RESEARCH ARTICLE

Advances in the Management of Spinal Durotomy

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ABSTRACT

Spinal durotomy, whether incidental or intentional, requires a watertight closure to prevent potentially significant complications. As a result of relatively recent technological advancements and research, spine surgeons now have many options for both intra-operative dural repair as well as managing post-operative cerebrospinal fluid (CSF) leak. This review presents a comprehensive overview of the current and historical treatment strategies in the management of spinal durotomy. Intra-operative treatment of intentional and incidental durotomies through a variety of available dural sutures, dural sealants and other patches and grafts as well as post-operative CSF leak management strategies including conservative measures, epidural blood patches, CSF diversion therapies and definitive surgical repair will be presented.

INTRODUCTION

Spinal surgery often results in dura or arachnoid membranes opening around the spinal cord whether intentionally or incidentally. Several potentially serious consequences have been reported in literature as a result of durotomies. In instances when durotomies are not properly closed or go unrecognized, patients can present with dizziness, nausea, postural headaches, vertigo, neck pain, meningismus, diplopia, photophobia, tinnitus, blurred vision.[52] Other potentially serious complications include wound breakdown, development of a pseudomeningocele, meningitis, hydrocephalus, arachnoiditis, and even death.[51]

Given the wide-ranging and sometimes serious complications of spinal durotomies, effective management strategies to reduce and even potentially eliminate such consequences are important. It is useful to discuss management of spinal durotomies by first categorizing them into iatrogenic and traumatic causes. Iatrogenic durotomies can be encountered incidentally or intentionally. Although unintended durotomies occur commonly during posterior lumbar surgeries, they can occur anywhere along the spine from the cranio-cervical junction down to the sacral levels where the spinal dura ends. When accessing intradural tumors, the dura is opened intentionally, thus increasing the risk of potential post-operative CSF leak. Spinal durotomies resulting from trauma (such as motor vehicle accident or gunshot wound) can be challenging to treat since they often result in more complicated dural tear and robust treatment strategies are not well established in literature.

Finally, durotomy management also varies among surgical approaches to the spinal dura, namely open surgical approaches versus minimally invasive strategies and anterior versus posterior techniques. Understandably, repairing an anterior durotomy while accessing the anterior cervical spine requires an entirely different approach than when one encounters a dural tear while performing a lumbar microdiscectomy.

INCIDENTAL DUROTOMY EPIDEMIOLOGY

Intra-operative, incidental durotomy, particularly in lumbar spinal surgery, can be a common occurrence. Rates of unintended durotomy vary widely in literature, ranging from 0.3% in lumbar discectomy to almost 35% in a single retrospective study. [1,2] Durotomy rates understandably vary among open and minimally invasive spine surgeries with one recent systematic review citing a durotomy rate of 8.11% in open-approach surgical techniques for lumbar degenerative conditions (range 2% – 20%) and a durotomy rate of around 7% in minimally-invasive techniques[3]. However, the authors did note that there were inconsistently applied definitions of "durotomy" in minimally invasive case series and therefore reported a wide range of 1% to 14% for the incidence.

The incidence of intra-operative, incidental durotomy in cervical spine surgery is considerably lower than in thoracic or lumbosacral surgeries.[4,5] This is presumably from the fact that surgeons are more likely to manipulate the dura around the cauda equina than around the spinal cord at cervicothoracic levels, which in turn leads to a higher incidence of incidental durotomy. Incidence of CSF leaks in elective anterior cervical spine surgery ranges from 0.3% to 21.4%. [6,7] As expected, the incidence is higher with calcified lesion adherent to dura. In a single-institution case series, there was a marked difference in the incidence of CSF leaks between patients with ossified posterior longitudinal ligament (OPLL) (18.8%) and cervical spondylotic myelopathy (CSM)

(0.5%). [8] The data for the incidence of thoracic durotomies is sparse in literature, but Sun et al. studied 266 patients with thoracic ossification of the ligamentum flavum and noted that almost one third of those patients had durotomy.[5,7]

INTRA-OPERATIVE CLOSURE TECHNIQUES

Intra-operative dural repair strategies will be discussed first since identifying and promptly addressing a dural violation, whether intentional or incidental, is the first step to preventing future complications. Although subject to some debate an important maxim in neurosurgery is ensuring a "watertight" seal of dura.[9] Due to the unique biomechanical properties of dura mater which tends to be fragile or inaccessible location of durotomy, perfect watertight closure is often difficult. The goals of a sufficient dural repair is to effectively contain neural elements, prevent pseudomeningocele and CSF fistulas and thus allow early mobility of the patient. The actual treatment of the durotomy varies according to the size and anatomic location of the tear. Generally, if the durotomy is accessible, primary repair is recommended and if not accessible, then observation, glue, or CSF diversion therapies are used. [29,30] Many dural repair techniques have been described in literature such as direct suturing, use of sealants to augment sutures, laser tissue welding, bioabsorbable staples, and different types of grafts and patches. It is, therefore, helpful to arrange dural repair strategies into three main categories: dural sutures, dural sealants, dural patches or grafts.[31,32,33,34,35,36]. Despite all of the numerous options available to the spine surgeon for dural closure, there is no clear consensus regarding the most effective method.

