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What you need to know about ossification of the posterior longitudinal ligament to optimize cervical spine surgery: A review

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Abstract

What are the risks, benefits, alternatives, and pitfalls for operating on cervical ossification of the posterior longitudinal ligament (OPLL)? To successfully diagnose OPLL, it is important to obtain Magnetic Resonance Images (MR). These studies, particularly the T2 weighted images, provide the best soft-tissue documentation of cord/root compression and intrinsic cord abnormalities (e.g. edema vs. myelomalacia) on sagittal, axial, and coronal views. Obtaining Computed Tomographic (CT) scans is also critical as they best demonstrate early OPLL, or hypertrophied posterior longitudinal ligament (HPLL: hypo-isodense with punctate ossification) or classic (frankly ossified) OPLL (hyperdense). Furthermore, CT scans reveal the “single layer “ and “double layer” signs indicative of OPLL penetrating the dura. Documenting the full extent of OPLL with both MR and CT dictates whether anterior, posterior, or circumferential surgery is warranted. An adequate cervical lordosis allows for posterior cervical approaches (e.g. lamionplasty, laminectomy/fusion), which may facilitate addressing multiple levels while avoiding the risks of anterior procedures. However, without lordosis and with significant kyphosis, anterior surgery may be indicated. Rarely, this requires single/multilevel anterior cervical diskectomy/fusion (ACDF), as this approach typically fails to address retrovertebral OPLL; single or multilevel corpectomies are usually warranted. In short, successful OPLL surgery relies on careful patient selection (e.g. assess comorbidities), accurate MR/CT documentation of OPLL, and limiting the pros, cons, and complications of these complex procedures by choosing the optimal surgical approach. Performing OPLL surgery requires stringent anesthetic (awake intubation/positioning) and also the following intraoperative monitoring protocols: Somatosensory evoked potentials (SSEP), motor evoked potentials (MEP), and electromyography (EMG).

Key Words: Anesthesia, cervical surgery, diagnosis, intraoperative monitoring, ossification posterior longitudinal ligament, surgical management

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INTRODUCTION

This review focuses on how to maximize benefits, limit risks, and avoid the pitfalls of surgery for ossification of the posterior longitudinal ligament (OPLL). Careful patient selection, neurodiagnostic confirmation, and appropriate surgical planning utilizing strict intraoperative anesthetic and monitoring protocols are critical to obtaining the best results for OPLL surgery. Patients presenting with progressive myeloradiculopathy should be evaluated with both Magnetic Resonance Imaging (MR) and Computed Tomographic (CT) studies to document cord/root compression attributed to one of the 4 classic OPLL variants: "segmental", "continuous", "mixed", and "other". MR scans provide the best soft-tissue documentation of cord/root compression and intrinsic cord abnormalities, particularly on T2 weighted studies. CT examination, however, better document early punctate ossification centers within hypertrophied OPLL, or show classical ossification of mature OPLL [Figures 1-25]. CT studies may further demonstrate the single layer" and "double layer" signs indicative of potential dural penetrance by OPLL.

Multiple factors dictate whether anterior or posterior cervical surgery is appropriate for OPLL. The presence of an adequate cervical lordosis may lead to posterior approaches (laminoplasty, laminectomy/fusion). Advantages of posterior surgery include avoiding the major risks of anterior surgery; cervical CSF fistulous formation (most occur during anterior approaches), carotid/vertebral injuires, esophageal compromise, and others. Alternatively, the absence of lordosis and presence of kyphosis may require anterior surgery. These typically warrant single/multilevel corpectomies for resection of segmental, continuous, or mixed OPLL. Only rarely do single or multilevel diskectomy/fusion (ACDF) adequately address OPLL or early OPLL (HPLL: hypertrophied posterior longitudinal ligament) usually categorized as the "other type" of OPLL found at the disc spaces. Nevertheless, anterior procedures for OPLL must anticipate a higher risk of CSF leaks, and should include prophylactic preparation/draping for simultaneous wound-peritoneal shunts; placement of these shunts as soon as a CSF fistula is encountered should help avoid the subsequent respiratory decompensation that follows if CSF fills the wound unchecked. Also, immediately following completion of the cervical surgical procedure (anterior, posterior, or circumferential), one should plan for immediate placement of a lumbo-peritoneal shunt. The optimal operations for OPLL must be based on a multiplicity of factors and a thorough understanding of the unique OPLL pathology. Whether anterior, posterior, or circumferential approaches are utilized, the spinal surgeon must be fully aware of the neuroradiological complexities of this disease, and must, therefore, anticipate and limit, where feasible, the risks and complications associated with cervical OPLL surgery.

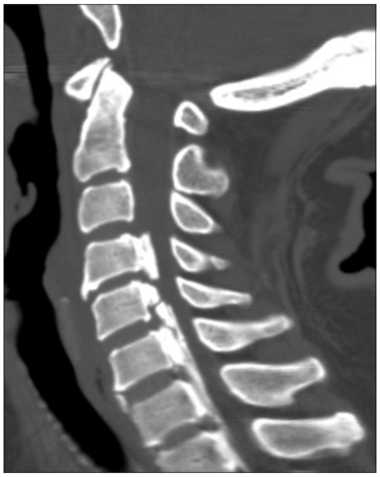

Figure 1: Segmental, Continuous, and Mixed OPLL Combined with Single and Double Layer Signs of Dural Penetrance. The sagittal 2D-CT study in one patient exhibited segmental, continuous, and mixed classic (mature) OPLL, along wit the single and double layer signs. The segmental OPLL is most clearly defined behind the C4 vertebral body, the continuous at C6, C7, and the mixed a combination of the two. Note the double layer sign opposite the C5-C6 disc space: the hypodense dura is between the hyperdense OPLL anteriorly and then intradural calcification posteriorly

This surgery also warrants the adoption of a strict anesthetic protocol (awake intubation/positioning) and "real time" intraoperative neural monitoring (IONM); somatosensory evoked potentials (SEP), motor evoked potential monitoring (MEP), and electromyography (EMG).

Pathology and genetics of OPLL

2011 Genetics of OPLL

In 2011, Stetler *et al*., evaluated the various genetic inheritance theories regarding OPLL's ectopic calcification in the cervical spine.[57] There are apparently multiple genes that contribute to the different inheritance patterns of OPLL [Table 1]. These genes are involved in the production of; collagen, nucleotide pyrophosphatase, transforming growth factors, vitamin D receptors, cytokines, growth factors (e.g. bone morphogenetic

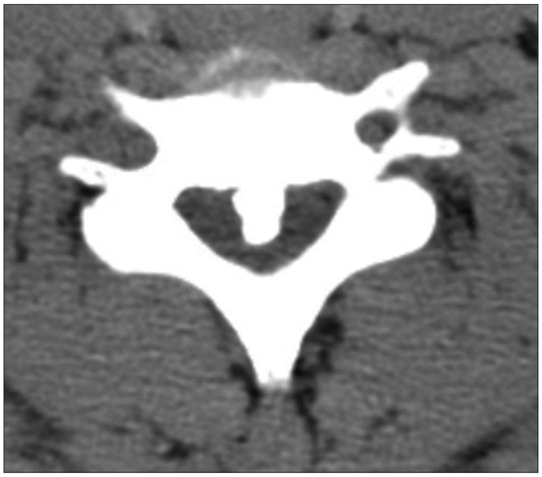

Figure 2: Massive "Single Layer Sign" Without "C" Sign in Same Patient as Fig. 1. The patient demonstrated multilevel massive continuous OPLL with the "single layer sign" noted at the mid C7 vertebral level (not at the disc space). Note here there is no lateral imbrication of the dura in the absence of the "C" sign

Table 1:Summary of Cervical OPLL Surgery

Section	Summary
Pathology and Genetics of OPLL	
2011 Genetics of OPLL	In 2011, Stetler *et al*., evaluated the various genetic inheritance theories regarding OPLL's ectopic calcification in the cervical spine.[57] Further mechanical and metabolic elements (diabetes, obesity) have been shown to predispose patients to OPLL.
2013 Genetics and Inheritance for Cervical spondylotic myelopathy and Ossification of the posterior longitudinal ligament	Previously, the assumption was that multiple combinations/permutations of environmental and genetic factors contributed to CSM and OPLL. First, there was an inherited predisposition to CSM and OPLL. Second, the collagen 6A1 gene (COL6A1/Intron 32(-29)) and the collagen 11A2 gene (COL11A2/Intron 6(-4)) were associated with OPLL.
Symptoms and Signs of OPLL: Myelopathy and Radiculopathy	However, much discussion has surrounded the pros and cons of cervical OPLL surgery particularly for patients who are asymptomatic/minimally symptomatic (not warranted).[62] At the other extreme, are those who have been hospitalized with OPLL and decline surgery, but are found to be at markedly increased risk of significant spinal cord injury.[60]
2012 Etiology and Natural History of OPLL	When Matsunaga and Sakoou reviewed the etiology and natural history of cervical OPLL, the prevalence of OPLL in Japan ranged from 1.9% to 4.3 for people over the age of 30, and included a significant Genetic component.[45]
2012 Is Surgery Indicated for Asymptomatic/Mild Myelopathy but Significant OPLL	Yonenobu looked at the indications/timing for surgery in patients with little to no myelopathy but with signification OPLL.[62] He concluded that there was no substantial evidence supporting the use of OPLL surgery in patients without mild cervical myelopathy, and that "prophylactic" OPLL surgery was not warranted.
2012 Conservative Management of Symptomatic OPLL Increases Spinal Cord Injury (SCI) Risk	Wu *et al*., evaluated the extent to which patients hospitalized with radiographically documented OPLL were at risk of Spinal cord Injury (SCI) if managed conservatively (no surgery).[60] They concluded that the incidence of cervical SCI in the OPLL group was 32.16-fold ($P<0.001$) higher for OPLL patients.
2012 Factors Contributing to the Risk of Spinal Cord Injury (SCI) in OPLL Patients	Based on CT findings, patients in the SCI (spinal cord injuury) and CM (cervical myelopathy) groups demonstrated significantly greater congenital stenosis, more acquired stenosis attributed to mixed/segmental OPLL, and the presence of OALL.
Diagnosis of Early OPLL or OPLL in Evolution	
1979 CT Documentation of Multiple Shapes of OPLL	OPLL typically involved more than two vertebral bodies, was not uniform, often obliterated the spinal canal, and appeared in different CT-documented shapes/configurations at different levels described as; polymorphic, mushroom, irregular, cubic and round.
1994 Description of Early OPLL or OPLL in Evolution	In 1994, Epstein described early OPLL, HPLL (hypertrophied posterior longitudinal ligament), or OPLL in evolution (OEV) in 12 of 43 (28%) patients undergoing OPLL surgery.[11] Although both MR and CT studies documented early OPLL, add MR findings were often being confused with multilevel disc disease, CT examinations better identified punctate or "pearls" of ossification within the hypertrophied ligament that was typically associated with retrovertebral extension.
1996 Value of CT in Diagnosing OPLL	CT studies provide direct visualization of HPLL with its early-ossified "pearls" and later-evolving frank ossification.[13] OPLL may be readily viewed demonstrating all four classical types.
1987 CT Documents Cervical Cord Compression of OPLL in Non-Oriental Patients	In 1987, MCAfee *et al*., reported 14 patients with symptomatic OPLL and incomplete spinal cord syndromes.[47] Enhanced CT best localized cord compression, while MR (4 recent cases) better revealed the extent of sagittal involvement.
1993 Optimal Surgical Management of OPLL Utilizing Both MR and CT	Optimal planning for OPLL surgery warrants full radiographic assessment utilizing both MR and CT-based studies (non-contrast CT, myelo-CT, three-dimensional CT) to document the full extent of disease.[9] Experience with 51 OPLL patients indicated superior results after anterior (41 patients) versus posterior (10 patients) surgery, utilizing continuous intraoperative somatosensory evoked potential (SSEP) monitoring.
1997 CT Documentation of OPLL in Asians and Europeans	In 1997, Seloprantos *et al*., Identified 6 Europeans with cervical OPLL.[54]
1997 CT Single and Double Layer Signs Increased Risk for CSF Fistulas with OPLL	Hida *et al*., observed that anterior cervical decompressions in patients with OPLL might result in CSF fistulas.[29] Nine patients had the" single-layer" sign, consisting of an irregular but continuous ventral OPLL mass.The double-layer sign was defined by a ventral hyperdense mass, hypodense intervening dura, and hyperdense intradural OPLL mass.
2001 Additional Signs of OPLL Extending To and Through the Dura on Preoperative CT	In addition to the "single layer" sign, Epstein added unilateral or bilateral "C signs" that consisted of ossified/OPLL presenting laterally in the spinal canal characterized by an angular C shaped configuration; the "C" signs indicated whether the lateral dura had become imbricated in the OPLL mass [Figure 3].[18]

Table 1: Continued

Section	Summary
2002 Role of CT and MR in Diagnosis/ Surgical Management of Cervical OPLL	Patients with early OPLL, often in their mid-forties, with radiculopathy or mild/moderate myelopathy, demonstrate HPLL with punctate ossification opposite multiple disc spaces on MR/CT.[13-15,21,24] Alternatively, those with classical OPLL, who become symptomatic in their mid-fifties and later, present with more severe spastic myeloradicular syndromes.
2005 Neuroimaging of Dural Ossification and Cervical OPLL: CT Better than MR	In a retrospective analysis of preoperative plain X-rays, polytomography, MR and CT studies for 111 OPLL patients undergoing anterior cervical surgery, Mizuno *et al*., documented a 15.3% (17 patients) frequency of dural ossification (DO).[48]
2009 Dural Ossification in Anterior Cervical OPLL Surgery	Direct anterior excision of OPLL and dural ossification (DO) risks cerebrospinal fluid (CSF) leakage at surgery, and increases the potential for neurological injury.[5]
2010 Cervical Disc Herniations Documented on MR and CT in Patients with OPLL	Utilizing plain X-rays, MR and CT studies, Yang *et al*., documented that 26 of 142 patients with cervical OPLL (15 segmental-type, 9 mixed-type, 2 continuous-type) also had herniated discs.[61]
2011 MR and CT Imaging in OPLL Impact Management Strategies	Smith *et al*., noted that up to 25% of patients with cervical myelopathy have OPLL.[56] While MR images document cord compression from hypointense (HPLL or OPLL) ventral masses, CT's directly imaged coalescence of ossification behind the cervical vertebrae/disc spaces resulting in cord compromise.
2011 Evaluation of OPLL with Three-dimensional (3D) CT and MR	Utilizing 3D-CT and MR studies, Kawaguchi *et al*., better defined the location and extent of cervical OPLL's contribution to spinal cord compression.[34]
2012 Using Modified K-Line, Sagittal CT Scans Determine Optimal OPLL Surgical Strategy	Tian *et al*., utilized sagittal CT scans to determine the optimal surgery strategy for dealing with cervical OPLL.[58] In a retrospective study of 161 patients undergoing OPLL surgery, averaging 54.5 years of age, operations included; 26 ACDF, and 14 ACF, 120 process-splitting laminoplasty, and one circumferential operation.
2013 Accuracy of Classifying OPLL Utilizing X-ray vs. CT Images	Kudo *et al*., (kudo) compared the interobserver and intraobserver reliability for 16 observers classifying OPLL images in 5 groups utilizing X-ray vs. CT studies.[38] The reliability of classifying and diagnosing cervical OPLL was substantially improved with CT.

