Muscle patch grafts and free flap muscle grafts utilized for DTs repair

Muscle pedicle grafts and even free flap muscle grafts have been utilized for years to address intracranial and skull-base CSF fistulas, but rarely, cervical fistulas [Table 1]. When utilized in skull base surgery, Abuzayed *et al*. described performing a duraplasty combining a fascia lata autograft (free graft) with an on-site vascularized pedicle muscle flap (sutured to the fascia lata graft).[1] This method was successfully applied to five of six patients with postoperative recurrent CSF fistulas utilizing adjunctive Tisseel fibrin glue (Baxter Healthcare Corporation, Deerfield, IL), and a lumbar drain for 3 days. One patient, who required additional surgery 3 weeks later, demonstrated neovascularization of the muscle graft to the dural graft. In Hyun *et al*. study, a CSF fistula involved a ventral DT of the oropharyngeal cavity in a patient who had previously undergone anterior cervical surgery for a recurrent chordoma followed by radiation therapy.[29] When diagnostic testing revealed a CSF fistula involving the posterior pharyngeal wall and the ventral cervical dura, they rotated a semispinalis cervicis muscle pedicle flap from the posterior approach, followed by an anterior, transoral endoscopic augmentation utilizing a bovine pericardial patch graft.[29]

Open surgical repair options for partial thickness tears

For patients with partial thickness tears of the dura, defined by arachnoid "pouting" through the dural opening without a CSF leak, one can utilize a Valsalva and other maneuvers to determine if there is a subtle open communication [Table 1]. If there is no communication there are several treatment choices. The first, particularly if the dura is atretic, is not to attempt direct closure at the weakened site as this may risk "opening" a dural fistula, and increasing rather than decreasing the fistula size. A small muscle graft, tamped down to flatten it (e.g., between gauze) may be simply applied "en face," (without suturing) followed by the application of fibrin sealant (Tisseel) and Duragen (microfibrillar collagen). Alternatively, if the arachnoid appears to be "pouting" through the partial thickness tear, and looks like it may rupture, direct suturing of the edges utilizing 7-0 Gore-Tex sutures (interrupted) under the operating microscope should be performed. To further secure the defect, if indicated, taking care not to cut the needles off of the Gore-Tex sutures, needles can then be utilized to sew in a muscle patch graft over the repair site, followed by the application of fibrin sealant and Duragen.

MINIMALLY INVASIVE ALTERNATIVES FOR DURAL REPAIR

MIS complete repair of full thickness dural fistulas

In Ruban and O'Toole's series, only 8 of 46 full thickness DTs could be repaired with primary suturing [Table 1].[48] The authors utilized 4-0 Nurolon (Ethicon, Johnson and Johnson, Brunswick, NJ, USA). In general, this suture would not be appropriate for this task as it is a monofilament that tends to slide, unfurl, slip, unravel, and loosen. Furthermore, since the needle is larger than the suture, this repair may increase rather than decrease the risk of a persistent CSF leak. The suture of choice should be the 7-0 Gore-Tex applied individually. These authors also utilized a muscle graft, fibrin sealant, and strict bed rest (<24 hours) when warranted.

MIS incomplete repair of full thickness DTs

In the remaining 38 cases in Ruban and O'Toole MIS series, the dural defects could not be primarily repaired [Table 1].[48] They applied Gelfoam soaked in blood to cover the dural defect, followed by microfibrillar collagen matrix (Duragen, Integra Life Sciences, Plainsboro, NJ, USA), fibrin glue, and bed rest overnight; they avoided placing lumbar/subfascial drains. Although this technique was apparently successful in their series, it often results in delayed fistulas once the fibrin sealant begins to liquefy 7 days later. Additionally, there are multiple complications reported with the use of Gelfoam (Baxter Healthcare Corporation, Hayward, CA, USA) which according to the product's disclaimer, should not be left near neural tissues as swelling, particularly in closed spaces, can lead to neurological injury: "Whenever possible, Gelfoam Sterile Sponge should be removed after use in laminectomy procedures and from foramina in bone, once hemostasis is achieved. This is because Gelfoam Sterile Sponge may swell to its original size on absorbing fluids, and produce nerve damage by pressure within confined bony spaces. When Gelfoam Sterile Sponge was used in laminectomy operations, multiple neurologic events were reported, including but not limited to cauda equina syndrome, spinal stenosis, meningitis, arachnoiditis, headaches, paresthesias, pain, bladder and bowel dysfunction, and impotence."