Dural Sutures

Neurosurgical literature is replete with various suturing techniques and materials to achieve the often elusive watertight dural closure. Four main suture materials are used almost universally by spine surgeons to primarily repair dura, namely Nurolon® (Ethicon, Inc., Sommerville, NJ), Prolene® (Ethicon, Inc., Sommerville, NJ), Gore-Tex® (W. L. Gore & Associates, Inc., Flagstaff, Arizona) and Silk. Nurolon is a non-absorbable, braided suture composed of the long-chain aliphatic polymer of Nylon 6 or Nylon 6,6. It is noted to have 81% tensile strength at 1 year, 72% at 2 years, and 66% at 11 years and elicits minimal acute inflammatory reaction. [24] Prolene is a non-absorbable monofilament suture composed of an isotactic crystalline stereoisomer of polypropylene, a synthetic linear polyolefin. This material does not adhere to tissues, is biologically inert, and elicits minimal tissue reaction and maintains tensile strength for up to 2 years.[21] Gore-Tex suture is a microporous, non-absorbable monofilament made of expanded polytetrafluoroethylene (ePTFE) and its unique structure allows the attachment of needles that approximate the diameter of the thread and is therefore thought to fill the entire needle hole, thus reducing CSF leak at the suture site.[22,23] Finally, silk suture is made of raw silk spun by silkworms and, although classified as non-absorbable, silk suture becomes absorbed by proteolysis and is often undetectable in the wound site by 2 years. In earlier neurosurgical literature, silk suture was routinely used to close dura although such practice is not as widely used and has been supplanted by Nurolon, Gore-Tex or Prolene sutures.

A recent biomechanical study demonstrated that dural closure techniques using Gore-Tex suture resulted in a higher mean CSF peak pressure at which fluid leakage was observed (34 cm H_20) when compared to closing with Nurolon suture (21 cm H_20). In fact, in this study, for each of the three groups by closure technique (running, locked continuous, and interrupted) Gore-Tex closures had a significantly higher peak pressure to failure than Nurolon closures.[20] In another recently published paper by Bakhsheshian et al., the authors studied cadaveric specimens and were able to show that 6-0 Prolene dural closures had significantly higher mean pressure thresholds for CSF leakage than dural closures with 4-0 Nurolon.[25] To date, there are no studies comparing Gore-Tex with Prolene.

Different suturing techniques for dural closures have also been studied, albeit in only a handful of published papers. Megyesi et al., showed that particularly in small linear incisions, simple interrupted silk suturing was superior to either simple running, running locked or interrupted vertical mattress techniques.[26]. However, in the same study, no suturing technique proved advantageous for the closure of a duraplasty. Yet another paper studied 6-0 Prolene in both simple running and simple interrupted and found no significant difference between leakage pressures.[27]

Dural Sealants

Dural sealants have been developed to reduce CSF leakage by augmenting dural closure. Commercially available dural sealants come in two types: synthetic absorbable sealants consisting of polyethylene glycol (PEG)-based polymers and biological absorbable fibrin-based sealants made from allogenic or autogenic fibrinogen in combination with thrombin and other hemostatic factors. Both types are available in liquid forms and patches and different formulations of each are used in both cranial and spinal surgery.

Among fibrin-based sealants, liquid glue formulations include Tisseel® or Tissucol™ (Baxter, Deerfield, IL, USA), Evicel® (Ethicon US, LLC), and dry patch products such as Tachosil® (Baxter, Deerfield, IL, USA) and Tachocomb® (CSL Behring, Tokyo, Japan). Tisseel consists of two active components with one component containing human fibrinogen and aprotinin while the other containing human thrombin and calcium chloride dihydrate .[37] When the two components mix via an applicator, the fibrinogen and thrombin combine to form a fibrin clot that adheres to tissue and provides hemostasis and acts as a biological glue. Evicel is a newer fibrin-based sealant derived from pooled human plasma and contains two components: Biological Active Component 2, mostly comprising cryoprecipitate, and thrombin. Evicel has been studied in a Phase 3 randomized control study completed in 2017 and has been shown to be effective as an adjunct to dural sutures to provide watertight closure of the dura mater in cranial surgery.[38] However, for Tisseel, the manufacturer's insert clearly states, "The safety and effectiveness (of Tisseel) used alone or in combination with biocompatible carriers in neurosurgical procedures or other surgeries involving confined spaces have not been evaluated, and its use in this setting is not approved by the FDA.

Neurosurgical literature has been mixed in terms of fibrin-based sealants' ability to augment sutures and achieve watertight dural closure and prevent post-operative CSF leaks. Jankowitz et al. showed in a retrospective case series of patients undergoing posterior lumbar spine surgery and experiencing an incidental durotomy that the use of fibrin sealant to augment dural sutures did not significantly decrease the incidence of a persistent CSF leak when compared to sutures alone.[39] In that paper, fibrin sealant was used during 278 of incidental durotomy cases (50.8%) to augment the dural closure. No significant difference in CSF leak was noted between the use of fibrin sealant, 33/278 (11.9%) and without, 31/269 (11.5%). At this time, there are no published studies studying treatment of intraoperative incidental durotomies in the spine with fibrin-based sealants. In a randomized control trial, Green et al., studied fibrin sealants in the setting of elective cranial surgery. The primary endpoint in that 2015 study was the percentage of patients attaining intraoperative watertight dura closure. This endpoint was met in 92.1% of fibrin sealant managed patients and 38% of those managed with just sutures ($p<0.001$). However, this significant difference had no effect on the frequency of postoperative leaks, which occurred in 6.7% of fibrin sealant patients and 2% of the suture control group.[38]