OPLL: Ossification of the posterior longitudinal ligament, CSM: cervical spondylotic myelopath,SCI: Spinal cord injury,DO: Dural ossification

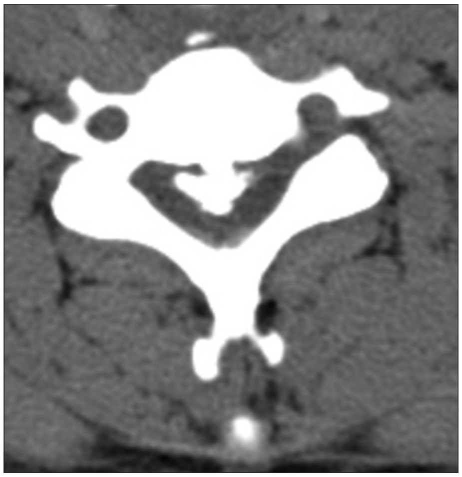

Figure 3: "C" Sign Combined with "Single Layer Sign" in Same Patient as Fig. 1. Caudal to the C7 Single Layer Sign the ventral OPLL branches out laterally into bilateral "c" signs indicating the imbrication of the dura. The risk of a CSF fistula if an anterior approach is adopted in this situation markedly increases the risk of an intraoperative CSF fistula

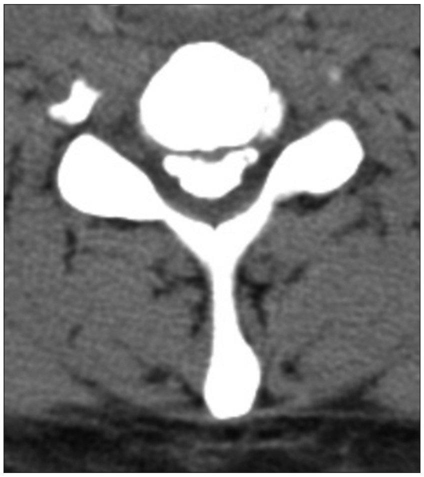

Figure 4: "Double Layer Sign" In the Same Patient as Fig. 1 At the C6/C7 Level. The patient also demonstrated at the C6/C7 level the "double layer sign". Note that there is a hypointense mass between the ossified posterior aspect of the vertebral body and the dorsal intradural OPLL mass. The hypointense tissue is typically dura that has become integrated into the OPLL mass, and attempted resection anteriorly has a much higher chance of resulting in a spinal fluid fistula

proteins), proteins, and interleukins. Further mechanical and metabolic elements (diabetes, obesity) have been shown to predispose patients to OPLL.

2013 Genetics and inheritance for cervical spondylotic myelopathy and ossification of the posterior longitudinal ligament

Wilson *et al*., systematically analyzed the English literature (1980-2012) to document the genetics and heritability of cervical spondylotic myelopathy (CSM) and OPLL.[59] Previously, the assumption was that multiple combinations/permutations of environmental and genetic factors contributed to CSM and OPLL. Two independent

Figure 5: The "Double Layer Sign" At the Superior C5-C6 Level in the Same Patient as Fig. 1. Note the different appearance of the double layer sign at the C5-C7 level. However, what remains consistent is the hypodense material that intervenes between the dorsal aspect of the vertebral body and the intradural OPLL ossification

Figure 6: On the Postoperative Enhanced MR Following a Cervical Laminectomy/Posterior Fusion the Cord Migrated Dorsally, Away From Ventral OPLL (Same Patient as Fig. 1)

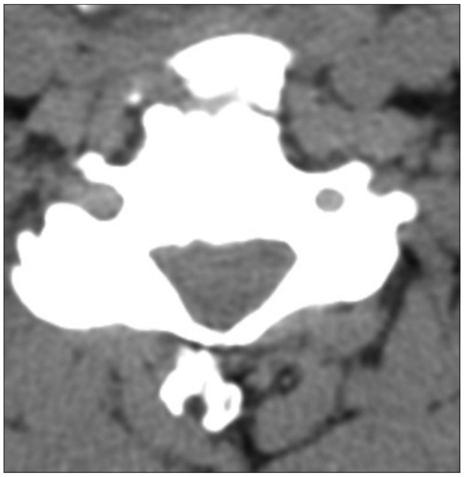

Figure 7: Ossification of the Anterior Longitudinal Ligament (OALL) on Axial CT OALL was present in this patient resulting in significant compression of the anterior cervical structures including particularly the esophagus

Figure 8: Ossification of the Anterior Longitudinal Ligament (OALL) on 2D-Sagittal CTOALL is more frequent that OPLL or OYL, and in this case, the sagittal CT scan demonstrated marked multilevel OALL particularly involving the anterior longitudinal ligament ventral to the C4, C5, and C6 vertebral bodies. Often this has to become extremely severe before patients developed dysphagia. However, it may intubation, even performed fiberoptically, more challenging

reviewers assigned GRADEs regarding the quality of evidence provided in various studies (e.g. heritability, and genetic inheritance using HuGENet Working Group in the Venice Interim Guidelines). Twenty-three of 118 studies that met the inclusion criteria led the authors to the following four conclusions; first, there was an inherited predisposition to CSM and OPLL, second, the collagen 6A1 gene (COL6A1/Intron 32(-29)) and the collagen 11A2 gene (COL11A2/Intron 6(-4)) were associated with OPLL, third, there appeared to be no specific haplotypes associated with CSM, fourth, there were no genetic predictors in the literature that could anticipate the surgical outcomes of CSM and OPLL surgery.

Symptoms and signs of OPLL: Myelopathy and radiculopathy

The symptoms and signs of progressive spastic cervical myelopathy/radiculopathy attributed to OPLL may lead to different treatment strategies based on the severity of neurological and radiographic findings [Table 1]. Some consider the natural history of OPLL with its significant underlying genetic predisposing factors, to include the progression of symptoms and signs (e.g. myelopathy/radiculopathy).[45] However, much discussion has surrounded the pros and cons of cervical OPLL surgery particularly for patients who are asymptomatic/

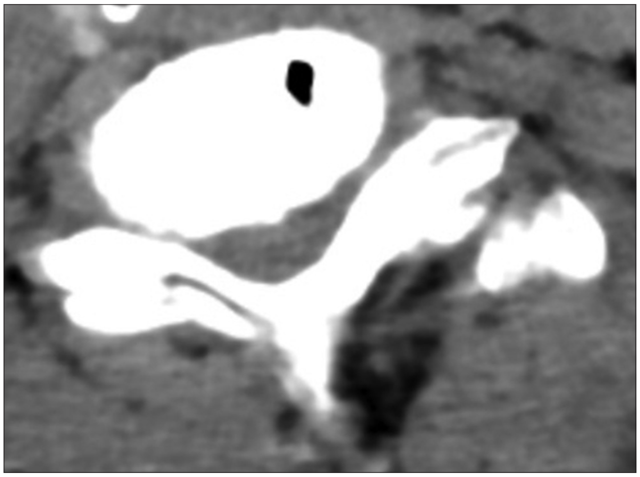

Figure 9: Shingled Laminae Indicate Hyperlordosis and The Potential for Posterior Cervical Decompression When evaluating a patient for posterior surgery with/without OPLL, the presence of an adequate lordotic curvature or hyperlordosis is critical. In this axial CT study, you can see, particularly on the right side, the double laminae that indicate shingling of one lamina under the other and the presence of hyperlordosis. Posterior decompression in these patients is often very effective

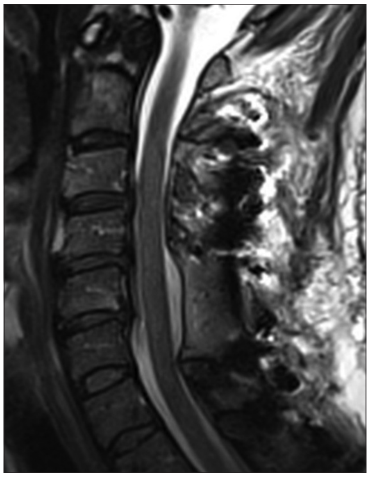

Figure 11: The Postoperative T2 Weighted Midline Sagittal MR (Patient from Fig. 10) Showed the Laminectomy C5, C6 Defect with Dorsal Migration of the Cord and Thecal Sac into the Decompression Site On the postoperative midline sagittal T2 weighted MR documented adequate decompression of the cord away from ventrally situated pathology at the C4-C5 and C5-C6 levels. Not the absence of an increased signal in the cord, and the presence of adequate decompression at all levels

Figure 10: Preoperative Midline Sagittal T2 Weighted Cervical MR Study Showing Multilevel Hypertrophied Posterior Longitudinal Ligament Extending From Mid C4-Mid C6 The midline sagittal T2 weighted MR study demonstrated multilevel cord compression from hypertrophied posterior longitudinal ligament (not disc herniations) from the Mid C4- Mid C6 vertebral levels (not HPLL changes at C34 were still very mild). Note the dorsal presence of an excellent cervical lordosis/hyperlordosis with inward shingling of the C5 and C6 laminae. The patient underwent a laminectomy of C5, C6 with posterior fusion

Figure 12: The midline sagittal T2 weighted MR Documented a Straightened Configuration (Lack of Lordosis) with Ventral OPLL Extending from Mid C3 Through the C5-C6 Level (Maximal at the C3-C4, C4-C5 Levels) The midline sagittal T2 weighted MR documented ventral OPLL/ HPLL extending from the Mid C3-C5/6 Levels, with maximal cord compression opposite C3-C4 and C4-C5. Note the inhomgeneity of the signal from the HPLL (hypertrophied rather than frankly ossified PLL) which typically contains punctate ossification centers ("pearls"). In this case, multilevel ACDF would not fully decompress the cord, and would subject the cord to be pulled over/tethered over residual compression HPLL

minimally symptomatic (e.g. not warranted).[62] At the other extreme, are those who have been hospitalized with OPLL and decline surgery, but are found to be at markedly increased risk of significant spinal cord injury (SCI).[60]

2012 Etiology and natural history of OPLL

When Matsunaga and Sakoou reviewed the etiology and natural history of cervical OPLL, the prevalence of OPLL in Japan ranged from 1.9% to 4.3 for people over the age of 30, and included a significant Genetic component.[45] Although diagnoses could occasionally be established with plain X-rays, MR and CT images better demonstrated OPLL-related cord compression.

Figure 13: Multilevel Hypertrophied PLL (HPLL) Rather than Disc Disease on MR On this parasagittal T2 weighted MR study, there is diffuse ventral compression opposite multiple disc spaces (C3-C4, C4-C5, C5-C6, C6-C7). Despite the presence of HPLL at this level, there was no significant cord compression and the patient did not warrant an operation

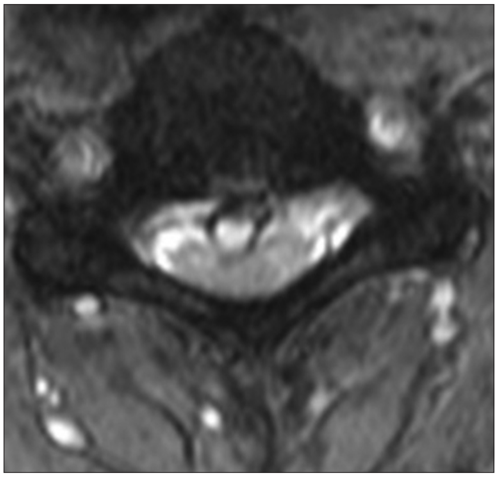

Figure 14: Hyperintense Signal (Reflecting Fat Signal) Within Ventral OPLL Mass on the Axial MR Indicative of Active Bone Marrow Production This axial MR, obtained at the mid vertebral body level, demonstrates a central, ventral OPLL mass containing a high signal indicative of active bone marrow production (fat) within the OPLL

Figure 15: Parasagittal 3D-CT Study Documenting Ventral OPLL and HPLL Extending from the C5-C7 Levels On this parasagittal 3D-CT Study, hypertrophied PLL containing punctate ossification centers and more frankly ossified areas are seen extending from the mid/lower C5-C7 vertebral body levels

Figure 16: Midline Sagittal T2 Weighted MR Documents Ventral OPLL C5-C7 Combined with Hyperlordosis/Dorsal Shingling of the C5, C6, C7 Laminae, Making a Posterior Approach Optimal On this midline sagittal T2 weighted study, there is significant OPLL or HPLL (cannot tell without a CT) compressing the ventral cord from C5-C7. Posteriorly, the laminae of C5, C6, C7 are shingled underneath each other. The hyperlordosis and dorsal shingling make a posterior approach (laminectomy/fusion) optimal for managing the cord compression in this patient

2012 Is Surgery indicated for asymptomatic/Mild myelopathy but significant OPLL

Yonenobu looked at the indications/timing for surgery in patients with little to no myelopathy but with signification OPLL.[62] He concluded that there was no substantial evidence supporting the use of "prophylactic" OPLL surgery in patients with/without mild cervical myelopathy.

