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Review Article

Review/Perspective: Incidence and treatment of CSF leaks/dural tears (DT) occurring during anterior cervical surgery

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ABSTRACT

Background: The incidence of cerebrospinal fluid (CSF) leaks/dural tears (DT) occurring during anterior cervical diskectomy and fusion (ACDF) are typically relatively low. However, this frequency markedly increases when anterior corpectomy and fusion (ACF) are performed to address ossification of the posterior longitudinal ligament (OPLL).

Methods: The reported frequencies of CSF leaks/DT occurring during elective ACDF (i.e. exclusive of trauma), ranges from 0.24% to 1.7%. Notably, this incidence substantially rises for multilevel ACF addressing anterior OPLL, markedly varying from 3.4 - 44.7%.

Results: The classical risks of anterior cervical CSF leaks/DT with anterior cervical surgery may be minimized utilizing an operating microscope. For OPLL, careful evaluation of preoperative non-contrast CT studies is critical, especially to document whether any of the 3 signs of dural penetrance is present. Here, posterior operative choices should be strongly considered in the presence of sufficient lordosis and/or a Positive K Line (+ K Line) as this will avoid an anterior cervical CSF leak/dural fistula. Alternatively, for patients with kyphosis and a Negative K Line (- K Line), preoperative anticipation and planning to treat an intraoperative anterior CSF leak/DT (i.e. direct anterior primary dural graft repair with 7-0 Gore-Tex sutures, microdural staples, microfibrillar collagen, wound-peritoneal shunt, and lumbar drain or lumboperitneal shunt) are essential in the course of performing direct anterior OPLL resection.

Conclusion: The incidence of anterior cervical CSF leaks/DT is relatively low (i.e. range 0.24 - 1.7%) where ACDF is performed for disc disease/spur/spondylosis exclusive of OPLL. However, where ACF is performed for multilevel OPLL, the risk of CSF Leaks/DT is substantially higher (i.e. range 4.3-44.7%).

Keywords: Anterior Cervical Diskectomy/Fusion (ACDF), Anterior Corpectomy Fusion (ACF), Ossification Posterior Longitudinal Ligament (OPLL), Radiculopathy, Myelopathy, Cervical Cerebrospinal Fluid (CSF) Leaks, Dural Tears (DT), Repair Stragies CSF Fistulas

INTRODUCTION

The frequencies of anterior cervical CSF leaks/dural tears (DT) occurring during anterior cervical surgery vary markedly dependent upon the pathology; relatively low rates are observed for anterior cervical diskectomy/fusion (ACDF)[1,3,4,12,18,19] vs. much higher frequencies for anterior corpectomy and fusion dealing with ossification of the posterior longitudinal ligament (OPLL)[1,6,11,14,17] [Table 1].[1-20] Routinely using an operating microscope, the range of frequencies for cerebrospinal

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Table 1: Clinical data for cerebrospinal fluid leaks/dural tears occurring during anterior cervical surgery.