Among the synthetic PEG-based sealants, DuraSeal® Exact (Integra Life Sciences, Plainsboro, NJ) and Adherus® (Stryker, Durham, NC) spinal sealant systems have established safety and efficacy in their respective prospective, randomized, controlled, multicenter trials. DuraSeal® Exact spine sealant (DESS) is an absorbable PEG hydrogel developed for use as a sealant in spinal dural repair. DESS was developed by modifying the original DuraSeal to a new low-swell formulation to obviate neurological complications due to mass effect were reported with use of DuraSeal in the spine [10,11]. The Adherus Dural Sealant consists of a modified PEG polymer with terminal electrophilic ester groups and a polyethyleneimine (PEI) solution with a component containing nucleophilic amine groups. These two solutions combine to form a solid, absorbable biocompatible PEG-based hydrogel.[12]

DuraSeal exact has been studied extensively and is currently the only FDA-approved secondary agent for dural closure in the spine.[40] A recent multicenter non-randomized, prospective postapproval study by Kim et al. evaluated DESS in both incidental and intentional durotomies and demonstrated no significant difference in CSF leakage rate between the control (standard of care) and DESS groups.[41] Although the rates of deep surgical site infections and neurological serious adverse events were similar in both groups, the authors did find a higher rate of superficial skin infection in DESS group (2.8%) when compared to the control group (0.5%). Nevertheless, the study did establish non-inferiority of DESS to current standard of care. [41] Adherus Dural Sealant is currently being investigated in comparison with DuraSeal in a randomized control trial.

Dural Substitutes

Numerous materials are currently in use for dural substitutes for both cranial and spinal areas. An ideal dural substitute restores the continuity of the dura mater, prevents CSF leaks while minimizing infection, facilitates suturing, mimics the compliance of natural dura, and minimizes local tissue inflammation and encourages the infiltration of cells and vasculature to reconstruct native dura without inducing fibrosis or adhesions.[58] Currently used dural substitutes include autograft, allograft, xenograft, and non-biologic synthetic materials. Although dural substitues such as autologous pericranium, bovine pericardium, cadaveric dura, autologous fascia lata, muscle have been widely used in cranial surgery, spine surgery generally has relied on using animal-derived or synthetic substitutes. Some of the widely used dural substitutes include, but are not limited to, the following: Durasis, DuraGen or DuraMatrix, Durepair, DuraGuard, Alloderm, Preclude, and Neuro-Patch. Furthermore, Surgicel is sometimes used to augment some dural repairs.

Arguably, the most popularly used dural substitutes are collagen-based xenografts, namely DuraGen, DuraMatrix, and Durepair. DuraGen (Integra Neuroscience, Plainsboro, NJ) and DuraMatrix (Stryker, Kalamazoo, MI) are synthetic substitutes consisting of type I collagen matrix made from bovine achilles tendon. DuraGen has 20% more conformability than DuraMatrix while DuraMatrix has a 50 times lower liquid permeability rate than DuraGen.[64,65] DuraGen is perhaps now the most widely used dural substitute for spinal surgeries, presumably because it has more published clinical studies than all other dural collagen grafts combined.[66] DuraGen's porosity allows platelets to infiltrate the matrix and promote fibrin clot formation as well as fibroblasts to enter and lay down natural collagen fibers thus preventing CSF leakage and initiate the dural repair process. In humans, implanted DuraGen was completely resorbed within 1 year (often much earlier) and replaced by the host's collagen derived from infiltrating fibroblasts.[63] After over 10+ clinical trials and 1400+ patient later, it is reported to have a 0% foreign body response and a 1.9% infection rate along with a 2.1% leakage rate.[67] Durepair (Medtronic Inc., Goleta, CA) contains type I and type III collagen produced from bovine skin.[68] A recent biomechanical study has suggested that Durepair has between two to four times more tensile strength than cranial dura mater.[69]

The Durasis (Cook Medical, Bloomington, IN) is derived from porcine small intestinal submucosa which is made by harvesting the layer between the mucosal and muscular layers and removing the cells, keeping the extracellular membrane intact. The resulting biomaterial is a naturally derived substitute that contains structural collagens, other bioactive proteins, and cytokines that guide host-tissue remodeling.[60] Several animal models demonstrated that porcine submucosa is rapidly integrated into an organism's surrounding tissues to form a new and completely natural tissue.[61] Bejjani et al. in 2007 demonstrated comparable rates of infection, CSF leakage, and meningitis of Durasis to other comparable dural substitute materials of that time and quickly was approved for use in both cranial and spinal applications thereafter. DuraGuard (Integra, Plainsboro, NJ) is prepared from bovine pericardium which is cross-linked with glutaraldehyde. Some surgeons prefer DuraGuard for its superior tear resistance and tensile strength that is beneficial when suturing.