Repair of partial thickness DTs

In the Ruban and O'Toole study, the seven patients who developed traumatic (surgery-related) partial thickness dural fistulas and were treated with fibrin glue and bed rest overnight exhibited no recurrent leaks [Table 1].[48] However, a certain number of such tenuous partial tear repairs would likely result in the subsequent rupture of arachnoid through the partially intact dura; when this occurs, it will likely require direct secondary surgical repair.

ALTERNATIVE METHODS FOR REPAIRING DURAL FISTULAS EXCLUDING DIRECT DURAL REPAIR

Spontaneous resolution of pseudomeningoceles

On occasion, as described by Kumar *et al*., patients with pseudomeningoceles may experience spontaneous resolution of these collections [Table 1].[35] They presented a 65-year-old female who following an L4-L5 diskectomy developed an MR-documented pseudomeningocele. She continued to improve without operative intervention, and was asymptomatic 3 years later without having undergone any further treatment. The subsequent MRI further documented complete resolution of the collection. Therefore, in patients who are asymptomatic with pseudomeningoceles, no further treatment may be warranted, although others may require protracted bed rest or other forms of treatment.

Ultrasound guided blood patch for persistent CSF leaks after spinal surgery

Clendenen *et al*. evaluated the efficacy of utilizing ultrasound guided epidural blood patches in 6 patients with persistent CSF leaks following lumbar surgery with instrumentation [Table 1].[8] In the absence of OYL, high-resolution 4-dimensional (4-D) ultrasound (US) and a Tuohy needle were utilized to successfully perform epidural blood patches.

Low pressure headaches/intracranial hypotension treated with blood patches

In the Hasiloglu *et al*. study, the authors reported two cases of SIH resulting from intradural osteophyte/disc in the thoracic region; both were successfully treated with epidural blood patches [Table 1].[24]

Treatment of pseudomeningocele with epidural blood patch

Fridley *et al*. assessed the value of repair of pseudomeningoceles in two adolescent females utilizing aspiration under ultrasound guidance followed by application of epidural blood patches [Table 1].[18] Although typically these collections involving DTs require open surgical repair, or long-term lumbar drains with/without blood patches, here the authors successfully utilized ultrasound to aspirate CSF from these collections (thus collapsing them down), followed by the application of epidural blood patches.

Treatment of DTs with lumbar drains

Kitchel *et al*. retrospectively assessed the efficacy of percutaneously placing lumbar drains and leaving them in place for 4 days in 19 patients with CSF leaks following spinal surgery [Table 1].[33] Fifteen of 17 patients who had the drains in place for up to 4 days (14 of 15) experienced resolution of their CSF fistulas. In 11 patients, followed over the long-term, 4 developed persistent leaks requiring reoperation and direct dural repair; additionally, 2 of these patients developed infections that resolved utilizing appropriate antibiotics (without surgery). LP drains, therefore, effectively treated 15 of 19 postoperative CSF fistulas, but resulted in 4 reoperations and 2 infections.

DTs treated with oversewing of wounds or lumbar drains

Tosun *et al*. observed that 3.2% (12 patients) out of 360 patients having thoracic/lumbar surgery exhibited unrecognized DTs postoperatively [Table 1].[54] The five pseudomeningoceles were managed with lumbar drains, while the seven CSF fistulas were treated with over-sewing of the wounds; none subsequently developed new neurological deficits, or wound infections.

Management of giant pseudomeningoceles with lumbar drains

Weng *et al*. treated giant (>8 cm long) spinal pseudomeningoceles in 11 patients following spinal surgery [Table 1].[56] Patients underwent open surgical revision of the pseudomeningocele, repair of the dural fistulas, and placement of subarachnoid catheters; none recurred in 16.5 postoperative months.

Treatment of DTs with lumbo-peritoneal shunts

Yadav *et al*. summarized the indications and complications of LP shunts utilized to treat various spinal conditions most prominently including spinal fluid leaks, pseudomeningoceles, and syringomyelia [Table 1].[57] They reviewed the risks of infections, CSF leaks, over drainage (headaches, subdural hematomas, intracranial bleeds), and acquired Chari malformation. Once spinal fistulas resolved, although shunts could be removed or occluded, there was still the potential risk of a persistent CSF fistula at the catheter site.