Author [Ref] Journal Year	Study Design	Data	Data	Data	Outcomes
Mazur[15] **Neurosurg Focus 2011**	Rx CSF Leaks/DT in OPLL pts	Review 11 Studies Intra and postop Rx DT Ant Surg OPLL	Range Intraop DT with OPLL 4.3% to 32%	Techniques Prevention Intraop DT Repair Postop Drainage/Shunts	Direct Dural Repair Prefer Not Always Feasible Use Adjuncts
Lei[14] **Orthop Surg 2012**	CSF Leak/DT Ant C Surg Severe OPLL Prevent Rx 15 ACDF; 32 ACF	Retro 47 Severe OPLL Ages 39-73 Avg Age 56.4 DT Intraop 15: Postop 5 1 Partial DT Intact Arach (44.7%)	Local or Segmental OPLL > 5 mm Canal St > 50%	Rx OPLL Excision Floated (PA)	Repair DT Sutures GS, MP Postop BR Results: No Reop No Shunts Imp JOA Postop 7.3 to 13.7 Imp Rate 65.98%
Lee[13] **Eur Spine J 2014**	DT CSF Leak After Trauma	Intraop CSF Leaks 53 with Ant C Surg After Trauma 2004-2011	7 (13.2%) DT CSF Leak Intraop Avg Age 44.7 Poor ASIA Score Assoc CSF Leaks	MR Disrupt YL Correlate DT Intraop Rx FG Early removal WD within 1st 24 h Early Rehab No LD	No Later DT More Trauma Related DT vs. Routine Degenerative ACDF
Syre[18] **Spine 2014**	13 pts Traumatic CSF Leaks/DT ACDF	**13 (1%) DT/1223 ACDF** 3 Surgeons Logs	9/13 DT Rx Intraop Repair	4/9 Postop LD Success 1/9 3 Reop/Dural Repair Failed 3 Need Shunts (1 new HC)	Lit 7 Cases Trauma DT ACDF Here, 1% Traumatic DT ACDF
Epstein[3] **SNI 2014**	OPLL C Surg-Obtain MR/CT Exams: Look Edema MM, HCS	Ant, Post, 360 Deg Surg Mild-Severe Rad/Myelop Surg: NT Intubation, IONM	OPLL 3 Signs on CT Dural Pen	Indic Ant C Surg Kyphosis No Lord: Risks CSF Leak/DT Vascular-Vertebral, Carotid	Indic Post Surg Good Lord: Lesser Risk vs. Anterior C Surg
Fengbin[6] **J Spinal Disord Tech 2015**	126 Pts Ant C Surg OPLL +/- DO 89M/37F 2008-2012 Avg age 61 Dx 4.2 yrs	DO 11 of the 126 pts: 7 of 11 with DO had Intraop DT(63.6%) Followed Avg 12.8 mos	115 pts No DO: 4 (3.5%) DT |Intraop **Repair:** Gelatin Foam/FG/Bed Rest/ LD	Total 11(8.7%) of 126 OPLL Pt DT/ CSF Leak 3 Resolved (5 d Postop) 8 Persisted PB, Aspiration, LD (resolved 14-30 Postop d	Avg JOA Score 51.2% No New Sig Neuro deficits or Headaches
Yoshihara[19] **J Spinal Disord Tech 2015**	US NIS 2009 Incid DT C Surg	Incid DT 0.45% (855/190,021) >Risk DT Myelop OPLL Post Ant/Post	DT > AE 21.6% vs. 7.3% DT> LOS 6.0 d vs. 3.2 d DC Home 66.3% vs. 83.9%	DT Inc HC $96,424 vs. $62,416 Mort Similar 0.6% vs. 0.4%	DT Cervical Surgery Ant/Post 0.45% Highest OPLL (58.4 Fold) DT Inc Inhospital AE

(*Contd...*)

Table 1: (*Continued*).