Alloderm is created from human donor skin but is an acellular tissue product that retains all of the original biochemical and structural components.[70] Alloderm is not packaged with any chemical preservatives and quickly becomes vascularized and integrated with native dura.[70] A study by Bower et al. found that the reoperation rate for cerebrospinal fluid leak in Chiari decompression surgeries causing pseudomeningocele was 2.2% with the AlloDerm graft and 17.1% with other materials such as DuraGuard, DuraGen, and Durepair.[70]

Preclude and Neuro-Patch are synthetic dural substitutes. Preclude (W. L. Gore & Associates, Newark, DE) is made up of inert expanded polytetrafluoroethylene with a comparably inert elastomeric fluoropolymer in a three-layer construct.[85] Neuro-Patch (Aesculap Inc., Center Valley, PA) is a microporous fleece made from highly purified polyester urethane and is supposed to support rapid fibroblastic proliferation.[83]

Surgicel (Ethicon, Inc., Somerville, NJ) consists of oxidized regenerated cellulose and is usually used as a fast, hemostatic agent. When hydrated, the material swells into a brownish or black gelatinous mass that is fully absorbed in one week to fourteen days and causes almost no tissue reaction. The manufacturer also suggests that Surgicel is bactericidal in vitro against both anaerobic and aerobic bacteria.[59] Surgicel is often used with sutures or dural substitutes to increase the success of dural repair. A study by Haq et al., in which four dural substitutes (Surgicel, Durasis, DuraGen, and Preclude) were studied in an animal model with regard to post-operative adhesion and fibrosis-induced spinal cord tethering, found that DuraGen produced the least amount of inflammation in the subarachnoid space and Preclude generated the most.[63]

POST-OPERATIVE CSF LEAKS AND PSEUDOMENINGOCELES

Pathophysiology and Epidemiology

It is important to recognize the difference in terminology when one refers to a "pseudocyst" or a "pseudomeningocele." Unintended dural tears or intentional dural violations with an intact arachnoid mater can result in development of a true "pseudocyst" lined by arachnoid through the accumulation of CSF by a ball-valve mechanism.[47,48] Dural tears with arachnoid violations that are not adequately repaired can lead to a one-way CSF flow into the extradural tissue, thereby resulting in a false cyst or "pseudomeningocele." Miller et al. first categorized pseudomeningoceles and pseudocysts as congenital, iatrogenic, and traumatic in origin. [43] Although each type of pseudomeningocele/pseudocyst is theoretically possible from cranio-cervical to sacral levels, congenital pseudomeningoceles/pseudocysts have typically been described in thoracolumbar levels; iatrogenic pseudomeningoceles have mostly been described at lumbar levels; traumatic pseudomeningoceles have mostly been described in cervical spinal segments.[44,45,46]

Congenital pseudocysts are associated with connective tissue disorders such as Marfan's syndrome and also neurofibromatosis.[45] Iatrogenic pseudomeningoceles form due to an incomplete closure of dural and arachnoid violations, thus causing CSF extravasation into paraspinal tissues. The vast majority of such CSF extravasations are self-limited and resolve on their own as the dura heals, particularly in small dural tears. However, in some cases, the extravasated CSF causes progressive reactive changes in the surrounding soft tissues and leads to non-resorption of the fluid, thus contributing to a "false" pouch (pseudomeningocele).[49] Fortunately, pseudomeningoceles are uncommon iatrogenic complications of spinal surgery.[42] The vast majority occur in the lumbar spine because the CSF in the lumbar thecal sac is under a much higher pressure when compared to cervical or thoracic spines. Furthermore, lumbar surgical procedures are much more common than thoracic or cervical ones and surgeons tend to manipulate the thecal sac a lot more often in the lumbar spine.[47,50] The true incidence of pseudomeningocele after incidental durotomy is unknown since many cases are probably asymptomatic.[55] Some older studies suggest the incidence of iatrogenic pseudomeningocele ranges between 0.068% as reported by Swanson et al. in 1700 exploratory laminectomies to 2% as reported by Teplick et al in 400 laminectomy patients who underwent postoperative CT scanning.[53,54]

POST-OPERATIVE PSEUDOMENINGOCELE TREATMENT

Thorough evaluation of preoperative neuroimaging studies, careful use of the Kerrison rongeur, proper microscopic visual assistance, and meticulous use of the surgical drill are all important techniques in avoiding dural tears and decreasing the risk of post-operative pseudomeningocele. However when pseudomeningocele occurs, a variety of treatment strategies exist.

Conservative Therapy

Controlling CSF leak and preventing pseudomeningocele formation relies on impeding the flow based on the difference in subarachnoid and epidural pressure.[81] Conservative measures include Trendelenburg positioning, increasing local wound pressure, or abdominal binders. Direct pressure at the site of durotomy with pressure dressing or brace may counteract CSF egress through the area of least resistance.[84] Common protocols include flat bed rest orders for lumbar or lumbosacral patients for 24 hours, or elevated head of bed for cervical and thoracic patients. Some authors also describe keeping a subfascial drain that would normally be placed intraoperatively for a longer period but off suction for several more days until drainage slowed.[79] Inhibiting CSF formation with acetazolamide has also been described in a randomized clinical trial to stop CSF leak in cranial patients.[82] However data is limited to the efficacy of azetazolamide for spinal durotomy and pseudomeningocele. In most cases, the presence of a pseudomeningocele inhibits wound healing and surgery may be required.