Lumbo-peritoneal and pseudomeningocele-peritoneal shunts for treating postoperative CSF fistulas

Hughes *et al*. suggested treating persistent postoperative CSF leaks in 16 of 184 patients by leaving the postoperative Jackson Pratt (JP) drains in place for a more prolonged period of time to avoid reoperations [Table 1].[26] Following repair, subfascial JP drains were placed. For eight patients, the drains were left in place, and patients were sent home on oral antibiotics. Drains were removed 10-17 days later, without sequelae. None exhibited subsequent complications; no infections, and no persistent CSF leaks. Nevertheless, this management strategy posed significant risks of infection, pneumocephalus, subdural hematoma, and persistent fistulous tracts, and therefore, one should not conclude that the method described is either, necessarily, safe or effective.

Treatment of persistent lumbar CSF fistulas with two shunts: Lumbar subarachnoid-peritoneal, and pseudomeningocele-peritoneal shunts

Deen *et al*. assessed the treatment of four patients with persistent CSF fistulas and pseudomeningoceles following lumbar surgery utilizing two CSF shunts: lumbar subarachnoid-peritoneal, and pseudomeningocele-peritoneal shunts [Table 1].[11] All four patients had failed secondary surgery, external drainage, and/or blood patches. Utilizing video-laparoscopic assistance, two shunts were successfully placed, without reverting to external drainage techniques.

Lumbar DT repair with aneurysm clip

Beier *et al*. utilized an aneurysm clip to occlude durotomies in five patients with friable dura.[3] Patients with persistent fistulas, following attempts at primary suture closure, later presented with friable, torn dura that made repeated microsurgical closure difficult [Table 1]. They noted that if the tear is more lateral under a bony edge, an aneurysm clip might facilitate these repairs without incurring the necessity for further bone removal/destabilization.

USE OF SHUNTS FOR CERVICAL DTS

Anterior cervical DTs treated with wound-peritoneal and lumbo-peritoneal shunts

The incidence of durotomies attributed to anterior cervical spinal surgery varies from 3.1% to 12.5%; the latter is specifically associated with OPLL [Table 1].[7,16,17,22] In Epstein's series of 82 patients with multilevel OPLL undergoing average 2.6 level anterior cervical corpectomy/fusion, 5 developed complex CSF fistulas.[16] All were successfully managed with dural grafts, microfibrillar collagen, WP, LP shunts, and fibrin sealant (Tisseel Baxter International Inc, Westlake Village, CA, USA) without neurological sequelae.[16]

Anterior cervical CSF fistula treated with sternocleidomastoid muscular flap

Lien *et al*. utilized a sternocleidomastoid muscular flap to prevent persistent CSF leaks following durotomies that occurred during two anterior cervical procedures [Table 1].[40] Neither patient exhibited a persistent postoperative CSF leak that required revision surgery.

Contraindications for using Gelfoam as adjunct to closure of DTs

There are multiple contraindications to utilizing Gelfoam and Thrombin in spinal surgery. As already discussed, Gelfoam's disclaimer states that this product should not be left in contact with neural tissues (e.g., the dura following a decompression); specifically increased swelling may produce a neurological deficit in confined bony spaces. "These adverse medical events have been associated with the use of Gelfoam Sterile Sponge for repair of dural defects encountered during laminectomy and craniotomy operations: fever, infection, leg paresthesias, neck and back pain, bladder and bowel incontinence, cauda equina syndrome, neurogenic bladder, impotence, and paresis." Additional risk factors of Gelfoam use include; fevers, nidus of infections and abscess, giant-cell granuloma, compression of brain and spinal cord, foreign body reaction, encapsulation of fluid, hematoma, neurologic events, excessive fibrosis, toxic shock syndrome, failure of absorption, and hearing loss.[15,17]

The use of Thrombin in conjunction with Gelfoam is also associated with increased risks/complications.[39] The diclaimer reads: "Gelfoam Plus contains Thrombin, which is made from human plasma. Products made from human plasma may contain infectious agents, such as viruses, that can cause disease. The risk that such products will transmit an infectious agent has been reduced by screening plasma donors for prior exposure to certain viruses, by testing for the presence of certain virus infections, and by inactivating and removing certain viruses. Despite these measures, such products can still potentially transmit disease. Because this product is made from human blood, it may carry a risk of transmitting infectious agents, e.g., viruses, and theoretically the Creutzfeldt-Jakob disease (CJD) agent." Originally, bovine derived thrombin was associated with antibody formation that would cross react with human coagulation factors, risking bleeding complications, anaphylaxis, and death. Human thrombin obtained from pooled donors also risked the transmission of blood-borne pathogens (HIV, Hepatitis, Slow Viruses), while having limited availability. The advantages of the subsequent development of recombinant thrombin are its minimal antigenicity, lack of risk of viral transmission, and that it can be utilized with Gelfoam, collagen, cellulose, fibrinogen, and in fibrin glues.

