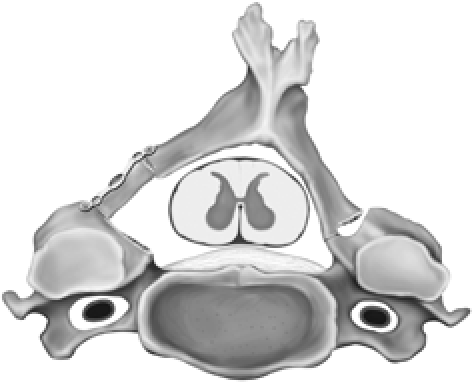

Introduction

Ossification of the posterior longitudinal ligament

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Since its first description in 1838, ossification of the posterior longitudinal ligament (OPLL) has been a fascinating disease for orthopedic surgeons and neurosurgeons. It was recognized early on as posing high risks to the surgeon attempting to alleviate the relentless progression of mechanical spinal cord compression, and the high rate of various treatment complications has been well described in the literature. Such was the hazard of surgical intervention that new procedures, such as cervical laminoplasty, were devised in an attempt to make surgical decompression more acceptable. Furthermore, the radiographic and clinical natural history OPLL has proven to be difficult to predict, further complicating management decisions.

In this month's issue of *Neurosurgical Focus,* we have collected a series of manuscripts to update the medical literature on the current state of the art for physicians faced with treating OPLL. Over the past 2 decades we have seen significant advances in our understanding of the natural history, epidemiology, and pathogenesis of OPLL, which is summarized nicely in several review articles. However, the mainstay of treatment remains surgical decompression, and we have attempted to provide a balanced review on this highly controversial topic as well as the techniques for managing the complications of CSF leakage, dysphagia, deltoid palsy, and neurological worsening.

Ultimately, when we as neurosurgeons are called upon to treat these challenging cases, careful preparation is necessary to avoid disastrous outcomes. Recognizing the disease as distinct from other causes of compressive myelopathy is a key and often overlooked first step. Choosing and then executing an appropriate surgical approach is a critical and often personal choice, as evidenced by the numerous expert opinions on this topic. We hope that this series of papers will be helpful in your endeavors when managing this fascinating disease. *(DOI: 10.3171/2011.3.FOCUS.Intro)*

Neurosurg Focus 30 (3):E1, 2011

Ossification of the posterior longitudinal ligament: a review

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Ossification of the posterior longitudinal ligament (OPLL) is most commonly found in men, the elderly, and Asian patients. There are many diseases associated with OPLL, such as diffuse idiopathic skeletal hyperostosis, ankylosing spondylitis, and other spondyloarthropathies. Several factors have been reported to be associated with OPLL formation and progression, including genetic, hormonal, environmental, and lifestyle factors. However, the pathogenesis of OPLL is still unclear. Most symptomatic patients with OPLL present with neurological deficits such as myelopathy, radiculopathy, and/or bowel and bladder symptoms. There are some reports of asymptomatic OPLL. Both static and dynamic factors are related to the development of myelopathy. Plain radiography, CT, and MR imaging are used to evaluate OPLL extension and the area of spinal cord compression. Management of OPLL continues to be controversial. Each surgical technique has some advantages and disadvantages, and the choice of operation should be made case by case, depending on the patient's condition, level of pathology, type of OPLL, and the surgeon's experience. In this paper, the authors attempt to review the incidence, pathology, pathogenesis, natural history, clinical presentation, classification, radiological evaluation, and management of OPLL. *(DOI: 10.3171/2010.11.FOCUS10276)*

Key Words • **ossification** • **posterior longitudinal ligament** • **spine**

Ossification of the posterior longitudinal ligament is a condition of abnormal calcification of the posterior longitudinal ligament. The most common location is at the cervical spine region. The spinal cord can be compressed by this lesion, which can cause neurological deficits. The treatment of choice for patients with symptomatic OPLL is surgery to relieve spinal cord compression. However, there are many unresolved controversies concerning OPLL: the exact pathogenesis and natural history of OPLL are still unclear, there is no standard treatment for patients with asymptomatic OPLL, and there is disagreement about the best surgical approach for OPLL surgery. In this study, we review the current literature including the incidence, pathology, pathogenesis, natural history, clinical presentation, classification, radiological evaluation, and management of OPLL.