Epidural Blood Patch

Epidural blood patches (EBP) have long been used to relieve post-dural puncture headaches in patients who do not respond to conservative measures (bedrest, intravenous hydration, etc.) or in patients who present with spontaneous intracranial hypotension.[13,14] EBP is a procedure in which a small volume of the patient's own blood is injected into the epidural space in an attempt to "plug" any small dural openings. In recent years, attempts have been made to expand the applicability of EBP. There are have been limited case reports in literature describing the efficacy of EBP in treating post-operative pseudomeningoceles but there have been no robust large studies.[15,16,17] It is thought that that the blood forms a clot over the dural tear and allows healing of the dura; furthermore, the clot in the epidural space raises extradural tissue pressure relative to subarachnoid pressure and decreases the gradient for CSF efflux.[18] However, skepticism exists among some spine surgeons about the effectiveness of EBP in post-operative pseudomeningoceles since, unlike the situation with dural puncture procedures, the epidural space has been opened by the decompression procedure, and the blood injected during the blood patch procedure is no longer contained within the epidural space. A recent retrospective study reported an 84% success rate in resolving persistent pseudomeningocele-related headache, with an average follow-up of 22.3 months after the last injection.[19] This study however was different than prior EBP-related studies in that the authors aspirated the pseudomeningocele and then applied the standard EBP. Nevertheless, the efficacy of EBP in post-operative pseudomeningoceles is not well established and more studies need to be performed.

Direct Repair

Definitive surgical treatment for post-operative pseudomeningoceles and other CSF fistulas are usually recommended after failure of conservative measures or neurological symptoms that suggest myelopathy or radiculopathy.[72] Ideally, the surgeon should make an adequate skin incision that encompasses the area of leak and dissection should adequately visualize the durotomy, usually under an operative microscope. The durotomy site must also be explored so that neural structures are not strangulated. The durotomy itself can be closed with or without a graft. For durotomies that are located far too lateral and inaccessible for direct primary closure, muscle or fat can be introduced into an intentional medial durotomy and then pulled into the defect.[73] Some surgeons will augment the dural sutures with a variety of dural sealants. The paraspinal muscle and overlying fascia is closed in two layers; typically, subfascial drains or epidural drains or even epi-fascial drains are not routinely placed since they may lead to a continued communication between the intra- and extradural space and may be a source of infection.

CSF Diversion Therapy

Lumbar drains are often used in cranial surgeries when there is concern for persistent CSF leak. In transsphenoidal surgery perioperative lumbar drain used alongside vascular nasoseptal flap closure significantly reduces the rate of postoperative CSF leaks.[74] However the benefit of lumbar drain after intraoperative spinal durotomy is not as clear.

There is a paucity of literature describing specific indications for CSF diversion therapy after intraoperative CSF leak and no consensus on when to use a lumbar drain. In patients with anterior cervical durotomies, Zhai et al described placement of a lumbar drain in 7 out of 14 patients with a dural defect greater than 2mm. They recommend considering a lumbar drain when CSF leak is observed in the anterior cervical spine.[75] In another review of CSF leak after anterior decompression for thoracic OPLL, subarachnoid drainage was used along with chest tube drainage in one group compared to chest tube drainage alone with no difference in outcomes or persistent CSF leak in either group.[76] Mitchell et al described intraoperative repair of anterior cervical CSF leak in 8 cases without the use of lumbar drain.[77]

In a study reviewing intentional intradural spine surgeries, 13 out of 460 cases were complicated by CSF leak and symptomatic pseudomeningocele. 91 of these cases used an external cerebrospinal fluid drain, and these cases were more associated with CSF leak and symptomatic pseudomeningocele. However, the authors state this to be due to selection bias, as CSF drainage was used in cases they felt were more high risk in CSF leak.[79] Essentially, the placement of intraoperative subarachnoid drain after durotomy depends on what a surgeon may deems high risk for postoperative leak. In the cases of large pseudomeningoceles, they are best treated by a combination of direct repair and implantation of a subarachnoid drain.[78] CSF shunting has not been reported for treating pseudomeningoceles related to incidental durotomies during spine surgery.

Lumbar drainage with subarachnoid catheter has a reported complication rate of up to 44% ranging from headache and nerve root pain to more severe complications including subdural hematoma from over drainage, pneumocephalus and meningitis.[80] These are important considerations in clinical decision making.

CONCLUSION

Many options are currently available to address incidental or intentional durotomies. Water-tight closure of intra-operative durotomy with sutures remains the treatment of choice when feasible. Dural sealants and dural substitutes may be used as an adjunctive treatment to minimize complications that may result from persistent CSF leaks. In post-operative setting, conservative therapies such as bed rest, direct pressure dressing or brace, epidural blood patch, and lumbar intrathecal drain are utilized. If these measures prove unsuccessful, patients may require additional surgery. Thus, the surgeons must stay abreast of all the available options to minimize the risk and ensure the best outcome.

REFERENCES

1. Mayfield FH, Kurokawa K. Watertight closure of spinal dura mater. Technical note. J Neurosurg. 1975;43(5):639-40.

2. Rodriguez-olaverri JC, Zimick NC, Merola A, et al. Comparing the clinical and radiological outcomes of pedicular transvertebral screw fixation of the lumbosacral spine in spondylolisthesis versus unilateral transforaminal lumbar interbody fusion (TLIF) with posterior fixation using anterior cages. Spine. 2008;33(18):1977-81.

3. Ghobrial GM, Theofanis T, Darden BV, Arnold P, Fehlings MG, Harrop JS. Unintended durotomy in lumbar degenerative spinal surgery: a 10-year systematic review of the literature. Neurosurg Focus. 2015;39(4):E8.

4. Mcmahon P, Dididze M, Levi AD. Incidental durotomy after spinal surgery: a prospective study in an academic institution. J Neurosurg Spine. 2012;17(1):30-6.