Two clinical studies documenting neurological deficits with Gelfoam

Two clinical studies, one in the cervical and the other in the lumbar spine, documented increased neurological deficits attributed to the use of Gelfoam near neural tissues [Table 1]. The first study reported that the immunogenicity of Gelfoam promoted postoperative swelling and significant neural compression in a patient who had undergone a cervical laminectomy/fusion.[15,17] The second revealed, markedly engorged Gelfoam densely adherent to and compressing the underlying dura.[15] Intraoperative cultures revealed Acinetobacter baumannii, treated with 6 weeks of intravenous Ertapenem (1-betamethyl-carbapenem) following which symptoms resolved. Friedman and Whitecloud reported a patient who, following a lumbar laminectomy/fusion for spinal stenosis, developed a cauda equina syndrome attributed to Gelfoam.[19] At the second surgery, the gelatin sponge had expanded and solidified, forming a substantial epidural mass; following removal of the mass, the patient's complaints resolved.[19]

Use of fibrin sealants and fibrin glues in spinal surgery

Closure of spinal durotomies requires varying combinations of sutures, microdural staples [medium], muscle grafts, dural patches, microfibrillar collagen, and "fibrin sealants" or "fibrin glues."[17] Epstein reviewed the manufacturers' inserts regarding two fibrin "sealants" DuraSeal (Confluent Surgical Inc, Waltham, MA, USA), and BioGlue (Cryolife, Kennesaw, Georgia, USA), and two "fibrin glues" Evicel (Johnson and Johnson, Ethicon Inc. Somerville, NJ, USA), and Tisseel (Baxter International Inc, Westlake Village, CA, USA). One of the two "fibrin sealants," DuraSeal, although Food and Drug Administration (FDA) approved for intracranial and spinal applications, resulted in two cases in the literature of spinal paralysis. Alternatively, the second fibrin "sealant" BioGlue, is not FDA approved for use in the spine, and was clearly defined by the manufacturer in their insert as neurotoxic. Despite the lack of FDA approval for both "fibrin sealants," Tisseel has been safely and effectively utilized in spinal surgery for years (documented in basic science and clinical literature), while the more newly available Evicel has been predominantly reviewed in animal studies (e.g., rats, rabbits).

Tisseel safe and effective in *in vivo* porcine laboratory studies

In a porcine skull base model, de Almeida *et al*. documented that Tisseel increased the biomechanical strength of a dural repair.[10] In their study, 10 pigs underwent the endoscopic creation of CSF leaks treated with pericranial grafts; 5 additionally received Tisseel. They observed no residual CSF leaks for those receiving Tisseel, while one occurred in the control group (pericranial graft without Tisseel) [Table 1]. Those utilizing fibrin glue also exhibited greater graft adherence and higher burst pressures without demonstrating increased inflammatory responses. Addtionally, when testing the *in vitro* burst pressures utilizing no adjunct, sutures, clips, or combined sutures and Tisseel, it was apparent that Tisseel improved the strength of CSF leak repairs.

Efficacy of fibrin glues vs. sealants in *in vivo* dog durotomy model

Hutchinson *et al*. assessed the efficacy of Evicel fibrin sealant (Human) vs. Tisseel (fibrin sealant) vs. DuraSeal (synthetic polyethylene glycol [PEG] hydrogel sealant) in preventing persistent CSF leaks following 2.0-cm durotomies in a mongrel dog model [Table 1].[27] Intraoperative and postoperative closures were assessed over a 28-day duration. Although all three sealants produced 100% intraoperative repair of CSF leaks (15 mm Hg), only the two (Evicel, Tisseel) were 100% effective postoperatively; DuraSeal failed. The extent of postoperative scarring was also less when utilizing the Evicel and Tisseel vs. DuraSeal.