2012 Conservative management of symptomatic OPLL increases spinal cord injury risk

Wu *et al*., evaluated the extent to which patients hospitalized with radiographically documented OPLL were at risk of Spinal cord Injury (SCI) if managed conservatively (no surgery).[60] From 1998 to 2005, 265 patients hospitalized for OPLL (symptomatic but not undergoing surgery) were compared with 5339 age- and sex-matched control patients. They concluded that the incidence of cervical SCI in the OPLL group was 32.16-fold ($P < 0.001$) higher for OPLL patients. They warned patients who chose conservative treatment of the increased risk the increased risk of SCI.

2012 Factors contributing to the risk of spinal cord injury (SCI) in OPLL patients

Onishi evaluated the risk factors contributing to SCI in OPLL patients.[49] Patients were divided into 3

Figure 17: Patient with Marked Dorsolateral Shingling/Hyperlordosis to C5, C6, C7 Combined with Ventral OPLL/HPLL C4-5, C5-C6, C6-7. Making Patient Optimal Candidate for Posterior Decompression As this patient has a hyperlordosis with dorsolateral shingling of the laminae of C5, C6, C7 and multilevel ventral compression C4-C7, a posterior decompression and fusion would be optimal.

Figure 18: Patient from Fig.17 Underwent CT in Conjunction with MR Documenting C5-C7 HPLL and Dorsolateral Shingling of the Laminae of C5, C6, C7 with Hyperlordosis. On the CT study, the ventral compression opposite the disc spaces of C4-5, C5-C6, and C6-7 was compatible with HPLL (non ossified but hypertrophied PLL). Note the direct visualization of the hyperlordosis and inward shingling of the lamina of C5, C6, C7

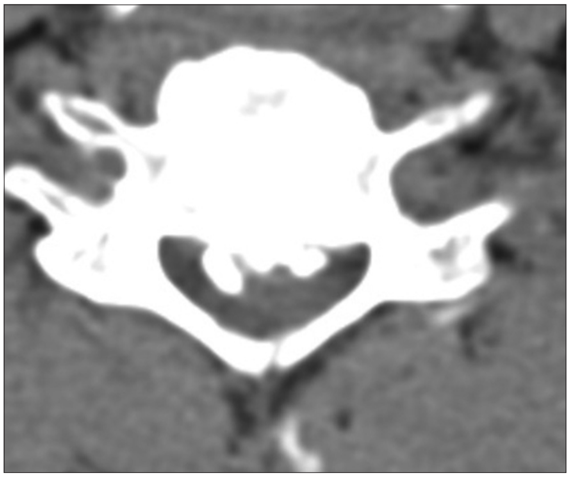

Figure 19: Another Version of the "Single Layer Sign" and Bilateral "C Signs" on Axial CT The axial CT image demonstrates a ventral "single layer sign" (not at all a smooth layer sign as it is very inhomogeneous in configuration) with accompanying mild but present bilateral "C" signs

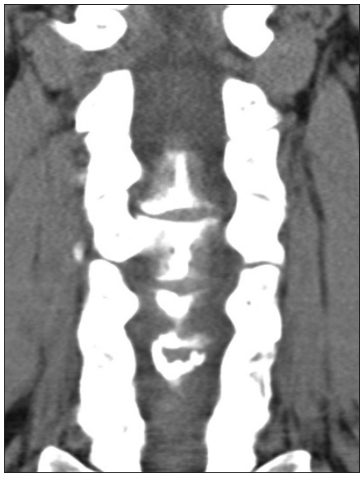

Figure 20: Coronal CT Showing OPLL In the Ventral Spinal Canal (Same Patient as Fig. 19). The coronal CT study demonstrates OPLL located ventrally in the spinal canal at multiple levels

groups based on CT findings; "34 with SCI associated with OPLL (average age 71.5), 32 with CM (cervical myelopathy) associated with OPLL (63.3 average age), and 32 normal controls". Based on CT findings, patients in the SCI and CM groups demonstrated significantly greater congenital stenosis, more acquired stenosis attributed to mixed/segmental OPLL and the presence of OALL.

Diagnosis of early OPLL or OPLL in evolution

1979 CT documentation of multiple shapes of OPLL

In 1979, Kadoya utilized CT-scans to identify OPLL in 15 patients exhibiting myelopathy (severe 30%), and concluded that CT's were essential for operative planning. [Table 1].[32] OPLL typically involved more than two vertebral bodies, was not uniform, often obliterated the spinal canal, and appeared in different CT-documented shapes/configurations at different levels. These findings were described as; polymorphic, mushroom, irregular, cubic and round. Accompanying spondylosis was also noted in 87% of patients. Unlike plain X-rays, CT could readily define OPLL at the most superior and inferior vertebral levels. Patients exhibiting severe myelopathy, characterized by quadriparesis or neurogenic bladders, typically presented with spinal canal stenosis of more than 30%.

1994 Description of early OPLL or OPLL in evolution

In 1994, Epstein described early OPLL, also called

Figure 21: Midline Sagittal 2D-CT Showing Marked Dorsolateral Shingling of the Laminae involving C4, C5, C6, C7. The patient's axial soft tissue window CT demonstrated marked cord compression from ventral multilevel HPLL and the patient underwent a posterior decompression/fusion

Figure 23: Midline Sagittal 2D-CT Documented Segmental OPLL/HPLL C4-C7 with Multiple Double Layer Signs. The midline sagittal 2D-CT study documented segmental OPLL behind the C4 vertebral body and a yet not fully ossified continuous OPLL/HPLL behind the C5-C7 vertebral bodies. Note the "double layer sign" behind the C4, C5, and C6 vertebral bodies

HPLL (hypertrophied posterior longitudinal ligament), or OPLL in evolution (OEV) in 12 of 43 (28%) patients undergoing OPLL surgery.[11] Utilizing MR and CT studies to establish the diagnosis, early OPLL patients were younger, in their mid-forties, and had less severe spastic myeloradicular syndromes. Although both MR and CT studies documented early OPLL, with MR findings often being confused with multilevel disc disease, CT examinations better identified punctate or "pearls" of ossification within the hypertrophied ligament that was typically associated with retrovertebral extension.

Since early OPLL was often accompanied by retrovertebral extension, surgery critically required removal of the full extent of hypertrophied PLL utilizing anterior cervical corpectomies rather than multilevel diskectomies with fusions. Subsequently in 1996, in a follow-up study of 50 OPLL patients, the full spectrum of early and mature OPLL was further demonstrated.[9-13]

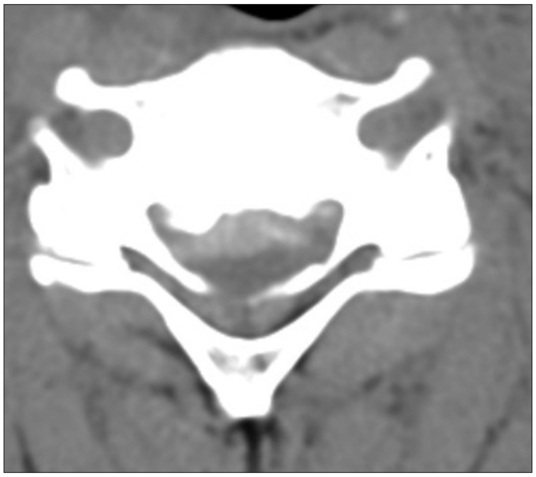

Figure 22: Axial Soft-Tissue 3D-CT Demonstrating HPLL Producing Ventral Compression and Dorsolateral Compression From Shingled Laminae and Hyperlordosis. This soft tissue 3D-CT axial image documents ventral OPLL with greater compression from additional HPLL. Note dorsolaterally the double laminae which appear on this image secondary to hyperlordosis and dorsolateral shingling of the laminae

Figure 24: Midline Sagittal T2 Weighted MR of Multilevel C3-T1 HPLL Opposite Disc Spaces In Addition to Stenosis. The midline sagittal T2 weighted MR study documented HPLL vs. OPLL opposite the C3-C4, C4-C5, C5-C6, C6-C7, and C7-T1 levels. Additional CT here demonstrated punctate ossification within the HPLL (not consistent with disc diseases)

1996 Value of CT in diagnosing OPLL

CT studies provide direct visualization of HPLL with its early-ossified "pearls", as well as the later-evolving frank ossification of OPLL.[13] Utilizing axial, sagittal, and 3 dimensional imaging, the four classical type of OPLL may be readily viewed demonstrating all four

Figure 25: Midline T2 Sagittal MR Documenting Ventral Cord Decompression Following. C5, C6 Corpectomy with C4-C7 Fusion This midline sagittal MR study demonstrated anterior cord decompression following a C5, C6 corpectomy and C4-C7 fusion. Note the billowing in of the ventral dura opposite these levels and that the lordosis was straightened, precluding a posterior approach.

classical types. The segmental variant arises solely behind the vertebral bodies, stopping at the interspaces. The continuous variant includes OPLL behind the vertebral bodies, but extends behind the disc spaces as well. Mixed OPLL includes both the segmental and continuous OPLL components, while the other form of OPLL is localized behind the vertebral disc spaces themselves.

1987 CT documents cervical cord compression of OPLL in Non-oriental patients

In 1987, MCAfee *et al.*, reported 14 patients with symptomatic OPLL and incomplete spinal cord syndromes.[47] Twelve had severely myelopathy, 7 were confined to wheelchairs before the diagnosis of OPLL was established, and 6 had previously undergone operations at outside institutions. Enhanced CT best localized cord compression, while MR (4 recent cases) better revealed the extent of sagittal involvement.

1993 optimal surgical management of OPLL utilizing both MR and CT

Optimal planning for OPLL surgery warrants full radiographic assessment utilizing both MR and CT-based studies (non-contrast CT, myelo-CT, three-dimensional CT) to document the full extent of disease.[9] Experience with 51 OPLL patients indicated superior results after anterior (41 patients) versus posterior (10 patients) surgery, utilizing continuous intraoperative somatosensory evoked potential (SSEP) monitoring.

1997 CT Documentation of OPLL in asians and europeans

In 1997, Seloprantos *et al.*, identified 6 Europeans with cervical OPLL.[54] CT scans were "invaluable in demonstrating the full extent of the disease in all 5 symptomatic patients", while MR helped exclude myelomalacia in 2 patients being considered for surgery. Notably, 3 of 4 patients with severe myelopathy significantly recovered following operative decompressions.

1997 CT Single and double layer signs increased risk for csf fistulas with OPLL

Hida *et al.*, observed that anterior cervical decompressions in patients with OPLL might result in CSF fistulas.[29] In order to better anticipate when these fistulas would occur, the authors reviewed the bone window CT studies of 21 OPLL patients. They identified two signs of potential dural penetrance attributed to cervical OPLL. Nine patients had the" single-layer" sign, consisting of an irregular but continuous ventral OPLL mass; only one patient with this defect developed a CSF fistula [Figures 2, 3 and 19]. Alternatively, 10 of 12 patients with the double-layer signs (e.g. ventral hyperdense mass, hypodense intervening dura, and hyperdense intradural OPLL mass), developed CSF fistulas [Figures 4, 5 and 23]. They concluded that preoperative CT studies were of great value in documenting whether and where dural defects were likely to occur with anterior cervical OPLL surgery.

2001 Additional signs of OPLL extending to and through the dura on preoperative CT

Epstein further expanded on the value of preoperative CT scans in documenting whether OPLL penetrated the dura increasing the risk of an intraoperative CSF fistula.[18] In addition to the "single layer" sign, Epstein added unilateral or bilateral "C signs" that consisted of ossified OPLL presenting laterally in the spinal canal characterized by an angular C shaped configuration; the "C" signs indicated whether the lateral dura had become imbricated in the OPLL mass [Figure 3].[18] Several additional configurations of the "double layer sign" were also presented characterized by the hyperdense ventral ossification continuous with the posterior aspect of the vertebral body, interrupted by a hypodense line (the remnant of the dura), and succeeded by another hyperdense mass which was now intradural.

In Epstein's series, only 2 of 54 patients undergoing multilevel cervical circumferential OPLL procedures had absent dura at surgery.[18] Dura was absent in 1 of 12 patients with the "single-layer " and "C" signs on CT. One of 4 patients with the "double-layer sign" developed intraoperative CSF fistulas. The remaining 38 patients had the "smooth-layer sign", characterized by smoother, more rounded and regular appearance indicative of classic mature OPLL (22 patients) or early OPLL/HPLL (16 patients). The author concluded that the "double-layer" CT sign was most pathognomonic for dural penetration, followed by the "single-layer" and "C" signs. Alternatively, the "smooth layer" sign usually signaled a clean dural plane (e.g. more typical in North American patients), and was not likely to be associated with dural penetration and CSF fistulas.

2002 Role of CT and MR in diagnosis/surgical management of cervical OPLL

Epstein emphasized in 2002 that as the treatment of multilevel OPLL evolves, the extent of OPLL involvement must be better recognized and more clearly defined.[21] Patients with early OPLL, often in their mid-forties, with radiculopathy or mild/moderate myelopathy, demonstrate HPLL with punctate ossification opposite multiple disc spaces on MR/CT.[13-15,21,24] Alternatively, those with classical OPLL, who become symptomatic in their mid-fifties and later, present with more severe spastic myeloradicular syndromes. Their MR scans show greater cord compression often attended by high T2 weighted intrinsic cord signals indicating edema or myelomalacia, while CT studies show OPLL extending across disc spaces, and behind multiple vertebral bodies.