5. Williams BJ, Sansur CA, Smith JS, et al. Incidence of unintended durotomy in spine surgery based on 108,478 cases. Neurosurgery. 2011;68(1):117-23.

6. Cammisa FP, Girardi FP, Sangai PK, et al. Incidental durotomy in spine surgery. Spine. 2000;25:2663–7.

7. Tani T, Ushida T, Ishida K, et al. Relatively safety of anterior microsurgical decompression versus laminoplasty for cervical myelopathy with a massive ossified posterior longitudinal ligament. Spine. 2001;27:2491–8.

8. Mochizuki M., Koda M. (2019) Management of Anterior Durotomy in Cervical Spine. In: Koller H., Robinson Y. (eds) Cervical Spine Surgery: Standard and Advanced Techniques. Springer, Cham

9. Barth M, Tuettenberg J, Thomé C, Weiss C, Vajkoczy P, Schmiedek P. Watertight dural closure: is it necessary? A prospective randomized trial in patients with supratentorial craniotomies. Neurosurgery. 2008;63(4 Suppl 2):352-8.

10. Mulder M, Crosier J, Dunn R. Cauda equina compression by hydrogel dural sealant after a laminotomy and discectomy: case report. Spine. 2009;34(4):E144-8.

11. Tseng WL, Xiao F. Duraseal thecal sac compression after lumbar discectomy causing radiculopathy. Spine J. 2015;15(8):1892-3.

12. Strong MJ, West GA, Woo H, et al. A Pivotal Randomized Clinical Trial Evaluating the Safety and Effectiveness of a Novel Hydrogel Dural Sealant as an Adjunct to Dural Repair. Oper Neurosurg (Hagerstown). 2017;13(2):204-212.

13. Buddeberg BS, Bandschapp O, Girard T. Post-dural puncture headache. Minerva Anestesiol. 2019 May;85(5):543-553.

14. Pagani-Estévez GL, Cutsforth-Gregory JK, Morris JM, Mokri B, Piepgras DG, Mauck WD, Eldrige JS, Watson JC. Procedural predictors of epidural blood patch efficacy in spontaneous intracranial hypotension. Reg Anesth Pain Med. 2019 Jan 13.

15. Maycock NF, van Essen J, Pfitzner J. Post-laminectomy cerebrospinal fluid fistula treated with epidural blood patch. Spine (Phila Pa 1976) 1994; 19:2223–2225.

16. Fridley JS, Jea A, Glover CD, et al. 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.

17. McCormack BM, Taylor SL, Heath S, et al. Pseudomeningocele/CSF fistula in a patient with lumbar spinal implants treated with epidural blood patch and a brief course of closed subarachnoid drainage. A case report. Spine (Phila Pa 1976) 1996; 21:2273–2276.

18. McCormack BM, Taylor SL, Heath S, et al: Pseudomeningocele/CSF fistula in a patient with lumbar spinal implants treated with epidural blood patch and a brief course of closed subarachnoid drainage. A case report. Spine 21:2273–2276, 1996

19. Sandwell S, Walter K, Westesson PL. Pseudomeningocele Aspiration and Blood Patch Effectively Treats Positional Headache Associated With Postoperative Lumbosacral Pseudomeningocele. Spine. 2017;42(15):1139-1144.

20. Ghobrial GM, Maulucci CM, Viereck MJ, et al. Suture Choice in Lumbar Dural Closure Contributes to Variation in Leak Pressures: Experimental Model. Clin Spine Surg. 2017;30(6):272-275.

21. Chu CC, Pratt L, Zhang L, Hsu A, Chu A. A comparison of a new polypropylene suture with Prolene. J Appl Biomater. 1993;4(2):169-81.

22. Miller CM, Signal P, Jacobson II JH. Reduced anastomotic bleeding using new sutures with a needle-suture diameter ratio of one. Surgery 1987;101:156-160.

23. Dang M-C, Thacker JG, Hwang JC-S, Rodeheaver GT, Melton SM, Edlich RF. Some biomechanical considerations of polytetrafluoroethylene sutures. Archives of Surgery 1990;125:647-650.

24. Dafford EE, Anderson PA. Comparison of dural repair techniques. Spine J. 2015;15(5):1099-105.

25. Bakhsheshian J, Strickland BA, Patel NN, et al. The use of a novel perfusion-based cadaveric simulation model with cerebrospinal fluid reconstitution comparing dural repair techniques: a pilot study. Spine J. 2017;17(9):1335-1341.

26. Megyesi JF, Ranger A, Macdonald W, Del maestro RF. Suturing technique and the integrity of dural closures: an in vitro study. Neurosurgery. 2004;55(4):950-4.

27. Ebel F, Wanderer S, Beck J, Raabe A, Ulrich CT. The Optimal Dura Closure Technique and Material – An In-Vitro Evaluation. J Neurol Surg A Cent Eur Neurosurg. 201;78(1):24.

28. Cain JE, Dryer RF, Barton BR. Evaluation of dural closure techniques. Suture methods, fibrin adhesive sealant, and cyanoacrylate polymer. Spine. 1988;13(7):720-5.

29. Hannallah D, Lee J, Khan M, Donaldson WF, Kang JD. Cerebrospinal fluid leaks following cervical spine surgery. J Bone Joint Surg Am. 2008;90(5):1101-5.

30. 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(7):984-7.

31. Eismont FJ, Wiesel SW, Rothman RH. Treatment of dural tears associated with spinal surgery. J Bone Joint Surg Am, 63A (1981), pp. 1132-1136.