Clinical efficacy of Tisseel in chiari malformation type I repairs in children

Parker *et al*. reviewed the high incidence (3-40%) of complications attributed to duraplasties performed in children with Chiari I malformations (CM-I) [Table 1].[47] Different fibrin sealants/glues were evaluated in 114 patients; complication rates were 14.8% for no sealant, 18.7% for Tisseel, but a much higher 50% for DuraSeal.

FIBRIN SEALANT (TISSEEL) FOR CLOSING DTS IN SPINAL SURGERY

Tisseel safety/efficacy with anterior cervical surgery

Two studies documented the safety/efficacy of Tisseel when utilized for anterior cervical dural repair [Table 1].[16,58] In the Yeom *et al*. study, 30 pairs of matched patients underwent anterior cervical fusions over three or more levels: 30 received Tisseel (2.0 mL sprayed over/around the plate/fusion sites), while the other 30 did not.[58] Those receiving Tisseel exhibited reduced volumes of drainage (47 vs. 98 mL), a shorter duration of drainage (<20 cc at 17 and 24 hours), and reduced LOS (1.2 vs. 2.1 days). In Epstein's study, 5 of 82 patients undergoing multilevel ACF for OPLL followed by PF developed CSF fistulas managed with varying techniques; all 5 received microfibrillar collagen, Tisseel, and WP/LP shunts, with one additionally receiving a dural graft (bovine pericardium).[16]

TISSEEL SAFETY AND EFFICACY IN SPINE SURGERY

Fibrin sealant supplementing DT closure in lumbar surgery: Comparable rate of persistent CSF fistulas with/without tisseel

Jankowitz *et al*. evaluated the efficacy of Tisseel in preventing CSF fistulas after inadvertent durotomies accompanying lumbar spinal surgery [Table 1].[30] Performing a retrospective analysis of 4,835 lumbar procedures over a 10 year period with a 90-day follow-up yielded 547 (11.3%) CSF leaks. CSF fistulas were confirmed utilizing clinical assessment, B-2 transferrin assays, and radiographic images. Tisseel was utilized to supplement the repair in 278 of these patients (50.8%) (none developed neurological complications), while the remainder received no fibrin glue. Persistent CSF leaks (those that did not resolve within 90 days utilizing bed rest/over-sewing) were observed in 64 patients (11.7%); they were significantly higher with prior lumbar surgery (21%) vs. initial operations (9%), there was no significant difference in the incidence of persistent CSF leaks with/without the use of fibrin glue, and no complications were attributed to fibrin glue.

Attenuation of epidural cervical and/or lumbar hemorrhage with Tisseel

Tisseel, in addition to increasing the strength of epidural closure following a CSF fistula, may be utilized to control/reduce epidural bleeding [Table 1]. In Sekhar *et al*. study, Tisseel effectively controlled venous hemorrhage from the epidural compartment [200 patients], vertebral venous plexus [20 patients], and anterior cavernous sinus [46 patients] without complications.[50] Additionally, in Yeom *et al*. study, involving 30 pairs of matched patients (experimental versus controls) undergoing anterior cervical fusions involving 3 or more levels, Tisseel reduced the volume/duration of drainage, and LOS.[58]

Tisseel minimizes intraoperative bleeding and limits postoperative drainage

Tisseel is safe and effective whether utilized clinically to minimize intraoperative bleeding, or to limit postoperative drainage [Table 1]. For patients with significant cardiovascular history, who likely require early (<10 days to 2 weeks) reintroduction of antiplatelet aggregants (e.g., carotid/coronary stents/peripheral vascular stents), or full anticoagulation (e.g., hypercoagulation syndromes, mechanical heart valves), utilizing Tisseel to supplement closure by occluding/limiting epidural bleeding limited the risk for significant postoperative symptomatic seroma/hematoma.

CONCLUSION

In spine surgery, CSF fistulas may be attributed to removal of tumors, placement of shunts, marsupialization of cysts, or to inadvertent/traumatic DTs (e.g., secondary to surgery/revisions, trauma). Early recognition, utilizing clinical (postural headaches, frank CSF drainage from the wound) and radiographic findings (MRI, CT, cisternographic studies) is critical to limit both short-term complications, and longer-term sequelae. To be effective, DT repair may utilize a multitude of adjunctive measures; interrupted 7-0 Gore-Tex sutures, muscle patch grafts, dural patches/substitutes (bovine pericardium), microfibrillar collagen, fibrin glues/dural sealants, lumbar drains, and rarely WP and/or LP shunts.