Author [Ref] Journal Year	Study Design	Data	Data	Data	Outcomes
Mitchell[16] **World Neurosurg 2016**	Repair Intraop CSF Leak/DT Ant C Surg Review 8 Cases OPLL, ID, DE	AE of Ant C Leaks/ DT Dehiscence Meningitis Headaches LD Reop	Repair 1st CSF Drain DT Cover DS + Sealant Reduced Interbody Graft Allow Expansion Sealant + WD	8 Cases No Dehiscence No Cord Compression No Deficits No Meningitis No Headaches No LD	Repair Drain CSF DS+Sealant Smaller Graft/No AE
Elder[2] **World Neurosurg 2016**	Rx DT/CSF Leak During ACDF Impact Fusion Use Scope 9/14 Cases	Retro Series 14 Pts CSF Leak ACDF 1995-2014 Avg FO 13.1 mos	Diagnoses 10 SP/DDD 3 Disc/Rad 1 Kyphosis	# Levels ACDF 7 at 1-Level 5 at 2-Level 2 at 3-Level Open PLL in all cases	Repair DT FG+Synth Dura 5 LD (3 LPH) 2 RLN 8 Dysphagia Transient Fusion 12=100% No Infection
Goodwin[8] **J Clin Neurosci 2016**	Case PN EsophI CSF Leak/DT ACDF Post Trauma	21 yo M C56 Sublux Comp SCI Quad s/p MVA	1 Wk Postop Trach Fevers CT Frontal PN + Air Retroph	Esophagram Perforation C56	Rx Closure Dural Defect Esoph Repair
Adamson[1] **J Neurosurg Spine 2016**	ACDF ASC 1000 vs 484 Inpt ACDF 2016-2013 FO 90 Days Reop MM Readmit	Safety ASC 1000 Pts 629 (62.9%) 1-level 365 (36.5%) 2-Level Avg Age 49.5	484 M PACU Obs Window 4 h **Postop AE:** 8 (0.8%) Transfer Hospital for 3 Pain, 2 EKG, 2, DT 1 Clot; 1 Weak/Reop 1	No Deaths 30-Day readmit 2.2% 90 Day AE Similar ACS vs. Inpt 1 or 2 Level ACDF	AE Rate 1% Diagnosed RX in 4 hr PACU Obs Window **Similar** Results Safe ACDF in ASC
Guppy[9] **Word Neurosurg 2017**	2 Old Cases 1 New Case Reports SCH C ACF OPLL CSF Leaks	56 yo F Bilateral UE Pain/ Weak 3 Prior Ant C Surg Last 7 yr ago	Prior C5/C6 ACF Persistent CSF Leak	MR/Myelo-CT SCH Through Mesh Case C6 Redo ACF C5/C6/ Untether Cord	Better 2 yrs Later
Odate[17] **J Neurosurg Spine 2017**	1st LOP for OPLL 2nd Surg ACDF 2006-2013 19 C OPLL Revision Rx K Line = Horizontal from Mid C2-Mid C7	Avg Age 66 Interval 63 mos Avg FO 41 mos +K Line 8 pt -K Line 11 pt Before ACDF Thick OPLL 7.2 mm	Mean C2-C7 Angle 1.3 +/- 14 Degrees Mean JOA 10 Pre ACDF -11 Post ACDF Avg Imp Rate 18%	16 (63%) ACDF AE (12 pts) 8/19 CSF Leak Intraop (42%) 5 (26%) Neuro Worse SCHDD 1 Unclear 3 C5 Palsy	Other Intubate 1 Delirium 1 RLP 1 No Reop All Fused LOP: High 2nd Risk CSF Leak ACDF 8/19 (42%)
Epstein[4] **Surg Neurol Int 2019**	AE for ACDF 137,000 Per Yr Overall Morbidity 13.2-19.3%	Dysphagia 1.7-9.5% Postop Clot 0.4-5.6% (Epidural 0.9%) Worse Myelopathy 0.2-3.3% RLN 0.9-3.1% CSF Leak 0.5-1.7%	Wound Inf 0.1-1.6 Worse Rad 1.3% Horner's Syndrome 0.06=1.1% Resp Insuff1.1%	Esoph Perf 0.3-0.9% Motor 0.1% Inst Fail 0.1-0.9% Single Cases Internal Jugular Vein Occlusion Phrenic Nerve Injury	Pseud 1=Level 0-4.3% 2-Level 24% 3-Level 43% 4-Level 56% Reop Rate for Pseud 11.1% Readmit 5.1% at 30 days to 7% at 90 Days

(*Contd...*)

Table 1: (*Continued*).

Author [Ref] Journal Year	Study Design	Data	Data	Data	Outcomes
Kapadia[12] **Clin Spine Surg 2019**	Risk Factors CSF Leaks/DT ACDF No OPLL	NIS 1998-2010 OPLL Excluded 1,261,140 pts	3048 (0.24%) Postop Leaks Ages 55-89 Vs. Over 70 More DT vs. Ages 40-54	Increased Risk CSF Leak/DT No White Obesity HTN Not DM HL	CSF Leak/DT Increased LOS 6 d vs. 2.1 d Controls
Epstein[5] **Surg Neurol Int 2021**	Case Contrain Use DuraSeal ACF Caused Quad DuraSeal Insert Integra LifeSicences Princeton NJ	Contrain Use Anterior Cervical Spine Hydrogel Swells 12% in All Directions.	Not Use to Treat Unrepaired CSF Leaks Adjunct to Sutured Dural Repair Not for Gaps > 2 mm	C4, C5 Fusion C3-C6 Failed to Diagnose OPLL Applied DuraSeal Caused Postop Quad	2nd Surg LamiPF Only Failed Reop Anteriorly/
Halayqeh[10] **N Am Spine Soc J 2023**	Delayed CSF Leak/DT After ACDF Case Report	43-year-old F Ehlers-Danlos Syndrome 1 yr post ACDF Positional Headache Light-headed	Imaging ACDF Plate Subsidence CSF Leak Inf Displaced Cerebellar Tonsils	Revision Surg Removal of Original Screws; Replaced Shorter, Larger Diameter Screws	Postop Imaging 2-6 wk Postop Resolved CSF Leak/DT
Jang[11] **Neurospine 2023**	51 Ant C Surg Dec/Fusion OPLL 2018-2022 Pump-Regulated LD	CSF Leak +/- Intact Arach Placed Dural Sealant Patch Persistent Leak Rx PRLD	14/51 CSF Leaks/ DT 9 LD: 8/9 Resolved Ambulated	Over drainage Avoided PRLD Avoid Risks Bed Rest	Proposed PRLD Safe Effective for CSF Leak with OPLL After Anterior Dec/Fusion
Gazzeri[7] **Br J Neurosurg 2023**	Apply TachoSil (FS) Manage CSF Leak/ DT ACDF	Argue Fast No Sutures Repair Ant C CSF Leak 2012-2018	7 Cases 2 F 5 M Intraop DT Rx TachoSil (FS)+ Tisseel (FG)	CSF Leak/DT Due to Dissect PLL/Calcified Discs-Repair all in 1 Minute No Postop Recurrent Leaks at 6 Mos	Traumatic CSF Leak/ DT Rx ACDF 7 Cases TachoSil FS+Tisseel FG