32. Foyt D, Johnson JP, Kirsch AJ, Bruce JN, Wazen JJ. Dural closure with laser tissue welding. Otolaryngol Head Neck Surg. 1996;115(6):513-8.

33. Levy DI, Sonntag VK. Titanium dural clip testing. Technical note. J Neurosurg. 1994;81(6):947-9.

34. Kerr EE, Panchal RR, Kim KD (2014) Refractory Cervical Spinal Pseudomeningocele Successfully Treated with a Polycarbonate Face Mask: Technical Note. JSM Neurosurg Spine 2(1): 1011.

35. Mayfield FH, Kurokawa K. Watertight closure of spinal dura mater. Technical note. J Neurosurg. 1975;43(5):639-40.

36. Shimada Y, Hongo M, Miyakoshi N, et al. Dural substitute with polyglycolic acid mesh and fibrin glue for dural repair: technical note and preliminary results. J Orthop Sci. 2006;11(5):454-8.

37. Tisseel: Package Insert and Label Information. Italian version, March 2013, in, 2013. http://druginserts.com/lib/other/meds/tissell-1.

38. Green AL, Arnaud A, Batiller J, et al. A multicentre, prospective, randomized, controlled study to evaluate the use of a fibrin sealant as an adjunct to sutured dural repair. Br J Neurosurg. 2015;29(1):11-17.

39. 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; 18:1169–1174.

40. US Food & Drug Administration. Premarket Approval (PMA). https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfPMA/pma.cfm?id=P080013. Accessed September 22, 2017.

41. Kim KD, Ramanathan D, Highsmith J, et al. DuraSeal Exact Is a Safe Adjunctive Treatment for Durotomy in Spine: Postapproval Study. Global Spine J. 2019;9(3):272-278.

42. Sutterlin CE, Grogan DP, Ogden JA. Diagnosis of developmental pathology of the neuraxis by magnetic resonance imaging. J Pediatr Orthop. 1987;7(3):291-7.

43. Miller PR, Elder FW. Meningeal pseudocysts (meningocele spurius) following laminectomy. Report of ten cases. J Bone Joint Surg Am. 1968;50(2):268-76.

44. Lee KS, Hardy IM. Postlaminectomy lumbar pseudomeningocele: report of four cases. Neurosurgery. 1992;30(1):111-4.

45. Sutterlin CE, Grogan DP, Ogden JA. Diagnosis of developmental pathology of the neuraxis by magnetic resonance imaging. J Pediatr Orthop. 1987;7(3):291-7.

46. Kolawole TM, Patel PJ, Naim-ur-rahaman . Post-surgical anterior pseudomeningocele presenting as an abdominal mass. Comput Radiol. 1987;11(5-6):237-40.

47. Weng YJ, Cheng CC, Li YY, et al. Management of giantpseudomeningoceles after spinal surgery. BMC Musculoskeletal Disorders. 2010.

48. Hyndman OR, Gerber WF. Spinal extradural cysts, congenital and acquired; report of cases. J Neurosurg. 1946;3(6):474-86.

49. Pau A. Postoperative "meningocele spurius". Report of two cases. J Neurosurg Sci. 1974;18(2):150-2.

50. Hawk MW, Kim KD. Review of spinal pseudomeningoceles and cerebrospinal fluid fistulas. Neurosurg Focus. 2000;9(1):e5.

51. Couture D, Branch CL. Spinal pseudomeningoceles and cerebrospinal fluid fistulas. Neurosurg Focus. 2003;15(6):E6.

52. Deyo RA, Cherkin DC, Loeser JD, Bigos SJ, Ciol MA. Morbidity and mortality in association with operations on the lumbar spine. The influence of age, diagnosis, and procedure. J Bone Joint Surg Am. 1992;74(4):536-43.

53. Teplick JG, Peyster RG, Teplick SK, Goodman LR, Haskin ME. CT Identification of postlaminectomy pseudomeningocele. AJR Am J Roentgenol. 1983;140(6):1203-6.

54. Swanson HS, Fincher EF. Extradural arachnoidal cysts of traumatic origin. J Neurosurg 1947;4:530-538.

55. Lee KS, Hardy IM. Postlaminectomy lumbar pseudomeningocele: report of four cases. Neurosurgery 1992;30:111-114.

56. Oppel F, Schramm J, Schirmer M, Zeitner M. Results and complicated course after surgery for lumbar disc herniation. Adv Neurosurg. 1977;4:36–51.

57. Sun X, Sun C, Liu X, 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. 2012;37(12):E702-7.

58. MacEwan MR, Kovacs T, Osbun J, Ray WZ. Comparative analysis of a fully-synthetic nanofabricated dura substitute and bovine collagen dura substitute in a large animal model of dural repair. Interdisciplinary Neurosurgery: Advanced Techniques and Case Management. 2018; 13:145-150.

59. Ethicon, a Johnson & Johnson company: SURGICEL Absorbable Hemostat. (http://www.jnjgateway.com/home.jhtml?page=viewContent&contentId=fc0de00100000816&loc=USE NG) [Accessed May 2020]

60. Hodde JP, Badylak SF, , Brightman AO, & Voytik-Harbin SL: Glycosaminoglycan content of small intestinal submucosa: a bioscaf-fold for tissue replacement. Tissue Eng 2:209–217, 1996

61. Badylak S, Kokini K, , Tullius B, , Simmons-Byrd A, & Morff R: Morphologic study of small intestinal submucosa as a body wall repair device. J Surg Res 103:190–202, 2002

62. Bejjani GK, Zabramski J. Safety and efficacy of the porcine small intestinal submucosa dural substitute: results of a prospective multicenter study and literature review. J Neurosurg. 2007;106(6):1028-33.