2005 Neuroimaging of dural ossification and cervical OPLL: CT Better than MR

In a retrospective analysis of preoperative plain X-rays, polytomography, MR and CT studies for 111 OPLL patients undergoing anterior cervical surgery, Mizuno *et al*., documented a 15.3% (17 patients) frequency of dural ossification (DO).[48] DO was observed in 10 of 94 patients with segmental OPLL, and in 7 of 17 patients with nonsegmental OPLL (seven continuous, 10 mixed). DO was classified into isolated (3 patients), double-layer (10 patient: most common shape), and en bloc (4 patients) shapes. The 17 cases of DO and all OPLL cases were best diagnosed on bone-window CT studies. Although MR identified no DO cases, MR did document OPLL for 12 of the 17 patients (e.g. hyperintense signals within foci of active bone marrow production within the ventral OPLL masses).

2009 Dural ossification in anterior cervical OPLL surgery

Direct anterior excision of OPLL and dural ossification (DO) risks cerebrospinal fluid (CSF) leakage at surgery, and increases the potential for neurological injury.[5] In Chen *et al*., study of 138 patients undergoing anterior cervical corpectomy and fusion (ACF) for OPLL, 40 patients with more severe OPLL (higher occupying rate and larger extent) had DO encountered during anterior procedures. For patients with the "double-layer" sign, " a thin layer consisting of non-ossified degenerated PLL could be defined between the OPLL and DO to avoid a CSF leak. In other instances, the OPLL/DO masses were completely removed, but care was taken to preserve the arachnoid membrane (using the microscope) to avoid a large dural defect, and massive CSF leak. Although this description sounds fine in theory, in practice preserving the arachnoid, which is often densely adherent to the OPLL mass in these cases, is often not feasible.

2010 cervical disc herniations documented on MR and CT in Patients with OPLL

Utilizing plain X-rays, MR and CT studies, Yang *et al*., documented that 26 of 142 patients with cervical OPLL (15 segmental-type, 9 mixed-type, 2 continuous-type) also had herniated discs.[61] Utilizing MR studies, most discs occurred at the C5/6 level, followed by C3/4, C4/5, and C6/7; maximal cord compression occurred at the levels where discs and OPLL were combined. Surgical approaches included ACDF (8 patients), anterior corpectomy/fusion (ACF: 13 patients), and circumferential procedures (ACDF or ACF with laminectomy and fusion: 5 patients); outcomes were all noted to be favorable.

2011 MR and CT Imaging in OPLL Impact Management Strategies

Smith *et al*., noted that up to 25% of patients with cervical myelopathy have OPLL.[56] While MR images document cord compression from hypointense (HPLL or OPLL) ventral masses, CT's directly image coalescence of ossification behind the cervical vertebrae/disc spaces resulting in cord compromise. This can also provide the clinician with evidence of possible dural ossification. Together these studies document whether anterior, posterior, or circumferential decompressions/fusions are appropriate for dealing with the full extent of OPLL.

2011 Evaluation of OPLL with three-dimensional (3D) CT and MR

Utilizing 3D-CT and MR studies, Kawaguchi *et al*., better defined the location and extent of cervical OPLL's contribution to spinal cord compression.[34] Utilizing 3D-CT, OPLL was divided into the flat, irregular, or localized types. They compared 3D-CT studies with the lateral X-rays to define OPLL, while MR scans assessed the magnitude of cord compression. Of the 55 OPLL patients (35 men and 20 women; average 66 years of age) in the series, 39 (71%) of the ossified lesions on 3D CT were similar to those seen on lateral X-rays; in the remaining 16 patients, they were too small/unclear to be seen on X-rays alone. Of interest, MR added significant information about cord compression for OPLL patients; in 13 of 14 patients, MR confirmed spinal cord compression at the superior/inferior edges of the OPLL defined by 3D CT studies.

2012 Using Modified K-Line, Sagittal CT Scans Determine Optimal OPLL Surgical Strategy

Tian *et al*., utilized sagittal CT scans to determine the optimal surgery strategy for dealing with cervical OPLL.[58] In a retrospective study of 161 patients undergoing OPLL surgery, averaging 54.5 years of age, operations included; 26 ACDF, and 14 ACF, 120 spinous process-splitting laminoplasty, and one circumferential operation. Utilizing sagittal reconstructed CT images, the documentation of a cervical disc with OPLL (1-2 levels) led to anterior surgery, while OPLL of 1-5 levels led to more posterior surgery.

The modified K-line also facilitated choosing whether to perform anterior vs. posterior cervical procedures for OPLL. For those undergoing posterior surgery, the modified K-line, the line that connects the midpoints of the spinal canal at C (2) and C (7) on sagittal CT myelography, helped define the extent of cord compression. Cord compression that does not exceed the K-line was the (+) group vs. those that exceeded the K line who constituted the (-) group. Patients undergoing anterior surgery exhibited better recovery rates on the JOA scale vs. posterior surgery when they were in the K(-) vs. K(+) group. Alternatively, patients who were part of the posterior surgery K-line (+) group had better recovery rates than those in the K-line (-) groups. In short, those with extensive anterior disease exceeding the K line (K(-)) were better approached anteriorly, while those who did not exceed the K line (K (+)) did well with posterior surgery.

2013 Accuracy of Classifying OPLL Utilizing X-ray vs. CT Images
Kudo *et al*., compared the interobserver and intraobserver reliability for 16 observers classifying OPLL images in 5 groups utilizing X-ray vs. CT studies.[38] The reliability of classifying and diagnosing cervical OPLL was substantially improved with CT.

Anesthetic considerations: awake intubation protocols utilizing nasotracheal fiberoptic intubatation vs. Other new techniques (glidoscope techniques)

For patients undergoing anterior, posterior or circumferential cervical surgery for OPLL typically with marked cord compression, protocols involve awake nasotracheal fiberoptic (NT) intubation or less often awake endotracheal intubation (ET)) to avoid cervical manipulation [Tablel 2]. The NT route is typically chosen for anterior procedures, to avoid extending the jaw inferiorly obscuring the operative field particularly in more rostral (e.g. C3-C4) cases, while also facilitating the maintenance of postoperative intubation. For posterior procedures, awake NT intubation may still be utilized for ease of postoperative continued intubation, but awake endotracheal intubation ET is another option. What follows is the historical evolution of this technique, and the accompanying pros and cons. Notably, the attendant presence of ossification of the anterior longitudinal ligament may further complicate the intubation process [Figures 7 and 8].

1976 Awake intubation with double hangman's fracture
In a single case study, Patibandla *et al*., reported how awake intubation was required prior to perform circumferential surgery on a neurologically intact patient with a bipedicular fracture of C2/C3, and traumatic spondylolisthesis involving the C2/C3 over the vertebrae C4 vertebrae.[50] Gradual cervical traction for reduction of the spondylolisthesis with awake intubation were performed.; a The 360° fusion that followed included anterior C2/C3 and C3/C4 ACDF/plating, and subseuqent posterior lateral mass screws fixation C1-C5.

Table 2: Anesthetic Considerations: Awake Intubation Protocols Utilizing Nasotracheal Fiberoptic Intubatation vs. Other New Techniques (Glidoscope Techniques)

Section	Summary
1976 Awake Intubation with Double Hangman's Fracture	In a single case study, Patibandla *et al*., reported how awake intubation was required prior to performing circumferential surgery on a neurologically intact patient with a bipedicular fracture of C2/C3 and traumatic spondylolisthesis involving the C2/C3 vertebral bodies over the C4 vertebra.[50]
2002 Keeping Patients Intubated After Multilevel OPLL Surgery	In patients under 65 years of age, multilevel OPLL is often treated with circumferential procedures.[22] Epstein designed a specific anesthetic protocol that included awake, nasotracheal intubation/positioning, and maintained prophylactic intubation at least overnight. The study also identified 6 major risk factors increasing the risk of r prolonged intubation; repeated anterior surgery, operations lasting more than 10 hours, operations involving four or more levels (including C-2), obesity, asthma, and blood transfusions of more than 4 U (1000-1200 ml).
2012 Awake Fiberoptic Intubation and Self-positioning to Avoid Secondary Cervical Injury	Malcharek *et al*., documented the utility of awake fiberoptic intubation and awake, self-prone positioning utilizing topical tracheal anesthesia vs. sedation in 11 of 14 patients with cervical spine pathology.[44]
2012 Awake Intubation Devices and Techniques	Shirgoska *et al*., compared conventional vs. newer techniques for dealing with difficult airways (e.g. difficult intubation/ventilation.[55] They noted that awake fiberoptic intubation is a procedure of choice for managing difficult airways in the operating room (World Health Organization).
2013 Videolaryngoscopy with Glidescope Minimize Motion For Patients with Spine Injuries	In Kill *et al*., compared the value of the Glidescope vs. conventional intubation techniques in patients with "unsecured cervical spines".[37]
2013 Guided Video Intubation (Airtaq Laryngoscope) vs. Direct Laryngoscopy in Adults with Immobilized Cervical Spine	Utilizing the Manual in-line stabilization (MILS) maneuver, Amor *et al*., compared Airtaq's Guided Video Intubation vs. the utilization of the Macintosh laryngoscope for difficult intubations (decreased mobility).[1]

2002 Keeping patients intubated after multilevel OPLL Surgery
In patients under 65 years of age, multilevel OPLL is often treated with circumferential procedures including multilevel anterior corpectomy/fusion, with immediate posterior fusion, often accompanied by halo immobilization.[22] Epstein designed a specific

anesthetic protocol that included awake, nasotracheal intubation/positioning, that required maintaining prophylactic intubation at least overnight. The study identified 6 major risk factors that potentially contributed to continued intubation beyond the first postoperative night. These factors included; repeated anterior surgery, operations lasting more than 10 hours, operations involving four or more levels (including C-2), obesity, asthma, and blood transfusions of more than 4 U (1000-1200 ml). For patients exhibiting three or more major risk factors, extubation was typically delayed; instances, if delayed for up to one week, it occasionally led to tracheostomy.

Whether on the first or subsequent postoperative days, anesthesiologists would test whether extubation was feasible. First, they would let air out of the NT/ET balloon; if the patient could phonate, tracheal swelling around the NT/ET tube was estimated to be minimal and the patient would likely tolerate extubation. Second, on the postoperative CT scan (obtained the night following surgery), if air could be seen around the NT/ET tube, swelling was also likely to be minimal. Third, at the bedside, anesthesiologists would fiberoptically asses whether there was tracheal swelling both inside/outside the NT/ET tube prior to extubation. Furthermore, if extubation was considered, it was performed by an experienced anesthesiologist at the bedside who stood ready to reintubate fiberoptically if necessary. Notably, prior to extubation, drips utilized for sedation (e.g. typically Propofol (Diprivan- Fresenius Kabi USA, Lake Zurich, Illinois, USA; Remifentanil Abbott Laboratoties, Abbott Park, Illinois, USA) were halted to maximize adequate post-extubtaion spontaneous ventilation.

2012 Awake fiberoptic intubation and self-positioning to avoid secondary cervical injury

Malcharek *et al*., documented the utility of awake fiberoptic intubation and awake, self-prone positioning utilizing topical tracheal anesthesia vs. sedation in 11 of 14 patients with cervical spine pathology.[44] Topical anesthesia utilized oropharyngeal lidocaine spray with/without transtracheal lidocaine. Anxiolysis with Midazolam (2 to 4 mg, i.v.) was titrated to effect adequate sedation, tolerance for intubation, comfort, coughing/gagging, and changes in heart rate, blood pressure, and oxygen saturation.

2012 Awake intubation devices and techniques

Shirgoska *et al*., compared conventional vs. newer techniques for dealing with difficult airways (e.g. difficult intubation/ventilation.[55] They noted that awake fiberoptic intubation is the procedure of choice for managing difficult airways in the operating room (World Health Organization). Although conventional techniques rely on direct visualization, newer devices (e.g. video laryngoscopes include; V-Mac and C-Mac, Glide scope, McGrath, Airway Scope, Airtraq, Bonfils and Bullard devices) utilize indirect laryngoscopy (including lighted stylets and endotracheal tube guides) to visualize the glottis/vocal cords.

2013 Videolaryngoscopy with glidescope minimize motion for patients with spine injuries

Kill *et al*., compared the value of the Glidescope vs. conventional intubation techniques in patients with "unsecured cervical spines".[37] Of 60 patients, maximal lateral motions (extension angle alpha) were recorded for intubation utilizing videolaryngoscopy (GlideScope(®), Verathon Inc., Bothell, WA) vs. the conventional laryngoscope (MacIntosh). Deviation was 11.8 (maximal 19.2) degrees in the video group (less for those with experience) vs. 14.3% (29.3) in the routinely intubated patients. Of interest, 3 who could not be intubated in the conventional group were successfully intubated with the Glidescope. In summary, the GlideScope successfully reduced motion during intubation, and would likely limit secondary damage that might occur during emergency intubation for patients with traumatic spinal injuries.

2013 Guided video intubation (airtaq laryngoscope) vs. Direct laryngoscopy in adults with immobilized cervical spine

Utilizing the Manual in-line stabilization (MILS) maneuver, Amor *et al*., compared Airtaq's Guided Video Intubation vs. the utilization of the Macintosh laryngoscope for difficult intubations (decreased mobility).[1] In this prospective single blind randomized study, 120 patients had general ET anesthesia; they were randomly assigned to each of the two groups. They tracked the time necessary for intubation, and monitored patients' hemodynamic responses. All patients were successfully intubated utilizing the Airtaq device on the first attempt, while only half of the Macintosh patients were successfully intubated after athird attempt. Furthermore, the Airtaq intubations could be accomplished faster, and with fewer changes in vital signs.