Surg=Surgery, OPLL=Ossification Posterior Longitudinal Ligament, C=Cervical, Ant=Anterior, Post=Posterior, MM=Myelomalacia, HCS=High Cord Signal, Myelop=Myelopathy, Pen=Penetration, DT=Dural Tear, CSF=Cerebrospinal Fluid, Deg=Degree, Indic=Indications, Lord=Lordosis, NT=Nasotracheal, IONM=Intraoperative Neural Monitoring, US NIS=US Nationwide Inpatient Sample, Incid-=Incidence, AE=Adverse Events, LOS=Length of Stay, d=Days, DC=Discharged, Inc=Increased, HC=Hospital Costs, Mort=Mortality, Rx=Treatment, Retro=Retrospective Analysis, Avg=Average, St=Stenosis, ACDF=Anterior Cervical Diskectomy/Fusion, ACF=Anterior Cervical Corpectomy/Fusion, PA=Preserved Arachnoid, MP=Muscle Pedicle, GS=Gelatin Sponge, BR=Bed rest, Arach=Arachnoid, Reop=Reoperations, Imp=Improved, Postop=Postoperatively, LOP=Laminoplasty, Worse=Worsening, Delay=Delayed, FO=Follow-Up, SCH=Spinal Cord Herniation, DD=Defective Dura, RLP=Recurrent Laryngeal Nerve Palsy (Hoarseness), PN=Pneumocephalus, EsophI=Esophageal Injury, yo=Year Old, Sublux=Subluxation, SCI=Spinal Cord Injury, Comp=Complete, Quad=Quadriplegia, MVA=Motor Vehicle Accident, s/p=Status Post, Trach=Tracheostomy, Retroph=Retropharyngeal Space, Esoph=Esophageal, Assoc=Associated, ASIA=American Spinal Injury Association Score/Scale, YL=Yellow Ligament, FG=Fibrin Glue, WD=Wound Drain, wk/Wk=Week, h/hrs=Hour(s), yo=Year Old, LD=Lumbar Drain, Retro=Retrospective, SP/DDD=Spondylosis/Degenerative Disc Disease, Rad=Radiculopathy, PLL=Posterior Longitudinal Ligament, Synth=Synthetic, LPH=Low Pressure Headaches ASC=Ambulatory Surgery Center, Inpt=Inpatient, PRLD=Pump Regulated Volumetric Continuous Lumbar Drainage, MM=Morbidity/Mortality, Periop=Perioperative, Readmit=Readmission, M=Males, PACU=Postoperative Care Unit, Obs=Observation, h=Hours, TH=Transfer to Hospital, ACF=Anterior Cervical Corpectomy/Fusion, yr=Years, Dec=Decompression, FS=Fibrin Sealant, F=Female, M=Male, FG=Fibrin Glue, PLL=Posterior Longitudinal Ligament, HC=Hydrocephalus, DO=Dural Ossification, Dx=Diagnosis, PB=Pressure Bandages, ID=Intradural Disc, DE=Dura Ectasia, DS=Dural Substitute, WD=Wound Drain, HTN=Hypertension DM=Diabetes, HL=Hyperlipidemia Resp=Respiratory, Insuff=Insufficiency, Inf=Infection, Perf=Perforation, Esoph=Esophageal, Mort=Mortality, Pseud=Pseudarthrosis, Quad=Quadriplegia, Contrain-Contraindicated

fluid (CSF) leaks/dural tears (DT) occurring during anterior cervical diskectomy and fusion (ACDF) are relatively low (i.e. 0.24% (3048/1, 261,140 ACDF),[12] 0.45%,[19] 0.8% ACDF,[1] 1%,[18] and 0.5-1.7%).[1,4,12,18,19] However, the frequency increases

markedly with anterior corpectomy and fusion (ACF) addressing ossification of the posterior longitudinal ligament (i.e. 4.3%,[15] 8.7% (7 DT out of 11 with dural ossification,[6] 27.5%,[11] 42%,[17] and and 44%)).[6,11,14,15,17] In summary, the incidence of anterior cervical CSF leaks/DT is relatively low for ACDF, but markedly increases in OPLL patients.