63. Haq I, Cruz-almeida Y, Siqueira EB, Norenberg M, Green BA, Levi AD. Postoperative fibrosis after surgical treatment of the porcine spinal cord: a comparison of dural substitutes. Invited submission from the Joint Section Meeting on Disorders of the Spine and Peripheral Nerves, March 2004. J Neurosurg Spine. 2005;2(1):50-4.

64. Stryker Promotional Material #9410-400-152 Rev. A

65. Danish SF, et al: Experience with acellular human dura and bovine collagen matrix for duraplasty after posterior fossa decompression for Chiari malformations. J Neurosurg Pediatrics 104:16-20, 2006

66. Integra Promotional Material #0179537-2

67. Integra Promotional Material #0069447-3-EN

68. Mccall TD, Fults DW, Schmidt RH. Use of resorbable collagen dural substitutes in the presence of cranial and spinal infections-report of 3 cases. Surg Neurol. 2008;70(1):92-6.

69. Kizmazoglu C, Aydin HE, Kaya I, et al. Comparison of Biomechanical Properties of Dura Mater Substitutes and Cranial Human Dura Mater : An In Vitro Study. J Korean Neurosurg Soc. 2019;62(6):635-642.

70. Bowers CA, Brimley C, Cole C, Gluf W, Schmidt RH. AlloDerm for duraplasty in Chiari malformation: superior outcomes. Acta Neurochir (Wien). 2015;157(3):507-11.

71. MacEwan, MR.; Kovacs, T; Osbun, J; Ray, WZ. Comparative analysis of a fully-synthetic nanofabricated dura substitute and bovine collagen dura substitute in a large animal model of dural repair. Interdisciplinary Neurosurgery: Advanced Techniques and Case Management. 13,. 145-150. (2018).

72. Hadani M, Findler G, Knoler N, et al: Entrapped lumbar nerve root in pseudomeningocele after laminectomy: report of three cases. Neurosurgery 19:405–407, 1986

73. Mayfield FH, Kurokawa K: Watertight closure of spinal dura mater. Technical note. J Neurosurg 43:639–640, 1975

74. Zwagerman N, Wang E, Shin S, et al. Does Lumbar Drainage Reduce Postoperative Cerebrospinal Fluid Leak After Endoscopic Endonasal Skull Base Surgery? A Prospective, Randomized Controlled Trial. J Neurosurg. 2018. doi:10.3171/2018.4.JNS172447

75. Zhai J, Panchal R, Tian T, Wang S, Zhao L. The Management of Cerebrospinal Fluid Leak After Anterior Cervical Decompression Surgery. Orthopedics. 2018;41(2).

76. Cho J, Chan C, Lee S, Choi W, Maeng D, Lee H. Management of Cerebrospinal Fluid Leakage After Anterior Decompression for Ossification of Posterior Longitudinal Ligament in the Thoracic Spine: The Utilization of a Volume-Controlled Pseudomeningocele. J Spinal Disord Tech. 2012;25(4).

77. Mitchell B, Verla T, Reddy D, Winnegan K, Omeis I. Reliable Intraoperative Repair Nuances of Cerebrospinal Fluid Leak in Anterior Cervical Spine Surgery and Review of the Literature. World Neurosurg. 2016;88.

78. Weng Y-J, Cheng C-C, Li Y-Y, Huang T-J, Hsu RW-W. Management of giant pseudomeningoceles after spinal surgery. BMC Musculoskelet Disord. 2010;11:53.

79. Sellin JN, Kolcun JPG, Levi AD. Cerebrospinal Fluid Leak and Symptomatic Pseudomeningocele After Intradural Spine Surgery. World Neurosurg. 2018;120:e497-e502.

80. Açikbaş S, Akyüz M, Kazan S, Tuncer R. Complications of Closed Continuous Lumbar

Drainage of Cerebrospinal Fluid. Acta Neurochir (Wien). 2002;144(5).

81. Fang Z, Tian R, Jia Y-T, Xu T-T, Liu Y. Treatment of cerebrospinal fluid leak after spine surgery. Chinese J Traumatol. 2017;20(2):81.

82. Abrishamkar S, Khalighinejad N, Moein P. Acta Medica Iranica. Univ; 2013. http://acta.tums.ac.ir/index.php/acta/article/view/4410. Accessed June 13, 2020.

83. Raul JS, Godard J, Arbez-gindre F, Czorny A. [Use of polyester urethane (Neuro-Patch) as a dural substitute. Prospective study of 70 cases]. Neurochirurgie. 2003;49(2-3 Pt 1):83-9.

84. Kerr EE, Panchal RR, Kim KD. Refractory Cervical Spinal Pseudomeningocele Successfully Treated with a Polycarbonate Face Mask:Technical Note. JSM Neurosurg Spine 2(1): 1011. (2014)

85. Chappell ET, Pare L, Salehpour M, Mathews M, Middlehof C. GORE PRECLUDE MVP dura substitute applied as a nonwatertight "underlay" graft for craniotomies: product and technique evaluation. Surg Neurol. 2009;71(1):126-8.