Intraoperative neural monitoring in cervical OPLL Surgery and the role of TIVA (Total intravenous anesthesia)

1993 Evaluation of Intraoperative SEP Monitoring in 100 Cervical Operations

In 1993, Epstein *et al*., prospectively evaluated the efficacy of real time intraoperative SEP monitoring for cervical spine surgery in 100 patients (1989-91) and contrasted the results with those obtained in 218 previously unmonitored cervical surgical patients (1985-9) [Table 3].[8] At that time, SEP monitoring had previously been documented to reduce the incidence of neurologic injury for scoliosis surgery from 4-6.9% to 0-0.7%. The cervical operations performed addressed disc disease, stenosis, spondylosis, and OPLL. Eight of 218 previously unmonitored cervical surgical patients had become quadriplegic (3.7%), and one had died (0.5%). Alternatively, of the 100 SSEP

Table 3: Intraoperative Neural Monitoring (IONM) in Cervical OPLL Surgery and the Role Of TIVA (Total Intravenous Anesthesia)

Section	Summary
1993 Evaluation of Intraoperative SEP Monitoring in 100 Cervical Operations	In a 1993 publication in Spine, Epstein *et al*., prospectively evaluated the efficacy of real time intraoperative SEP monitoring for cervical spine surgery in 100 patients (1989-91) and contrasted the results with those obtained in 218 previously unmonitored patients (1985-9).[8] At that time, SEP monitoring had already reduced the incidence of neurologic injury for scoliosis surgery from 4-6.9% to 0-0.7%. Eight of 218 previously unmonitored patients became quadriplegic (3.7%) and one died (0.5%). Alternatively, of the 100 SSEP monitored patients, neither morbidity nor mortality occurred.
2006 Neurophysiological Alerts During Anterior Cervical Surgery	Lee *et al*., retrospectively evaluated 1445 patients undergoing anterior cervical diskectomy/corpectomy with fusion utilizing SEP, MEP and EMG monitoring.[40] In 267 (18.4%) cases, minor (spontaneous, sustained EMG) or major (MEP/SSEP amplitude reduction) alerts were more frequent for those having corpectomies (28% increased risk) vs. diskectomies, CSM (30%), and trauma (76%).
2006 IONM During 508 Cervical Corpectomies	Khan *et al*., retrospectively analyzed the utility of intraoperative SEP monitoring during 508 cervical single/multilevel corpectomies (average age 55.7).[36] SEPs detected impending or permanent neurological deficits with a 77.1% sensitivity and 100% specificity; if root deficits were excluded, both values were 100%. The authors concluded that the majority of SEP changes can be reversed and result in no permanent deficit.
2007 Value of IONM in 246 Cervical Spine Operations	In a prospective study of 246 patients undergoing cervical surgery (most with spinal stenosis), the sensitivity and specificity of multimodal intraoperative monitoring (MIOM) (SEP, MEP, EMG) was assessed.[7] The sensitivity of MIOM was 83.3% and specificity was 99.2%.
2008 Predictive Value of IONM in 1055 Cervical Spinal Operations	In Kelleher *et al*., prospective series of 1055 (average age 55) cervical operations, they documented the frequency of significant IONM (sensitivity, specificity, positive predictive values (PPVs), negative predictive values (NPVs)) changes and correlated these with the incidence of new postoperative neurological deficits.[35] SEP sensitivity was 52%, and specificity was 100% (PPV 100%/NPV 97%), MEP sensitivity was 100%, and specificity 96% (PPV 96%NPV 100%), while EMG sensitivity was 46%, and specificity 73% (PPV 3%NPV of 97%). They concluded that IONM helped prevent permanent/irreversible neurological damage from occurring during cervical spine surgery.
2009 Combined 100% Sensitivity of SEP/MEP in Adult Spinal Deformity Cases	Quraishi *et al*., retrospectively assessed IONM (SEP, EMG, MEP) in 102 spinal deformity/extensive thoracolumbar fusion cases.[51] No SEPs resulted in false positives, but there were 4 false negatives (sensitivity to 33%), while with MEPs there there were no false negatives.
2010 Interaction of Total Intravenous Anesthetic Techniques with Intraoperative Monitoring and Patient Variables (Hypertension, Diabetes, Age, Weight)	Anesthetic considerations are typically dictated by the necessity for real time SEP and MEP monitoring. Typically this requires utilizing the "balance technique" or TIVA (total intravenous anesthesia), consisting of propofol and alfentanil, without inhalation anesthetics to avoid interfering with intraoperative monitoring parameters.
2011 Value of SEP and MEP In Avoiding Brachial Plexus Attributed to Positioning Before Anterior Cervical Spine Surgery	Jahangiri *et al*., documented that the use of intraoperative SEP and MEP monitoring during anterior cervical surgery helped avoid brachial plexus injury.[30] In this case, IONM, consisting of both SEP/MEP, allowed for the immediate identification of significant changes, and the avoidance of a potential position-related neurological deficit (brachial plexus).
2012 Value of Somatosensory Evoked Potentials (SEP) and Transcranial Motor Evoked Potentials (MEPs) Combined: 100% in Cervical Surgery	Li *et al*., discussed the value of intraoperative SEP and transcranial electrical motor-evoked potentials (TcMEPs) in 200 spinal operations where TIVA (total intravenous anesthesia) was employed in all cases.[43] Alert criteria for SEP included; a 50% decrease in amplitude, a 10% increase in latency, a unilateral change, or increase in stimulation threshold (>100 V for TcMEP). Interestingly, the relative sensitivities of SEP and TcMEP alerts in detecting impending neurological damage were respectively 37.5% and 62.5%. However, together, they were 100%, and there were no false-positive or false-negative alerts.
2012 MEP Warning Thresholds (Amplitude) for Cervical Cord Compression	Sakaki *et al*., evaluated MEP loss of (differentiating tracts, segments) obtained form patients undergoing cervical spine surgery, and correlated these with clinical outcomes in 350 cases.[53] Potentials lost in 11 cases were directly attributed to the level of spinal surgery; 2 developed deficits. However for 43 cases in which MEP changes occurred below the level of surgery, there were no postoperative deficits.
2012 Compartment Syndrome Avoided by Loss of SEP and MEP During Cervical Surgery	Bronson *et al*., described a case in which SEP and MEP were lost indicating a compartment syndrome evolving during a 2 level ACDF.[2] These early changes led to the discovery of an infiltrated intravenous line that, once removed, allowed the swelling to resolve.

Contd...

Table 3: Contd...

Section	Summary
2013 Significant Change/Loss of IONM Over 25 Years In 12,375 Patients	Raynor *et al*., evaluated the efficacy of IONM (SEP, MEP, EMG) in 12, 375 patients involving the cervical (29.7% (3671 patients)), thoracic/ thoracolumbar (45.4% (5624 patients)), and lumbosacral (24.9% (3080 patients)) spine.[52] The authors concluded that IONM effectively limited permanent postoperative neurological deficits, as the overall frequency of permanent neurological sequelae was just 0.12%.
2013 Value of MEP Monitoring in Cervical Diskectomy	Fotakopoulos *et al*., assessed the prospective value and efficacy of "free running" EMG and MEP during cervical microdiskectomy/fusion for 38 patients with cervical radiculopathy attributed to disc herniations.[28] Those demonstrating a 41% increase in TcMEP amplitude exhibited excellent postoperative results, while those with<=11% improvement had only fair results.
2013 MEP Role in Surgery for Cervical Spondylotic Myelopathy	As MEPs monitor the corticospinal tracts for patients with CSM, Capone *et al*., correlated the preoperative and postoperative MEPs with the clinical results of 38 cervical spine operations.[4] The authors concluded that early surgery for CSM patients with lesser preoperative deficits correlated with better outcomes defined by improvement in MEPs.
Intraoperative Neural Monitoring Signals Hypotension and Impending Neurological Injury During Cervical Spine Surgery2006 Value of Intraoperative SEP Monitoring During 508 Cervical Corpectomies	In 2006, Kahn *et al*., reviewed 508 consecutive patients undergoing cervical corpectomies utilizing intraoperative SEP monitoring.[36] Significant SEP changes occurred in 5.3% or 27 patients, and were most commonly attributed to hypotension. New postoperative neurological deficits occurred in 2.4% of patients; 11 consisted of nerve root injuries, while one patient was irreversibly quadriplegic. SEP monitoring detected impending intraoperative iatrogenic neurologic deficits with a sensitivity of 77.1% and specificity of 100.
2009 Acute Hypotension Detected Utilizing SEP, MEP under TIVA Anesthesia During Post Traumatic Cervical Spine Fusion	Cann noted that hypotension should be avoided during cervical spine fusions for patients with acute traumatic injuries, as it may exacerbate the neurological deficit.[3] This article highlighted how intraoperative hypotension may precipitate sufficient ischemia in a traumatically injured spinal cord, to result in potential permanent neurological injury.
2012 Cervical Cord Infarct Following Cervical Spine Surgery	In 2012, Kalb *et al*., reported on five patients who, following cervical decompressions, developed permanent neurological deficits attributed to spinal cord infarction.[33]

TIVA: Interaction of total intravenous anesthetic techniques,CSM: Cervical spondylotic myelopathy, IONM: Intraoperative neural monitoring

monitored patients, neither morbidity nor mortality occurred. The reduction in neurologic deficits associated with SSEP monitoring of cervical surgery was attributed to: SEP detection of significant changes attributed to hypotension/vascular compromise, SEP detection of "mini-true" positives (signaling impending neurological deterioration) that could be addressed before they became true (significant) positives, over-manipulation, or mechanical compression. These changes were immediately addressed with a variety of successful resuscitative maneuvers; reversal of hypotension, reversal of "relative hypotension" (e.g. artificially elevating the blood pressure usually by 20%), irrigating the wound with Peroxide (hyper oxygenation), administering high dose steroids (in addition to the preoperative 1 gm of Methylprednisolone adding another 1 gm (Pfizer Inc, NY, NY, USA) administered on induction), adjustment of operative positioning, release of distraction, cessation of manipulation, and/or removal of grafts (resulting in over distraction).

2006 Neurophysiological alerts during anterior cervical surgery

Lee *et al*., retrospectively evaluated 1445 patients undergoing anterior cervical diskectomy/corpectomy with fusion utilizing SEP, MEP and EMG monitoring.[40] In 267 (18.4%) cases, minor (spontaneous, sustained EMG) or major (MEP/SSEP amplitude/latency reductions) alerts were more frequent for those having corpectomies (28% increased risk) vs. diskectomies, for CSM (30%), and trauma (76%). Eight cases were aborted due to sustained SEP/MEP amplitude loss, but resulted in no permanent deficits. When such losses occur, the following interventions/maneuvers should be considered; delaying or terminating surgery, infusion of Methylprednisolone, and/or the Stagnara wake up test.

2006 IONM during 508 cervical corpectomies

Khan *et al*., retrospectively analyzed the utility of intraoperative SEP monitoring during 508 cervical single/ multilevel corpectomies (average age 55.7).[36] Significant SSEP changes were observed in 5.3% (27 of 508 patients) of cases, while new postoperative deficits were observed in 2.4% of patients; deficits included 11 root injuries, and 1 instance of quadriplegia (SEP loss irreversible). SSEP loss mostly signaled hypotension or deltoid (C5) paresis. SEPs detected impending or permanent neurological deficits with a 77.1% sensitivity and 100% specificity; if root deficits were excluded, both values were 100%. The authors concluded that the majority of SEP changes can be reversed, and result in no permanent deficit.

2007 Value of IONM in 246 cervical spine operations

In a prospective study of 246 patients undergoing cervical surgery (most with spinal stenosis), the sensitivity and specificity of multimodal intraoperative monitoring (MIOM) (SEP, MEP, EMG) was assessed.[7] Of these, 232 patients were true negatives, 2 were false negatives, 2 false positives, and 10 were true positives (e.g. developed new postoperative neurological deficits). The sensitivity of MIOM was 83.3%, with a specificity of 99.2%.

2008 Predictive Value of IONM in 1055 Cervical Spinal Operations

In Kelleher *et al*., prospective series of 1055 (average age 55) cervical operations, they documented the frequency of significant IONM (sensitivity, specificity, positive predictive values (PPVs), negative predictive values (NPVs)) changes, and correlated these with the incidence of new postoperative neurological deficits.[35] The IONM included; SEP (1055 patients), MEP (26 patients), and EMG (427 patients). New postoperative deficits were observed in 34 patients (3.2%): 21 fully resolved, 9 showed partial improvement, while 4 were permanent. SEP sensitivity was 52%, and specificity was 100% (PPV 100%/NPV 97%), MEP sensitivity was 100%, and specificity 96% (PPV 96%NPV 100%), while EMG sensitivity was 46%, and specificity 73% (PPV 3%NPV of 97%). They concluded that IONM helped prevent permanent/irreversible neurological damage from occurring during cervical spine surgery.

2009 Combined 100% Sensitivity of SEP/MEP in Adult Spinal Deformity Cases

Quraishi *et al*., retrospectively assessed IONM (SEP, EMG, MEP) in 102 spinal deformity/extensive thoracolumbar fusion cases.[51] Intraoperatively, successful recordings included; SSEPs in 101 (99%), EMGs in 89 (87%), and MEPs in 12 of 16 (75%) cases. The overall combined sensitivity was 100%. Five true positives (4.95%) were noted; these included 2-SSEP, 2-EMG, and 1-MEP. No SEPs changes resulted in false positives, while there were 4 false negatives (sensitivity to 33%); with MEPs there were no false negatives.

2010 Interaction of Total Intravenous Anesthetic Techniques (TIVA) with Intraoperative Monitoring and Patient Variables (Hypertension, Diabetes, Age, Weight)

Patients undergoing OPLL procedures usually receive sedation (e.g. Midazolam) and local anesthetics to numb the airway (e.g. Lidocaine). Anesthetic considerations are typically dictated by the necessity for real time SEP and MEP monitoring. Typically this requires utilizing the "balanced technique" or TIVA (total intravenous anesthesia). TIVA utilizes propofol and alfentanil, without inhalation anesthetics to avoid interfering with intraoperative monitoring parameters.