Case Summary

A middle-aged patient had previously undergone a C6-C7 ACDF [Figure 1]. The patient newly presented after significant cervical trauma with cervical radiculopathy/myelopathy. When the MR documented a new large central disc herniation at the C56 level filling over 50% of the spinal canal, an ACDF at the C56 level was performed using a PEEK cage [Figure 2]. At surgery, we found the C56 acute disc herniation was accompanied by an irregular limbus vertebral fracture that had lacerated the dura; this DT was initially treated with microfibrillar collagen. However, within one postoperative week, the patient developed an MR-documented anterior fluid collection at the disc space level [Figure 3]. At the second surgery, the anterior dural leak was directly repaired by sewing in a dural patch graft with 7-0 Gore-Tex sutures, supplemented with 1.4 mm microdural staples between the sutures, and with the placement of microfibrillar collagen. To avoid anterior cord compression, the anterior interbody graft, utilized without a plate, was deliberately replaced anteriorly in the disc space over the repair construct. Several weeks later, due to concern regarding the stability of the C56 graft, the patient underwent a posterior cervical C5-C7 instrumented fusion. AP and Lateral cervical X-rays obtained 2 months and 2 years postoperatively confirmed the stability of both the anterior (C56 ACDF) and posterior instrumentation (C5-C7 fusion) [Figure 4]. Additionally, the patient remained asymptomatic over this interval.

Lessons Learned From This Case

In this patient, who sustained a traumatic cervical disc herniation, the first lesson was that we should have obtained a preoperative cervical CT scan in addition to the MR. This would likely have documented the attendant limbus vertebral fracture responsible for the ventral cerebrospinal fluid (CSF)/DT, enabling the surgeon to better anticipate the need for a complex anterior cervical dural repair. Second, surgery for traumatic cervical disc herniations require not only the routine use of an operating microscope, but also the ready availability of 7-0 Gore-Tex sutures, microdural staples (1.4 mm), and microfibrillar collagen in case a CSF leak is encountered.

Range of Incidence of CSF Leaks For Elective ACDF Surgery

The risk of CSF leaks/DT occurring during ACDF surgery ranges from 0.24-1.7% [Table 1].[1,4,12,18,19] Syre *et al.*

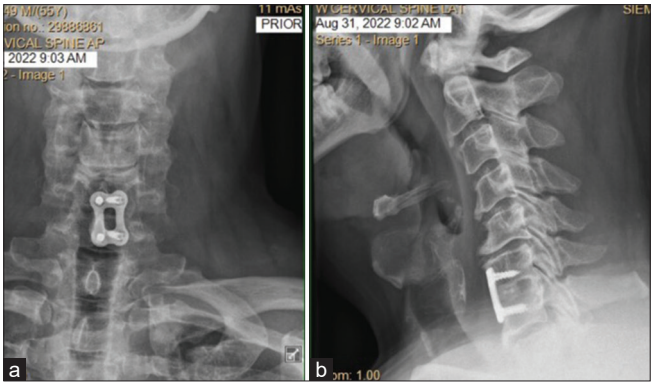

Figure 1: (a) Preoperative Anteroposterior (AP) and (b) Lateral Cervical X-rays. The AP (a) and Lateral (b) preoperative cervical X-rays documented a C67 anterior cervical diskectomy and fusion (ACDF) previously performed utilizing an anterior cervical plate/screws with an interbody graft.

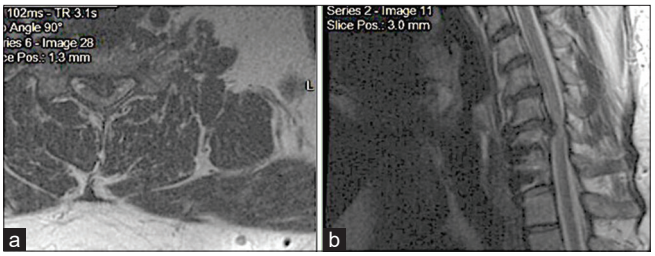

Figure 2: (a) Preoperative Axial and (b) Sagittal MR of the Cervical Spine. The preoperative Cervical Axial (a) and Sagittal (b) MR documented a large central disc herniation at the C56 level above the prior C67 anterior cervical diskectomy and fusion (ACDF). This disc herniation filled over 50% of the ventral spinal canal causing marked cord compression (i.e. as confirmed by the high intramedullary cord signal consistent with edema).