REFERENCES

1. Abuzayed B, Kafadar AM, Oğuzoğlu SA, Canbaz B, Kaynar MY. Duraplasty using autologous fascia lata reinforced by on-site pedicle muscle flap: Technical note. J Craniofac Surg, 2009;20:435-8.
2. Balkan II, Albayram S, Ozaras R, Yilmaz MH, Ozbayrak M, Mete B, *et al*. Spontaneous intracranial hypotension syndrome may mimic aseptic meningitis. Scand J Infect Dis, 2012;44:481-8.
3. Beier AD, Barrett RJ, Soo TM. Aneurysm clips for durotomy repair: Technical note. Neurosurgery, 2010;66:E124-5.
4. Berger CW, Crosby ET, Grodecki W. North American survey of the management of dural puncture occurring during labour epidural analgesia. Can J Anaesth, 1998;45:110-4.
5. Botwin KP, Castellanos R, Rao S, Hanna AF, Torres-Ramos FM, Gruber RD, *et al*. Complications of fluoroscopically guided interlaminar cervical epidural injections. Arch Phys Med Rehabil, 2003;84:627-33.
6. Brookfield K, Randolph J, Eismont F, Brown M. Delayed symptoms of cerebrospinal fluid leak following lumbar decompression. Orthopedics, 2008;31:816.
7. Cammisa FP Jr, Girardi FP, Sangani PK, Parvataneni HK, Cadag S, Sandhu HS. Incidental durotomy in spine surgery. Spine, 2000;25:2663-7.
8. Clendenen SR, Pirris S, Robards CB, Leone B, Nottmeier EW. Symptomatic postlaminectomy cerebrospinal fluid leak treated with 4-dimensional ultrasound-guided epidural blood patch. J Neurosurg Anesthesiol, 2012;24:222-5.
9. Couture D, Branch CL Jr. Spinal pseudomeningoceles and cerebrospinal fluid fistulas. Neurosurg Focus, 2003;15:E6.
10. de Almeida JR, Morris A, Whyne CM, James AL, Witterick IJ. Testing biomechanical strength of *in vitro* cerebrospinal fluid leak repairs. J Otolaryngol Head Neck Surg, 2009;38:106-11.
11. Deen HG, Pettit PD, Sevin BU, Wharen RE, Reimer R. Lumbar peritoneal shunting with video-laparoscopic assistance: A useful technique for the management of refractory postoperative lumbar CSF leaks. Surg Neurol, 2003;59:473-7.
12. Desai A, Ball PA, Bekelis K, Lurie J, Mirza SK, Tosteson TD, *et al*. SPORT: Does incidental durotomy affect long-term outcomes in cases of spinal stenosis? Neurosurgery, 2011;69:38-44.
13. Epstein NE, Hollingsworth R. Anterior cervical micro-dural repair of cerebrospinal fluid fistula after surgery for ossification of the posterior longitudinal ligament. Technical note. Surg Neurol, 1999;52:511-4.
14. Epstein NE. The frequency and etiology of intraoperative dural tears in 110 predominantly geriatric patients undergoing multilevel laminectomy with noninstrumented fusions. J Spinal Disord Tech, 2007;20:380-6.
15. Epstein NE, Silvergleid RS, Hollingsworth R. Increased postoperative cervical myelopathy and cord compression resulting from the use of Gelfoam. Spine J 2009;9:e19-21.
16. Epstein NE. Wound-peritoneal shunts: Part of the complex management of anterior dural lacerations in patients with ossification of the posterior longitudinal ligament. Surg Neurol 2009;72;630-4.
17. Epstein NE. Dural repair with four spinal sealants: Focused review of the manufacturers' inserts and the current literature. Spine J 2010;10:1065-8.
18. Fridley JS, Jea A, Glover CD, Nguyen KP. Symptomatic postsurgical cerebrospinal fluid leak treated by aspiration and epidural blood patch under ultrasound guidance in 2 adolescents. J Neurosurg Pediatr 2013;11:87-90.