Deiner further evaluated the interaction of IONM (SEP, EMG, MEP) with the different anesthetic techniques utilized in spinal surgery.[6] IONM is now considered part of the standard of care, and has decreased the incidence of intraoperative/postoperative new neurological deficits. It is well known that inhalation anesthetics more significantly decrease the waveforms (decrease amplitude and increase latency) vs. intravenous anesthetics (e.g. TIVA) that have a reduced impact. While studies have shown that halogenated agents and nitrous oxide depress MEP signals more than TIVA, less is known about the relationship between IONM and specific patient characteristics. This study went on to identify specific patient comorbid factors (e.g. hypertension, diabetes, more advanced age, and increased BMI) that warrant more stringent TIVA regimens to avoid inadvertent loss of potentials, and the need for utilizing a Stagnara wake-up test.

2011 Value of SEP and MEP In Avoiding Brachial Plexus Injuries Attributed to Positioning Before Anterior Cervical Spine Surgery

Jahangiri *et al*., documented that the use of intraoperative SEP and MEP monitoring during anterior cervical surgery helped avoid brachial plexus injuries.[30] During draping for surgery in a 43 year old, SEPs first significantly deteriorated, and were soon followed by the loss of MEP. Removal of tape restraining the shoulders allowed both potentials to recover shortly thereafter. In this case, IONM, consisting of both SEP/MEP, allowed for the immediate identification of significant changes, and the avoidance of a potential position-related neurological deficit (e.g. brachial plexus injury).

2012 Value of somatosensory evoked potentials (SEP) and transcranial motor evoked potentials (MEPs) Combined: 100% in Cervical Surgery

Li *et al*., discussed the value of intraoperative SEP and transcranial electrical motor-evoked potentials (TcMEPs) in 200 spinal operations where TIVA (total intravenous anesthesia) was employed in all cases.[43] Alert criteria for SEP included; a 50% decrease in amplitude, a 10% increase in latency, a unilateral change, or increase in stimulation threshold (>100 V for TcMEP). Three SEP alerts were attributed to; poor positioning of the arm (2 patients), and hypotension (1 patient). Four of 5 TcMEP alerts were due to hypotension, but one was attributed to cord compression by a bone graft. When all alerts were addressed intraoperatively, thresholds returned to normal values, and patients experienced no permanent sequelae/neurological deficits. Interestingly, the relative sensitivities of SEP and TcMEP alerts in detecting impending neurological damage were respectively 37.5% and 62.5%. However, together, they were 100%; furthermore, there were no false-positive or false-negative alerts. Notably, TIVA maximized SSEP and TcMEP evaluation intraoperatively (e.g. improved the sensitivity and specificity of intraoperative neural monitoring; IONM).

2012 MEP Warning thresholds (amplitude) for cervical cord compression

In 350 cases of cervical spine surgery, Sakaki *et al*., evaluated how the loss of MEPs (differentiating tracts, segments) correlated with clinical outcomes.[53] Potentials that were lost in 11 cases were directly attributed to the level of spinal surgery; 2 developed permanent deficits. However for 43 patients in which MEP changes occurred below the level of surgery, there were no postoperative neurological sequelae. Although the authors determined that raising the warning threshold by 30% of the control amplitude would likely have avoided both motor deficits, this would likely have resulted in 106 (30.3%) false positives. They therefore concluded “dividing the warning threshold on the basis of origin of amplitude changes could reduce false-positive cases and prevent intraoperative injuries”.

2012 Compartment Syndrome Avoided by Loss of SEP and MEP During Cervical Surgery

Bronson *et al*., described a case in which both SEP and MEP were lost during the performance of a 2-level ACDF.[2] As these early changes led to the discovery of an infiltrated intravenous line (e.g. rather than a neurological problem) which was immediately removed, a compartment syndrome was averted, and the swelling resolved. Had these changes not occurred, the patient would likely have developed a compartment syndrome, requiring fasciotomy to avoid neuromuscular damage.

2013 Significant Change/Loss of IONM Over 25 Years In 12,375 Patients

Raynor *et al*., evaluated the efficacy of IONM (SEP, MEP, EMG) in 12, 375 patients

Involving the cervical (29.7% (3671 patients)), thoracic/thoracolumbar (45.4% (5624 patients)), and lumbosacral (24.9% (3080 patients)) spine.[52] Of these, 77.8% (9633) were primary, and 22.2% (2742) involved secondary/revision procedures. IONM changes/loss occurred in 406 instances in 386 (3.1%) of 12,375 patients and were attributed to; instrumentation ($n = 131$), positioning ($n = 85$), correction ($n = 56$), systemic ($n = 49$), unknown ($n = 24$), and focal spinal cord compression ($n = 15$). IONM changes/loss were more common in revision (6.1%/167 patients) vs. primary (2.3%/219) surgical cases, and data improved following interventions in 88.7% of revision ($n = 360$) vs. 11.3% or primary ($n = 46$) cases respectively. For 93.3% of patients, data recovered, and patients exhibited no permanent neurological sequelae; only 15 (6.7%) had permanent deficits. The authors concluded that IONM effectively limited permanent postoperative neurological deficits, as the overall frequency of permanent neurological sequelae was just 0.12%.

2013 Value of MEP Monitoring in cervical diskectomy

Fotakopoulos *et al*., assessed the prospective value and efficacy of “free running” EMG and MEP during cervical microdiskectomy/fusion for 38 patients with cervical radiculopathy attributed to disc herniations.[28] Those demonstrating a 41% increase in TcMEP amplitude exhibited excellent postoperative results.

2013 MEP Role in Surgery for Cervical Spondylotic Myelopathy (CSM)

As MEPs monitor the corticospinal tracts for patients with CSM, Capone *et al*., correlated the preoperative and postoperative MEPs with the clinical results of 38 cervical spine operations.[4] For clinical evaluation, the study utilized the 18-point modified Japanese Orthopedic Association (mJOA) Score obtained preoperatively (7-15 days) and postoperatively (6-12 months). Additionally, the central motor conduction time (CMCT) was utilized to evaluate MEPs (biceps, abductor digiti minimi, and tibialis anterior muscles bilaterally). Postoperatively, the mJOA score increased significantly (10.1 to 15.1), and CMCT for the tibialis anterior muscles showed a slight but significant reduction (better results for those with lesser deficits). The authors concluded that early surgery for CSM patients with lesser preoperative deficits correlated with better outcomes defined by improvement in MEPs.

Intraoperative neural monitoring signals hypotension and impending neurological injury during cervical spine surgery

2006 Value of Intraoperative SEP Monitoring During 508 Cervical Corpectomies

In 2006, Kahn *et al*., reviewed 508 consecutive patients undergoing cervical corpectomies utilizing intraoperative SEP monitoring.[36] The study included analysis of SEP tracings in 508 patients (average age, 55.7 years) undergoing single or multilevel ACF, and included an analysis of outcomes. Significant SEP changes occurred in 5.3% (27 patients) of patients, and were most commonly attributed to hypotension. New postoperative neurological deficits occurred in 2.4% of patients; 11 consisted of nerve root injuries, while one patient was irreversibly quadriplegic. SEP monitoring detected impending intraoperative iatrogenic neurologic deficits with a sensitivity of 77.1% and specificity of 100. The authors concluded the SEP monitoring effectively alerts surgeons of impending adverse events, most often attributed to hypotension (reversing hypotension results in resolution of SEP loss), and followed by potential root injuries.

2009 Acute Hypotension Detected Utilizing SEP, MEP under TIVA Anesthesia During Post Traumatic Cervical Spine Fusion

Cann noted that hypotension should be avoided during cervical spine fusions for patients with acute traumatic injuries, as it may exacerbate neurological deficits.[3] In this case, a certified Registered Nurse Anesthetist utilized

SEP, MEP and TIVA anesthesia in a young, healthy male. During the surgery, a brief period of intraoperative hypotension precipitated acute decrement in the MEPs. The blood pressure was immediately raised, the wake-up test was normal, and the surgery was successfully completed. This article highlighted how intraoperative hypotension may precipitate sufficient ischemia in a traumatically injured spinal cord, to result in potential permanent neurological injury.

2012 Cervical Cord Infarct Following Cervical Spine Surgery

In 2012, Kalb *et al*., reported on five patients who, following cervical decompressions, developed permanent neurological deficits attributed to spinal cord infarction.[33] The following variables were evaluated: clinical course, diagnostic studies, types of operations, vascular disease/risk factors, intraoperative hypotension, intraoperative SEP changes, brain infarction, and the extent of radiographically-documented postoperative cord infarction. All 5 had prior cervical vascular compromise or systemic vascular comorbid risk factors. Although 4 developed hypotensive episodes (2 intraoperatively, two postoperatively), none exhibited clinical or radiographic evidence of brain ischemia. Notably, neurodiagnostic studies were performed following cervical decompressions looking for residual spinal cord compression to explain new neurological deficits.

Anterior and circumferential OPLL cervical surgery and plating considerations [Table 4]

1994 Improved outcomes for anterior surgical management of OPLL in 43 North Americans

Epstein found, from 1989 to 1992, that 43 of 174 (25%) consecutive North Americans had cervical OPLL.[10] After the non-random selection of ACF, ACDF, or five-level laminectomies, the preoperative and postoperative outcomes of these 43 OPLL patients were compared using Ranawat's neurological classes and grades. Those undergoing anterior OPLL surgery exhibited superior outcomes vs. laminectomies; they had the most severe preoperative deficits, and the best postoperative results. Notably, the 13 ACDF patients, with the least severe preoperative deficits, demonstrated intermediate recoveries, while the ten-laminectomy patients, with intermediate preoperative deficits, exhibited the least recovery.

1998 Circumferential surgery for OPLL

In 1998 Epstein determined that combined anterior and posterior (circumferential) surgery for patients with OPLL/stenosis achieved adequate decompression/fusion with an acceptable level of risk.[15] From 1989 to 1996, 22 circumferential procedures included average 2.5-level anterior cervical corpectomies (ACF) with average 5-level posterior wiring and fusions (PWF). Patients exhibited severe myelopathy (average Nurick grade 3.5) and were followed an average of 22 months (range 4-52 months). Circumferential surgery took an average of 9.8 hours, and required an average of 3.5 Units of transfused red blood cells. Patients improved an average of + 3.0 Nurick grades postoperatively.

2001 Multilevel circumferential cervical surgery for cervical Spondylosis/OPLL

Multilevel circumferential cervical surgery, consisting of multilevel ACF/PWF, offers direct resection/stabilization of spondylostenosis and OPLL.[19] These procedures are optimal for patients under the age of 65 with severe multilevel disease, but only for more carefully selected patients over the age of 65 with limited comorbidities and significant loss or reversal of the cervical lordosis (kyphosis). In this series, 65 patients averaged 56 years of age (40 males and 25 females), and exhibited multilevel MR and CT-documented spondylostenosis/OPLL. Patients exhibited moderate/severe preoperative myelopathy (average Nurick grade 3.8), and underwent 2 to 4-level ACF/PWF with halo devices. The initial 22 patients had no plates applied. These patients were followed sequentially by the application of; 22 constrained (Orion) plates, 13 semi-constrained (Atlantis) plates, and 8 dynamic (ABC Aesculap) plates. In all groups, patients improved an average of three postoperative Nurick Grades, there were no new cord injuries, but 3 had transient C5 root palsies (partial). However, graft/plate extrusions were observed in 3 of 22 nonplated patients, 2 of 22 constrained-plated patients, and 3 of13 semi-constrained-plated patients, but not in any of the 8 patients (0/8) receiving dynamic plates. For all patients, the adequacy of fusion was documented on dynamic radiographs and 2D-CT or 3D-CT studies obtained 3 and 6 months postoperatively (or later where indicated). Interestingly, these initial data indicated that anterior dynamic plates for multilevel ACF/PWF contributed to a reduced rate of plate/graft extrusion.