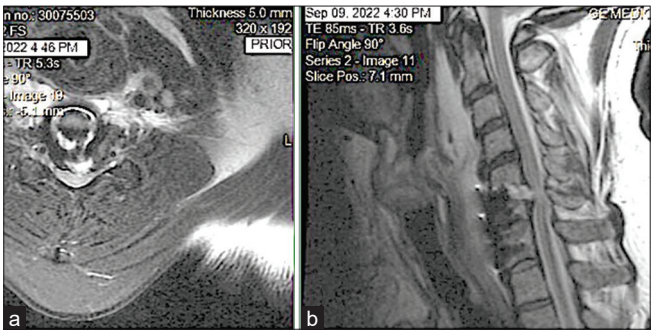

Figure 3: (a) Postoperative Axial and (b) Sagittal Cervical MR 5 Days Following the C56 ACDF. The initial C56 anterior cervical diskectomy and fusion (ACDF), performed under the microscope, required the removal of a large disc herniation and placement of microfibrillar collagen over a cerebrospinal fluid (CSF) fistula attributed to a traumatic limbus vertebral fracture. (i.e. occurring secondary to the history of trauma). A Polyetheretherketone (PEEK) cage was placed. However, 5 days later, fluid accumulated in the wound, and the follow-up Axial (a) and Sagittal (b) MR scans documented a ventral hyperintense fluid collection consistent with a CSF leak/DT in the anterior epidural disc space. The second surgery, also performed utilizing an operating microscope, included teatment of the anterior CSF leak/DT by direct suturing in an anterior dural graft with 7-0 Gore-Tex Sutures, placement of 1.4 mm microdural staples between the sutures, and the application of microfibrillar collagen.

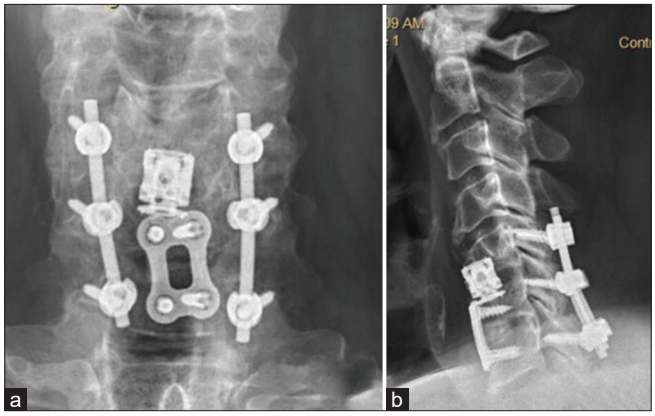

Figure 4: No Change in the (a) Anteroposterior (AP) and (b) Lateral Cervical X-rays Obtained 2 Months and 2 Years Following the C56 Anterior Cervical Diskectomy and Fusion (ACDF) and Posterior C5-C7 Instrumented Fusion. The AP (a) and Lateral (b) Cervical X-rays obtained 2 months and 2 years following the C56 ACDF and C5-C7 posterior instrumented fusion showed no changes in the location of the anterior (C56 ACDF) or posterior (C5-C7 fusion) instrumentation.