19. Friedman J, Whitecloud TS 3rd. Lumbar cauda equina syndrome associated with the use of gelfoam: Case report. Spine (Phila Pa 1976) 2001;26:E485-7.
20. Glassman SD, Gum JL, Crawford CH 3rd, Shields CB, Carreon LY. Complications with recombinant human bone morphogenetic protein-2 in posterolateral spine fusion associated with a dural tear. Spine J 2011;11:522-6.
21. Guerin P, El Fegoun AB, Obeid I, Gille O, Lelong L, Luc S, *et al*. Incidental durotomy during spine surgery: Incidence, management and complications. A retrospective review. Injury 2012;43:397-401.
22. Hannallah D, Lee J, Khan M, Donaldson WF, Kang JD. Cerebrospinal fluid leaks following cervical spine surgery. J Bone Joint Surg Am 2008;90:1101-5.
23. Hashizume K, Watanabe K, Kawaguchi M, Taoka T, Shinkai T, Furuya H. Comparison of computed tomography myelography and radioisotope cisternography to detect cerebrospinal fluid leakage in spontaneous intracranial hypotension. Spine (Phila Pa 1976) 2012;37:E237-42.
24. Hasiloglu ZI, Abuzayed B, Imal AE, Cagil E, Albayram S. Spontaneous intracranial hypotension due to intradural thoracic osteophyte with superimposed disc herniation: Report of two cases. Eur Spine J 2012;21 Suppl 4:S383-6.
25. Hoxworth JM, Trentman TL, Kotsenas AL, Thielen KR, Nelson KD, Dodick DW. The role of digital subtraction myelography in the diagnosis and localization of spontaneous spinal CSF leaks. AJR Am J Roentgenol 2012;199:649-53.
26. Hughes SA, Ozgur BM, German M, Taylor WR. Prolonged Jackson-Pratt drainage in the management of lumbar cerebrospinal fluid leaks. Surg Neurol 2006;65:410-4.
27. Hutchinson RW, Mendenhall V, Abutin RM, Muench T, Hart J. Evaluation of fibrin sealants for central nervous system sealing in the mongrel dog durotomy model. Neurosurgery 2011;69:921-8.
28. Hwang SW, Gressot LV, Chern JJ, Relyea K, Jea A. Complications of occipital screw placement for occipitocervical fusion in children. J Neurosurg Pediatr 2012;9:586-93.
29. Hyun SJ, Rhim SC, Ra YS. Repair of a cerebrospinal fluid fistula using a muscle pedicle flap: Technical case report. Neurosurgery 2009;65:E1214-5.
30. Jankowitz BT, Atteberry DS, Gerszten PC, Karausky P, Cheng BC, Faught R, *et al*. Effect of fibrin glue on the prevention of persistent cerebral spinal fluid leakage after incidental durotomy during lumbar spinal surgery. Eur Spine J 2009;18:1169-72.
31. Joseph V, Kumar GS, Rajshekhar V. Cerebrospinal fluid leak during cervical corpectomy for ossified posterior longitudinal ligament: Incidence, management, and outcome. Spine (Phila Pa 1976) 2009;34:491-4.
32. Khan MH, Rihn J, Steele G, Davis R, Donaldson WF 3rd, Kang JD, *et al*. Postoperative management protocol for incidental dural tears during degenerative lumbar spine surgery: A review of 3,183 consecutive degenerative lumbar cases. Spine (Phila Pa 1976) 2006;31:2609-13.
33. Kitchel SH, Eismont FJ, Green BA. Closed subarachnoid drainage for management of cerebrospinal fluid leakage after an operation on the spine. J Bone Joint Surg Am 1989;71:984-7.
34. Koutsoumbelis S, Hughes AP, Girardi FP, Cammisa FP Jr, Finerty EA, Nguyen JT, *et al*. Risk factors for postoperative infection following posterior lumbar instrumented arthrodesis. J Bone Joint Surg Am 2011;93:1627-33.
35. Kumar AJ, Nambiar CS, Kanse P. Spontaneous resolution of lumbar pseudomeningocoele. Spinal Cord 2003;41:470-2.
36. Lall R, Patel NJ, Resnick DK. A review of complications associated with craniocervical fusion surgery. Neurosurgery 2010;67:1396-403.
37. Landa J, Kim Y. Outcomes of interlaminar and transforaminal spinal injections. Bull NYU Hosp Jt Dis 2012;70:6-10.
38. Lee P, Liu JC, Fessler RG. Perioperative results following open and minimally invasive single-level lumbar discectomy. J Clin Neurosci 2011;18:1667-70.