2001 Reoperation rates for acute graft extrusion and pseudarthrosis following single-level corpectomy/fusion with/without plates for OPLL: Advantages of dynamic plates

Epstein evaluated reoperation rates following one-level anterior cervical corpectomy with fusion (ACF) performed without and with plates for myelopathic patients with spondylosis accompanying OPLL.[20] Reoperation rates for graft extrusion and symptomatic pseudarthrosis were evaluated for 48 nonplated (1989-1996) and 35 plated (1997-2000) one-level ACF. The latter plates included; 3 Orion, 12 Atlantis (Medtronic, Memphis, TN, USA), and 20 ABC plates (Aesculap; Tuttllingen, Germany). Fusion was documented on both dynamic X-rays, and 2- or 3-dimensional CT studies 3 and 6 months postoperatively (or until fusion occurred). Patients were followed an average of 82 months for the nonplated patients, and 21 months for the plated patients. Of 48 nonplated patients, 3 developed immediate graft extrusions within 24 hours of surgery and required graft replacement; another 2 exhibited symptomatic pseudarthrosis 6 months postoperatively,

Table 4: Anterior and Circumferential OPLL Cervical Surgery and Plating Considerations

Section	Summary
1994 Improved Outcomes for Anterior Surgical Management of OPLL in 43 North Americans	Epstein found, from 1989 to 1992, that 43 of 174 (25%) consecutive North Americans had cervical OPLL.[10] After the non-random selection of ACF, ACDF, or five-level laminectomies, the preoperative and postoperative outcomes of these 43 OPLL patients were compared using Ranawat's neurological classes and grades. Notably, the 13 ACDF patients, with the least severe preoperative deficits, demonstrated intermediate recoveries, while the ten-laminectomy patients, with intermediate preoperative deficits, exhibited the least recovery.
1998 Circumferential Surgery for OPLL	In 1998 Epstein determined that combined anterior and posterior (circumferential) surgery for patients with OPLL/stenosis achieved adequate decompression/fusion with an acceptable level of risk.[15] Circumferential surgery (in 22 patients) took an average of 9.8 h, and required an average of 3.5 U of transfused red blood cells. Patients improved an average of +3.0 Nurick grades postoperatively.
2001 Multilevel Circumferential Cervical Surgery for Cervical Spondylosis/OPLL	Multilevel circumferential cervical surgery, consisting of multilevel ACF/PWF, offers direct resection/stabilization of spondylostenosis and OPLL.[19] Graft/plate extrusions were observed in 3/22 nonplated patients, 2/22 constrained-plated patients, 3/13 semi-constrained-plated patients, and 0/8 dynamic-plated patients.
2001 Reoperation Rates for Acute Graft Extrusion and Pseudarthrosis Following Single-Level Corpectomy/Fusion With/Without Plates for OPLL: Advantages of Dynamic Plates	Epstein evaluated reoperation rates following one-level anterior cervical corpectomy with fusion (ACF) performed without and with plates for myelopathic patients with spondylosis accompanying OPLL.[20] Of 48 nonplated patients, 3 developed immediate graft extrusions within 24 hours of surgery and required graft replacement; another 2 exhibited symptomatic pseudarthrosis 6 months postoperatively, warranting secondary posterior wiring with fusion (PWF). In comparison, of 35 plated patients, one female developed plate displacement 6 weeks postoperatively, while 3 exhibited symptomatic pseudarthrosis 6 months later, requiring secondary posterior wiring and fusion (PWF).
2002 Role of CT and MR in Diagnosis and Surgical Management of Early and Classical Cervical OPLL	In 2002, Epstein noted better results with direct anterior rather than posterior management of cervical OPLL.[21] Anterior surgical options included multilevel plated anterior diskectomy and fusion, plated anterior cervical corpectomy with fusion (ACF), or plated multilevel ACF with posterior fusion. Posterior surgical options varied from laminectomy with or without simultaneous fusion to laminoplasty (the latter as performed in the literature).
2003 Fixed vs. Dynamic Plates For Multilevel Anterior Cervical Corpectomy/Fusion with Simultaneous Posterior Stabilization for OPLL Patients	In Spinal Cord in 2003, Epstein compared the complications of utilizing fixed (constrained/semi constrained) plates vs. dynamic plates to perform anterior cervical corpectomy and fusion (ACF) with posterior stabilization (PWF) in 66 patients with OPLL.[24] In short, a higher fixed-plated failure rate of 13% was observed for patients undergoing multilevel cervical ACF/PWF for OPLL, while the failure rate for dynamic plates of 3.6% was substantially lower.
2011 Anterior vs. Posterior Surgery for OPLL	Smith *et al*., noted that up to 25% of patients with cervical myelopathy have OPLL.[56] While MR images document cord compression from hypointense (HPLL or OPLL) ventral masses, CT's directly image the progressive coalescence of ossification behind the cervical vertebrae (narrower) and at the disc spaces (wider) resulting in cord compromise; classically, this pattern directly follows the normal contour of the PLL. Surgical alternatives include anterior, posterior, or circumferential decompression and/or stabilization.
2011 Efficacy of Dynamic-plated Single-level Anterior Diskectomy/fusion andCost Analysis	Epstein prospectively evaluated the fusion rates and outcomes for 60 consecutive patients undergoing 1-level ACDF utilizing iliac autograft and dynamic plates (ABC; Aesculap, Tuttlingen, Germany).[27] Although dynamic X-rays/2D-CT studies documented 100% fusion an average of 3.8 months (range 2.5-8 months] postoperatively, 5 heavy smokers exhibited delayed fusions [6-8 months postoperatively].
2013 Surgical Management of Degenerative Cervical Myelopathy: A Consensus Statement	In 2013, spinal surgeons from multiple institutions evaluated the surgical management of degenerative cervical myelopathy (DCM), including CSM, and OPLL.[39] They developed a treatment algorithm using the GRADE system that helped assess quality of evidence and, led to evidence-based recommendations.

warranting secondary posterior wiring with fusion (PWF). In comparison, of 35 plated patients, one female developed plate displacement 6 weeks postoperatively, while 3 exhibited symptomatic pseudarthrosis 6 months later, requiring secondary posterior wiring and fusion (PWF). Notably, all 4 complications occurred for patients with constrained or semi constrained plate designs (Orion and Atlantis plates), and none occurred amongst those receiving dynamic ABC plates. These data certainly indicated that one-level ACF performed with dynamic plates had the best results, demonstrating no pseudarthrosis or extrusion, whereas no plates or the use of constrained/semi constrained plates exhibited higher frequencies of pseudarthrosis or graft extrusion.

2002 Role of CT and MR in Diagnosis and Surgical Management of Early and Classical Cervical OPLL

In 2002, Epstein noted that although surgical alternatives for treating cervical OPLL included anterior, posterior or combined cervical approaches, better results were observed utilizing direct anterior vs. posterior procedures.[21]. Anterior surgical options included multilevel plated anterior diskectomy and fusion, plated anterior cervical corpectomy with fusion (ACF), or plated multilevel ACF with posterior fusion. Posterior surgical options varied from laminectomy with or without simultaneous fusion to laminoplasty (the latter as performed in the literature). Although outcomes with different approaches vary, many direct anterior resection techniques achieve more favorable results because of appropriate and adequate resection of OPLL.

2003 Fixed vs. Dynamic plates for multilevel anterior cervical corpectomy/fusion with simultaneous posterior stabilization for OPLL patients

In Spinal Cord in 2003, Epstein compared the complications of utilizing fixed (constrained/semi constrained) plates vs. dynamic plates to perform anterior cervical corpectomy and fusion (ACF) with posterior stabilization (PWF) in 66 patients with OPLL.[24] Patients in both sequential cohorts respectively averaged 52 to 53 years of age, included comparable 2:1 male/female ratios, and had similar demographics. Surgery addressed MR and CT documented multilevel OPLL in all patients who were severely myelopathic (average Nurick Grades 3.6 to 3.7). Patients underwent respective 2.6 to 3.0 level anterior corpectomies with average 7-level PWF with halo devices; the 38 initial patients received fixed plates, while the latter 28 received dynamic plates (ABC, Aesculap, Tuttlingen, Germany). Patients were followed for an average of 5.4 years in the fixed-plated group, and 2.7 years in the dynamic-plated population. CT and dynamic X-ray confirmed fusion an average of 4.5 to 4.9 months postoperatively in the respective groups. Five (13%) of 38 fixed plates (Medtronic, Sofamor Danek, Memphis, TN, USA) failed warranting secondary surgery, while only one (3.6%) of 28 dynamic-plated patients developed a pseudarthrosis that required a second posterior fusion. In short, a higher fixed-plated failure rate of 13% was observed for patients undergoing multilevel cervical ACF/PWF for OPLL, while the failure rate for dynamic plates of 3.6% was substantially lower.

2011 Anterior vs. Posterior surgery for OPLL

Smith *et al.*, noted that up to 25% of patients with cervical myelopathy have OPLL.[56] While MR images document cord compression from hypointense (HPLL or OPLL) ventral masses, CT's directly image the progressive coalescence of ossification behind the cervical vertebrae (narrower) and at the disc spaces (wider) resulting in cord compromise. The pattern classically directly follows the normal contour of the PLL. CT can further document possible dural ossification/penetration.

The surgical management of OPLL remains a challenge to spine surgeons. Surgical alternatives include anterior, posterior, or circumferential decompression and/or stabilization. Anterior cervical stabilization options include cervical corpectomy or multilevel anterior cervical corpectomy and fusion, while posterior stabilization approaches include instrumented or noninstrumented fusion or laminoplasty. Each of these approaches has distinct advantages and disadvantages. While anterior approaches may provide more direct decompression and best improve myelopathy scores, there is soft-tissue morbidity associated with the anterior approach. Posterior approaches, including laminectomy and fusion and laminoplasty, may be better tolerated in older patients, and with an adequate cervical lordotic curvature, posterior procedures may allow for excellent cord decompression from multilevel ventrally situated OPLL [Figures 6, 9, 10, 16-18 and 21]. However, for the latter patient group, there may be residual axial neck pain, and less improvement in myelopathy scores. In this review, the authors discuss the epidemiology, imaging findings, and clinical presentation of OPLL, and additionally discussed the merits of different surgical techniques in the management of cervical OPLL

2011 Efficacy of dynamic-plated single-level anterior diskectomy/fusion and cost analysis

Epstein prospectively evaluated the fusion rates and outcomes for 60 consecutive patients undergoing 1-level ACDF utilizing iliac autograft and dynamic plates (ABC; Aesculap, Tuttlingen, Germany).[27] Pathology included single-level disc disease/spondylosis (38 patients) and/or ossification of the posterior longitudinal ligament (OPLL, 22 patients); 18 had radiculopathy while 42 were myelopathic. Fusion was assessed at 3, 6, and up to 12 months with both X-rays and 2D/3D-CT scans. Outcomes were also assessed up to 24 months postoperatively utilizing Odom's Criteria, Nurick Grades, and Short-Form 36 (SF-36) outcome questionnaires. Patients were followed for an average of 4.8 postoperative years (minimum of 2 years). Although dynamic X-rays/2D/3D-CT studies documented 100% fusion an average of 3.8 months (range 2.5-8 months] postoperatively, 5 heavy smokers exhibited delayed fusions [6-8 months postoperatively]. Two years postoperatively, the average Nurick Score was 0.3 (mild radiculopathy), while Odom's Criteria revealed 52 excellent, 6 good, and 2 fair outcomes (the latter 8 patients were heavy smokers). SF-36 questionnaires showed marked improvement (>10.0 point gain) on 5 of 8 Health Scales within 6 months, on 7 of 8 Health Scales within 1 year, and on all 8 Health Scales within 2 postoperative years.

2013 Surgical management of degenerative cervical myelopathy: A consensus statement

In 2013, spinal surgeons from multiple institutions evaluated the surgical management of degenerative cervical myelopathy (DCM), including CSM, and OPLL.[39] The authors noted that no specific operative approach was clearly superior when dealing with the varied pathoanatomical considerations in DCM, CSM, and OPLL patients. They developed a treatment algorithm using the GRADE system that helped assess quality of evidence and, led to evidence-based recommendations. Factors to be included in the surgical analysis of patients included; sagittal alignment, location and number of levels compressed, instability/subluxation, type of disease (spondylosis vs OPLL), anatomy of the neck, osteoporosis/osteopenia or normal bone, and surgeon experience/preference.

Posterior surgery for OPLL with lordosis [Table 5]

1998 Treatment of pseudarthrosis after anterior cervical OPLL surgery

From 1989 to 1993, the incidence of pseudarthrosis was evaluated in 76 patients with cervical OPLL undergoing 2.5 level extended ACDF or average 3.0 level ACF performed without anterior plate instrumentation using iliac crest/fibular strut autografts.[14] White and Panjabi's fusion criteria included; >3.5 mm of sagittal plane translation (or 20%), and > 20 degrees of sagittal plane rotation on dynamic X-rays at 3 and 6 postoperative months. Additional fusion criteria on 2D and 3D dimensional (D) CT scans obtained 3 months postoperatively included: the lack of bony lucency and presence of bony trabeculation across fusion constructs. Patients were followed an average of 3 years (range 25-52 months). Three months postoperatively, dynamic X-rays in 20 patients showed radiographic instability consistent with pseudarthrosis; CT studies also indicated a lack of fusion. However, at 6 postoperative months, dynamic X-rays confirmed that 10 patients were now fused and that another 7 were clinically stable despite persistent, irregular, linear lucencies at graft/body interfaces on CT. Interestingly, only 3 (4%) patients with clinical instability and confirmed pseudarthrosis required secondary posterior wiring and fusion.

1999 Laminectomy with Posterior Wiring / Fusion Technique for OPLL

Following cervical laminectomy, Epstein described a novel posterior wiring and fusion technique to manage patients with OPLL, spondylosis, ossification of the yellow ligament (OYL), stenosis, and instability.[16] For 5 patients, averaging 73 years of age, all with severe myelopathy, dynamic X-rays confirmed adequate cervical lordotic curvatures with active subluxation and instability at one or two levels. MR and CT studies confirmed severe OPLL with varying degrees of other spondylotic changes. Following laminectomy, a PWF was performed that involved splitting fibular strut grafts and making holes at each vertebral level (to be fused) so that spinous process wires or facet wires could be utilized to complete the fusion. Mirror split grafts were then affixed on either side of the spinous processes, and held in place with cerclage wires. Utilizing cervicothoracic orthoses, patients fused within an average of 3.6 months, and exhibited mild to moderate residual myelopathy.

2003 Laminectomy for cervical myelopathy

Epstein reviewed the clinical, neurodiagnostic, and varied dorsal decompressive techniques (e.g. cervical laminectomy with or without fusion vs. laminoplasty) utilized to address multilevel stenosis/spondylosis, OPLL, and ossification of the yellow ligament (OYL).[23] Short and long-term outcomes following dorsal decompressions/fusion varied. Greater susceptibility to long-term deterioration included advanced age (>70 years), more severe original myelopathy, and recent trauma.