(2014) identified 13 (1%) of 1223 cervical trauma patients undergoing ACDF as having CSF leaks/DT (3 surgeons); notably, 9 patients underwent direct intraoperative repairs, and 4 of the 9 additionally received lumbar drains.[18] For these 9 patients undergoing primary repairs, 1 required no further intervention, 3 required additional surgery for failed dural repairs, and 3 needed shunts (i.e. including one ventriculoperitoneal shunt for newly developed hydrocephalus). Based on a Nationwide Inpatient Sample (NIS), the incidence of DT for Yoshihara *et al.* (2015) was 0.45% (855 patients) out of 190,021 patients undergoing cervical surgery; notably, the risk of DT increased 58.4-fold with OPLL, and anterior DT markedly increased the frequency of hospital adverse events (AE).[19] Adamson *et al.* (2016) performed 1000 ACF (i.e. single level vs. 2 level procedures in a 2:1 ratio) in an ambulatory surgical center (ASC), and compared the incidence of CSF leaks/DT and other AE occurring in the ASC vs. 484 control inpatients; 8 (0.8%) of the 1000 ASC patients had postoperative AE that included 1 CSF leak/DT, 3 transfers to the hospital for pain, 2 transfers for EKG changes, 1 postoperative clot, and 1 case of new postoperative weakness requiring additional surgery. [1] Of interest, there were no deaths among ASC patients, and the 30-day readmission rate was 22%. Epstein (2019) found the overall range of rates for AE following ACDF was 13.2-19.3%; CSF leaks/DT comprised 0.5-1.7% of these AE, while the reoperation rate was 11.1%, the readmission rate at 30 days was 5.1%, and the readmission rate at 90 postoperative days was 7%.[4] Kapadia *et al.* (2019) found 3048 (0.24%) CSF leaks/DT out of a Nationwide Inpatient Sample of 1,261,140 patients undergoing ACDF; most leaks occurred in older (i.e. over 70), non-white patients exhibiting obesity, and/or hypertension.[12] Notably, the length of stay was increased from 2.1 days to 6 days for patients with intraoperative dural fistulas.

Incidence of Anterior Cervical CSF Leaks/DT for Patients Undergoing ACDF For Trauma

Two studies, one case report and another small case series, discussed performing anterior cervical dural repairs of CSF leaks following traumatic injuries [Table 1].[8,13] In Goodwin *et al.* (2016), a 21-year-old male sustained a traumatic C56 subluxation with a spinal cord injury resulting in quadriplegia following a motor vehicle accident.[8] One week postoperatively, he developed fevers, retropharyngeal air, and pneumocephalus. The esophagram documented a perforation at the C56 level that was repaired, while the ventral CSF fistula was simultaneously closed. In Lee *et al.* (2014), the incidence of CSF leaks/DT for those undergoing ACDF for trauma was 13.2% (i.e. 7 patients) of 53 total patients; these DT were typically recognized intraoperatively, and repairs usually including the utilization of fibrin glues.[13] Notable, was that most fibrin glue/fibrin sealant package inserts warn, as a direct contraindication, against the use of these products in the anterior cervical spine.[5]

Single Case Reports or Small Series of Patients Developing Cervical CSF Leaks/DT Following ACDF Performed in the Absence of Trauma

Single case reports and small series recounted varying rates of CSF leaks/DT occurring following non-traumatic injuries requiring ACDF.[2,7,10] Elder *et al.* (2016) reported 14 OPLL patients undergoing 1-2 level ACDF who experienced CSF leaks/DT; DT repairs included fibrin glue, a synthetic dural substitute, and 5 lumbar drains.[2] In Halayqeh *et al.* (2023), a 43-year-old female with Ehlers-Danlos Syndrome presented 1 year following an ACDF with positional headaches; diagnostic studies showed inferior displacement of the cerebellar tonsils, anterior plate subsidence, and an anterior CSF leak/DT.[10] Here, surgery required repair of the DT, and replacement of the plate (i.e. adequate replacement confirmed on postoperative studies).[10] Also, in 2023, Gazzeri *et al.*, applied TachoSil, a fibrin sealant, to treat 7 anterior intraoperative CSF leaks/DT following ACDF where there was significant calcification of the anterior dura.[7] Again, note that most manufacturers' package inserts cite a direct contraindication for placing fibrin sealants/fibrin glues during anterior cervical surgery due to the risks of increased swelling and resultant significant cord compression contributing to neurological deficitis.

Large Series Summarizing Risks and Management of CSF Leaks/DT in OPLL Patients

Epstein, in 2014, looked at 3 CT signs of OPLL penetrating the anterior cervical dura [Table 1].[3] These findings markedly