39. Lew WK, Weaver FA. Clinical use of topical thrombin as a surgical hemostat. Biologics 2008;2:593-9.
40. Lien JR, Patel RD, Graziano GP. Sternocleidomastoid muscular flap: Treatment of persistent cerebrospinal fluid leak after anterior cervical spine surgery. J Spinal Disord Tech 2012 May 24. [Epub ahead of print].
41. Manchikanti L, Malla Y, Wargo BW, Cash KA, Pampati V, Fellows B. A prospective evaluation of complications of 10,000 fluoroscopically directed epidural injections. Pain Physician 2012;15:131-40.
42. Matsumoto M, Toyama Y, Chikuda H, Takeshita K, Kato T, Shindo S, *et al*. Outcomes of fusion surgery for ossification of the posterior longitudinal ligament of the thoracic spine: A multicenter retrospective survey: Clinical article. J Neurosurg Spine 2011;15:380-5.
43. McMahon P, Dididze M, Levi AD. Incidental durotomy after spinal surgery: A prospective study in an academic institution. J Neurosurg Spine 2012;17:30-6.
44. Morris RE, Hasso AN, Thompson JR, Hinshaw DB Jr, Vu LH. Traumatic dural tears: CT diagnosis using metrizamide. Radiology 1984;152:443-6.
45. Oertel MF, Ryang Y, Ince A, Gilsbach JM, Rohde V. Microsurgical therapy of symptomatic lumbar juxtafacet cysts. Minim Invasive Neurosurg 2003;46:349-53.
46. Palmer S, Davison L. Minimally invasive surgical treatment of lumbar spinal stenosis: Two-year follow-up in 54 patients. Surg Neurol Int 2012;3:41.
47. Parker SR, Harris P, Cummings TJ, George T, Fuchs H, Grant G. Complications following decompression of Chiari malformation Type I in children: Dural graft or sealant? J Neurosurg Pediatr 2011;8:177-83.
48. Ruban D, O'Toole JE. Management of incidental durotomy in minimally invasive spine surgery. Neurosurg Focus 2011;31:E15.
49. Sansur CA, Reames DL, Smith JS, Hamilton DK, Berven SH, Broadstone PA, *et al*. Morbidity and mortality in the surgical treatment of 10,242 adults with spondylolisthesis. J Neurosurg Spine 2010;13:589-93.
50. Sekhar LN, Natarajan SK, Manning T, Bhagawati D. The use of fibrin glue to stop venous bleeding in the epidural space, vertebral venous plexus, and anterior cavernous sinus: Technical note. Neurosurgery 2007;61:E51.
51. Suh SI, Koh SB, Choi EJ, Kim BJ, Park MK, Park KW, *et al*. Intracranial hypotension induced by cervical spine chiropractic manipulation. Spine (Phila Pa 1976) 2005;30:E340-2.
52. Sun X, Sun C, Liu X, Liu Z, Qi Q, Guo Z, *et al*. The frequency and treatment of dural tears and cerebrospinal fluid leakage in 266 patients with thoracic myelopathy caused by ossification of the ligamentum flavum. Spine (Phila Pa 1976) 2012;37:E702-7.
53. Tomoda Y, Korogi Y, Aoki T, Morioka T, Takahashi H, Ohno M, *et al*. Detection of cerebrospinal fluid leakage: Initial experience with three-dimensional fast spin-echo magnetic resonance myelography. Acta Radiol 2008;49:197-203.
54. Tosun B, Ilbay K, Kim MS, Selek O. Management of persistent cerebrospinal fluid leakage following thoraco-lumbar surgery. Asian Spine J 2012;6:157-62.
55. Webb CA, Weyker PD, Zhang L, Stanley S, Coyle DT, Tang T, *et al*. Unintentional dural puncture with a Tuohy needle increases risk of chronic headache. Anesth Analg 2012;115:124-32.
56. Weng YJ, Cheng CC, Li YY, Huang TJ, Hsu RW. Management of giant pseudomeningoceles after spinal surgery. BMC Musculoskelet Disord 2010;11:53.
57. Yadav YR, Parihar V, Sinha M. Lumbar peritoneal shunt. Neurol India 2010;58:179-84.
58. Yeom JS, Buchowski JM, Shen HX, Liu G, Bunmaprasert T, Riew KD. Effect of fibrin sealant on drain output and duration of hospitalization after multilevel anterior cervical fusion: A retrospective matched pair analysis. Spine 2008;33;E543-7.

Videos available on www.surgicalneurologyint.com