2008 Traditional posterior cervical fusion techniques

Epstein evaluated traditional posterior cervical fusion techniques in 35 patients in 2008.[25] For those with preserved lordotic curves, focal laminectomy (1-3 levels) and multilevel posterior fusion offered decompression with immediate stabilization. Patients averaged 65 years of age (22 men and 13 women), exhibited severe myelopathy (Nurick grade 4.1), and dynamic X-ray and MR and CT studies showed preserved cervical lordotic curvatures with 1-3 level cord compression due to stenosis, OPLL, OYL, and/or olisthy. Focal laminectomies (average 2 levels; range, 1-3) were accompanied by 7-level PWF utilizing spinous process-based wiring techniques. Complications included 2 transient root injuries (diabetic patients), 2 wound infections, 1 wound breakdown, no cord injuries, and no mortalities. Fusion occurred in 100% of patients typically within 5.2 postoperative months. Odom's criteria showed 29 good/excellent and 6 fair/poor outcomes. Patients improved on all 8 Health Scales of the SF-36. The author concluded that focal cervical laminectomies using multilevel posterior fusions, based on spinous process wiring techniques, resulted in high fusion rates with limited morbidity. Alternatively, in the literature, where other studies utilized lateral mass/pedicle screw techniques, even under optimal circumstances even utilizing CT-guidance (e.g. cadaveric studies), morbidity

Table 5: Posterior Surgery for OPLL with Lordosis

Section	Summary
1998 Treatment of Pseudarthrosis After Anterior Cervical OPLL Surgery	From 1989 to 1993, the incidence of pseudarthrosis was evaluated in 76 patients with cervical OPLL undergoing 2.5 level extended ACDF or average 3.0 level ACF performed without anterior plate instrumentation using iliac crest/fibular strut autografts.[14] Three months postoperatively, dynamic X-rays in 20 patients showed radiographic instability consistent with pseudarthrosis; CT studies also indicated a lack of fusion. However, at 6 postoperative months, dynamic X-rays confirmed that 10 patients were now fused and that another 7 were clinically stable despite persistent, irregular, linear lucencies at graft/body interfaces on CT.
1999 Laminectomy with Posterior Wiring/Fusion Technique for OPLL	Following cervical laminectomy, Epstein described a novel posterior wiring and fusion technique to manage patients with OPLL, spondylosis, ossification of the yellow ligament (OYL), stenosis, and instability.[16] For 5 patients, averaging 73 years of age, all with severe myelopathy, dynamic X-rays confirmed adequate cervical lordotic curvatures with active subluxation and instability at one or two levels.
2003 Laminectomy for Cervical Myelopathy	Epstein reviewed the clinical, neurodiagnostic, and varied dorsal decompressive techniques (e.g. cervical laminectomy with or without fusion vs. laminoplasty) utilized to address multilevel stenosis/spondylosis, OPLL, and ossification of the yellow ligament (OYL).[23]
2008 Traditional Posterior Cervical Fusion Techniques	Epstein evaluated traditional posterior cervical fusion techniques in 35 patients in 2008.[25] For patients with preserved lordotic curves, focal laminectomy (1-3 levels) and multilevel posterior fusion offered decompression with immediate stabilization. Patients averaged 65 years of age (22 men and 13 women), exhibited severe myelopathy (Nurick grade 4.1), and dynamic x-ray/MR/CT studies showed preserved cervical lordotic curvatures and 1-3 level cord compression due to stenosis, OPLL, OYL, and olisthy.
2013 Factors Utilized to Predict Outcomes of Cervical Laminoplasty for OPLL	Yoon *et al*., looked at different factors that could help predict outcomes of cervical laminoplasty performed to enlarge the cervical spinal canal while preserving stability for patients with CSM or OPLL.[63]
2013 Long-Term Outcomes of Laminectomy for Cervical OPLL	Lee *et al*., evaluated the long-term efficacy/outcomes (JOA score) of utilizing laminectomy alone for treating 34 patients with cervical OPLL (average age 57.8) over a mean of 57.5 months.[41] Notably, no statistically significant changes occurred in the cervical curvature or ROM, leading the authors to conclude that in the long-term, laminectomy alone could effectively manage cervical OPLL (e.g. without the evolution of kyphosis).

included a 13.4% incidence of noncritical, and 10.6% frequency of critical pedicle breaches (critical defined as impinging on vascular/neural structures).

2013 Factors utilized to predict outcomes of cervical laminoplasty for OPLL

Yoon *et al*., looked at different factors that could help predict outcomes of cervical laminoplasty performed to enlarge the cervical spinal canal, while preserving stability for patients with CSM or OPLL.[63] In this study, although 433 citations were reviewed, only one prospective and 11 retrospective cohort studies met inclusion criteria (e.g. multivariate analysis of least 20 patients, adjusted for age/confounding variables, and use of JOA or modified JOA scores for outcomes). Older age did not predict poorer outcomes for CSM patients (therefore not a contraindication), but proved equivocal for OPLL patients. More severe and more prolonged symptoms, however, might predict poorer outcomes for CSM patients, along with hill-shaped OPLL.

2013 Long-term outcomes of laminectomy for cervical OPLL

Lee *et al*., evaluated the long-term efficacy/outcomes (JOA score) of utilizing laminectomy alone for treating 34 patients with cervical OPLL (average age 57.8) over a mean of 57.5 months.[41] Contrary to typical expectations, laminectomy as reported in this series did not result in significant long-term kyphosis. Patients underwent laminectomy from 1999-2009, and they were followed both preoperatively and at the last visit with cervical global angle and range of motion (ROM) parameters. Alignment was characterized as: lordotic, straight, or kyphotic. The average preoperative JOA score (10.7) and postoperative score (14.3) yielded a recovery rate of 56.3%; it increased until the 6 th postoperative year at which point it slowly declined. The mean preoperative global angle was -11.3°, and the most recent global angle was -8.4°. Notably, no statistically significant changes occurred in the cervical curvature or ROM. This led the authors to conclude that in the

Table 6: Anticipation and Direct/Indirect Repair of Intraoperative Cerebrospinal Fluid (CSF) Fistulas Occurring During OPLL Surgery

Section	Summary
1999 Anterior Cervical Micro-dural Repair of CSF Fistula After Cervical OPLL Surgery	In 1999, Epstein and Hollingsworth presented a case in which a microdural repair of an anterior cervical dural fistula was performed during an ACF for OPLL.[17] These fistulas are frequently managed with dural substitutes just applied to the dural surface (often there are no remaining adequate dural margins to sew to), fibrin glue, microfibrillar collagen, lumbar drains, and lumboperitoneal shunts.
2009 Management and Outcomes of CSF Leaks Due to Cervical Corpectomy for OPLL	Joseph *et al*., evaluated how to manage patients with CSF fistulas following anterior cervical OPLL surgery, while also assessing outcomes.[31] Out of 144 patients treated with OPLL (n=144) over a 15-year period, 9 patients (6.3%) developed CSF leaks. Dural defects ranged from a few mm to 10-75 mm; all were successfully repaired utilizing fascial grafts, gelatin sponge, lumbar CSF drains, and bed rest.
2009 Wound-peritoneal Shunts and Lumbo-peritoneal Shunts in the Management of Traumatic Cervical CSF Fistulas with OPLL Surgery	Epstein noted the complexity of managing iatrogenic/traumatic intraoperative dural fistulas/CSF leaks occurring during cervical OPLL surgery.[26] The study included 82 OPLL patients with MR and CT studies documenting multilevel ventral cord compression due to OPLL with kyphosis. Patients underwent average 2.6 level ACF with average 6.6 level PWF under a single anesthetic. On preoperative CT studies, 5 patients with intraoperative dural fistulas demonstrated either the single-layer sign (2 patients: large central mass) or the double-layer sign (3 patients: hyperdense/hypodense/hyperdense layers).
2011 Literature Review for Managing CSF Leaks After Anterior Cervical Surgery for OPLL	Mazur *et al*., noted that although direct resection of anterior OPLL may more effectively resolve myelopathy due to OPLL, it does post an increased risk of a CSF fistula as OPLL may extend to/though the dura.[46]
2012 CSF Leaks During Anterior Cervical Surgery for OPLL: Prevention and Treatment	Lei *et al*., studied how to prevent and manage CSF leaks occurring during Cervical OPLL surgery.[42] During surgery, the OPLL mass was excised or floated, while the arachnoid was "reserved in order to reduce dural damage". CSF leaks were noted intraoperatively in 15 patients, and postoperatively in 5. No patients required secondary operations or shunt placement.

long-term, laminectomy alone could effectively manage cervical OPLL (e.g. without the evolution of kyphosis).

Anticipation and direct/indirect repair of intraoperative cerebrospinal fluid (CSF) Fistulas occurring during OPLL Surgery [Table 6]

1999 Anterior Cervical Micro-dural Repair of CSF Fistula After Cervical OPLL Surgery

In 1999, Epstein and Hollingsworth presented a case in which a microdural repair of an anterior cervical dural fistula was performed during an ACF for OPLL.[17] It is well known that CSF fistulas may occur during anterior cervical surgery for OPLL as OPLL may extend to/through the dura. These fistulas are frequently managed with dural substitutes just applied to the dural surface (often there are no remaining adequate dural margins to sew to), fibrin glue, microfibrillar collagen, lumbar drains, and lumboperitoneal shunts. However, if sufficient dural margins are present, more adequate dural repair may now be accomplished by combining 7-0 Gortex suture (WL Gore and Associates Inc, Newark DE), techniques with the 1.4-mm microdural titanium stapler (as long as margins between the residual dura and dural graft can be adequately everted). For a 59-year-old female with OPLL and severe myelopathy (Nurick Grade IV), a C3-C7 ACF with an Orion plate was followed by a C3-T1 PWF with halo device. During the anterior surgery, a 5-mm CSF fistula at C4-C5 was repaired under the microscope using a bovine pericardial graft sewn in with 7-0 Gortex sutures, followed by application of 1.4-mm microdural staples in-between the sutures. Next, a microfibrillar graft was placed on top of the repair, and was followed by the application of fibrin glue, a low-pressure wound-peritoneal, and subsequent lumboperitoneal shunt (with horizontal vertical valve). Postoperatively, the patient's myelopathy improved, and there was no residual CSF leak.

2009 Management and outcomes of CSF leaks due to cervical corpectomy for OPLL

Joseph *et al*., evaluated how to manage patients with CSF fistulas following anterior cervical OPLL surgery, while also assessing outcomes.[31] Out of 144 patients treated with OPLL (n = 144) over a 15-year period, 9 patients (6.3%)

developed CSF leaks. Dural defects ranged from a few mm to 10-75 mm; all were successfully repaired utilizing fascial grafts, gelatin sponge, lumbar CSF drains, and bed rest.

2009 Wound-peritoneal shunts and lumbo-peritoneal shunts in the management of traumatic cervical CSF fistulas with OPLL surgery

Epstein noted the complexity of managing iatrogenic/traumatic intraoperative dural fistulas/CSF leaks occurring during cervical OPLL surgery.[26] The study included 82 OPLL patients with MR and CT studies documenting multilevel ventral cord compression due to OPLL with kyphosis. Patients underwent average 2.6 level ACF with average 6.6 level PWF under a single anesthetic. On preoperative CT studies, 5 patients with intraoperative dural fistulas demonstrated either the single-layer sign (2 patients: large central mass) or the double-layer sign (3 patients: hyperdense/hypodense/hyperdense layers). All 5 patients required complex dural repairs that included sheep pericardial grafts, fibrin sealant, microfibrillar collagen, and wound-peritoneal (e.g. low-pressure wound-peritoneal shunts included Uni-Shunts; Codman, Johnson and Johnson, Dorchester, Mass) and lumboperitoneal shunts (LP). Utilizing these combined techniques, all 5 lacerations (DLs) resolved. The proximal ends of the WP shunts were placed lateral/parallel to the fibula strut graft/plate complex, whereas the distal catheters were tunneled into the peritoneum in the right upper quadrant (always prepared and draped in anticipation of the need for a shunt).

2011 Literature review for managing CSF leaks after anterior cervical surgery for OPLL

Mazur *et al*., noted that although direct resection of anterior OPLL may more effectively resolve myelopathy due to OPLL, it does pose an increased risk of a CSF fistula as it may extend to/though the dura.[46] Here the authors reviewed 11 studies dealing with intra- and postoperative CSF fistulas occurring during OPLL surgery; these fisutlas occurred in 4.3% to 32% of patients. The studies reviewed the various preventive measures, dural repair techniques, and drains/shunts that could be utilized to treat these CSF fistulas.

2012 CSF leaks during anterior cervical surgery for OPLL: Prevention and treatment

Lei *et al*., studied how to prevent and manage CSF leaks occurring during Cervical OPLL surgery.[42] In their analysis of 47 patients with severe OPLL, with patients averaging 56.4 years of age, patients underwent ACDF (15 patients) or ACF (32 patients). OPLL, evaluated utilizing preoperative CT studies, consisted of the local or segmental variants, was greater than 5 mm thick, and narrowed the canal by more than 50%. During surgery, the OPLL mass was excised or floated, while the arachnoid was "reserved in order to reduce dural damage". Sutures and gelatin sponge or muscle pedicles were utilized to repair dural defects. Postoperatively, patients were kept at bed rest, and lumbar taps were performed to facilitate distal drainage where needed. CSF leaks were noted intraoperatively in 15 patients, and postoperatively in 5. No patients required secondary operations or shunt placement.

My impression, however is that, the "floating" technique typically does not work as OPLL is not simply confined to the central canal, but is typically firmly and full adherent to the dura along the lateral gutters. Therefore, if the "floating" technique is attempted, it is very likely that a significant CSF leak will occur along the lateral margins that are supposed to free the central OPLL mass. This has the added disadvantage of producing a CSF leak prior to resecting the central compressive OPLL mass, making that resection more difficult. It also likely eliminates/limits intact lateral dura available for suturing any type of graft.

Summary

The optimal surgical management of cervical OPLL is complex. In order to optimally treat these patients, the preoperative neurological deficits, the neurodiagnostic studies (MR/CT), and the risks/complications of the varioius approaches (e.g. anterior, posterior, or circumferential surgery) must all be integrated/assessed. The decision to perform OPLL surgery should be based on the severity of the patient's myelopathy along with a careful assessment of their age and potential risks of neurological deterioration with/without surgical intervention. MR studies will demonstrating the presence/absence of kyphosis or lordosis and best reveal the extent of cord compression and increased signals in the cord (e.g. consistent with edema/myelomalacia). CT studies will critically document the full extent of puncate (HPLL) or classical ossification (OPLL) associated with OPLL, while also indicating whether it extends to/through the dura thus increasing the risk of CSF fisitulas with anterior approaches. Thorough familiarity with OPLL as summarized in this review study is essential to optimize conservative vs. surgical management this disease.

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