increase the risks of an anterior cervical CSF leak/DT occurring when choosing to perform anterior cervical surgery in OPLL patients [Table 1].[3] The frequency of risks for anterior cervical CSF leaks/DT with OPLL varied widely; 4.3-32%,[15] 8.7% (DO 63.6% no DO 3.5%),[6] 19.6%,[11] 42%[17] and 44.7%.[6,11,14,15,17] Mazur *et al*. (2011) reviewed 11 studies that identified 4.3 to 32% frequencies for CSF leaks/DT occurring following anterior cervical OPLL surgery; direct dural repairs were preferred over other ajunctive measures, including drains/shunts.[15] Lei *et al*. (2012) encountered 21 (44.7%) CSF leaks/DT occurring with anterior OPLL surgery (i.e. positively correlated with segmental OPLL of over 5 mm, and > 50% canal stenosis); 15 occurred intraoperatively, 5 were observed postoperatively, while a 6th involved a partial dural tear with intact arachnoid.[14] For such leaks they recommended primary suturing/repair of dural defects without the addition of shunts. Fengbin *et al*. (2015) found the overall incidence of anterior cervical CSF leaks/DT was 8.7% out of 126 OPLL patients; 7 (63.6%) of 11 with dural ossification developed DT vs. a lesser 4 (3.5%) instances occurring out of 115 patients without dural ossification (DO).[6] Of the 11 repairs, consisting of gelatin foam/fibrin glue, bed rest, and lumbar drains, 3 CSF leaks/DT resolved within 5 postoperative days, while 8 persisted, requiring pressure bandages, aspiration, and/or lumbar drainage. In Odate *et al*. (2017), 19 patients first underwent laminoplasty for OPLL followed secondarily by ACDF (revision surgery); 8 (42%) patients developed CSF leaks/DT (i.e. 8 with + K line (meaning pathology anterior to the K line allowed for anterior, posterior, or circumferential surgery) vs. 11 with - K line (pathology posterior to the K line required anterior cervical surgery)).[17] Jang *et al*. (2023) found 14 (19.6%) CSF leaks/DT out of 51 OPLL patients undergoing anterior cervical surgery, and discussed using a; "pump-regulated lumbar drain" to treat these fistulas while avoiding over-drainage and prolonged bed rest".[11]

One Small Case Series and One Case Report on Treatment of CSF Leaks/DT in OPLL Patients Undergoing Anterior Cervical Surgery

One small case series and one case report discussed the presentation/management of CSF leaks/DT occurring due to OPLL and/or other pathologies [Table 1].[9,16] Mitchell *et al*. (2016) discussed repairing 8 consecutive CSF leaks/DT in patients undergoing anterior cervical surgery for OPLL, intradural disc herniations, and/or dural ectasias; initial treatment included covering dural defects with dural substitutes, application of fibrin sealant, placement of an "undersized interbody anterior graft", a low-pressure drain, and/or an additional wound drain.[16] All 8 repairs were successful (i.e. no postoperative wound dehiscence, no residual cord compression, no new neurological deficits, no meningitis, no headaches, and no need to replace lumbar drains). Guppy *et al*. (2017) presented 2 older OPLL patients and added 1 case of a 56-year-old female with OPLL who presented with a new C56 anterior cervical Myelo-CT-documented CSF leak/DT secondary to a prior ACDF 7 years ago; she successfully underwent detethering of the cord and repair of the C56 anterior dural defect.[9]

Case Report of Anterior Cervical CSF Leak/DT in OPLL Patient Treated with Contraindicated DuraSeal Resulting in Quadriplegia

Epstein (2021) noted that the package insert for the fibrin sealant DuraSeal (Integra LifeSciences Princeton NJ) states that it's use is contraindicated for treating anterior cervical CSF fistulas/DT due to the risk of cord swelling/cord compression (i.e. the hydrogel swells 12% "in all directions") [Table 1].[5] Further, it should not be applied over unrepaired leaks, and should only be used as an adjunct over "sutured dural repairs" (i.e. and should not be applied for gaps of > 2 mm). In this case report, following C4 and C5 anterior corpectomies and C3-C6 anterior fusion for OPLL, the surgeon placed Duraseal over the massive, unrepaired anterior dural defect. When the postoperative MR demonstrated marked anterior cord compression due to the DuraSeal, he then performed the wrong second operation; a laminectomy/posterior fusion. No further postoperative MR studies were performed for several weeks, leaving the patient quadriplegic due to the continued anterior cord compression from DuraSeal.

CONCLUSION

The incidence of anterior cervical CSF leaks/DT is relatively low (i.e. 0.24% to 1.7%) for ACDF performed to address disc disease/spur/spondylosis exclusive of OPLL [Table 1].[1,4,12,18,19] However, for OPLL patients, performing single/multilevel ACF markedly increases the risks of CSF leaks/DT (i.e. 4.3-44.7%) [Table 1].[6,11,14,15,17]

Ethical approval

Institutional Review Board approval is not required.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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