Abbreviations used in this paper: ACDF = anterior cervical discectomy and fusion; BMD = bone mineral density; BMP = bone morphogenetic protein; CSM = cervical spondylotic myelopathy; DISH = diffuse idiopathic skeletal hyperostosis; JOA = Japanese Orthopedic Association; OALL = ossification of the anterior longitudinal ligament; OLF = ossification of ligamentum flavum; OPLL = ossification of the posterior longitudinal ligament; TGF = transforming growth factor.

Methods

The PubMed databases were searched for publications from January 2000 through August 2010 using the MeSH terms "OPLL" and "ossification of posterior longitudinal ligament." The search was limited to articles in the English language. Related reference sections of recent articles were reviewed and pertinent articles identified. Full-texts manuscripts of all articles were obtained and reviewed. Radiographic images from the senior author's institution are also included.

Results

Incidence

The incidence of OPLL was reported by Tsuyama et al.[126] The incidence is 2.4% in Asian populations and 0.16% in non-Asian populations, with the highest rates in Japan. OPLL is twice as common in men as in women, and symptomatic OPLL usually presents in the 5th to 6th decade of life. Most studies of OPLL are reported from Asian countries, but anecdotal reports of OPLL cases in European countries also exist in the literature. Maiuri et al.[72] reported on 8 Italian patients with cervical spine stenosis due to OPLL.

OPLL has been reported to be associated with other musculoskeletal diseases such as DISH (or Forestier disease),[16,26,27,30,51,60,69,81,109] ankylosing spondylitis, and other spondyloarthropathies.[54,108] Resnick et al.[109] found OPLL in 50% of patients with DISH. In 2009, Kawabori et al.[51] reported a rare case of DISH with continuous-type OPLL at C2–4 that presented with cervical myelopathy from C-1 posterior tubercle impingement. Multilevel fusion of the subaxial cervical spine from OPLL caused hypermobility at C1–2 and may lead to ligamentous damage and subsequent C-1 posterior tubercle impingement. In Japanese cases reported by Tsuyama,[126] 2% also had ankylosing spondylitis. Tyrrell et al.[128] reported a case of OPLL in a patient with Down syndrome. A high incidence of OPLL (20%) has been reported by Matsunaga et al.[75] in patients with schizophrenia. The authors also reported OPLL in dizygotic twins with schizophrenia.

Pathology

OPLL is believed to form through endochondral ossification. McAfee et al.[81] described the histopathology of OPLL, which is composed largely of lamellar bone with mature Haversian canals. Ultrastructural study of the ligamentum flavum in patients with OPLL revealed atrophic elastic bundles with a 2-layer structure, disappearance of microfibrils, irregular alignment of collagen fibrils, and many extracellular plasma membrane-invested particles that resemble matrix vesicles.[90]

Pathogenesis

The pathogenesis of OPLL remains poorly understood. There is some evidence that ligament cells from patients with OPLL have osteoblast-like characteristics. Ishida and Kawai[41] studied cell lines from nonossified sites in patients with OPLL and found that they have high alkaline phosphatase activity, response to calcitonin, and calcitriol. Parathyroid hormone and dinoprostone can also stimulate an increase in cyclic adenosine monophosphate in these cell lines. There are many proposed genetic, hormonal, environmental, and lifestyle factors that relate to pathogenesis and progression of OPLL, but most of these theories are still controversial.

An immunohistochemical study of extracellular matrix components in the twy (tiptoe walking Yoshimura) mouse, an animal model for the study of OPLL, shows that degeneration and subsequent herniation of the nucleus pulposus is the potent regional factor that initiates OPLL formation. At 14 weeks, the discs herniated into the thickened posterior longitudinal ligament, then cartilaginous tissue appeared in the posterior longitudinal ligament as if to repair the intervertebral disc degeneration.[35]

Hypertrophy of the posterior longitudinal ligament is believed to be an early stage of OPLL. Histological and biochemical study of hypertrophy of the posterior longitudinal ligament shows hyalinoid degeneration, proliferation of chondrocytes and fibroblast-like spindle cells, infiltration of vessels and small ossification, and staining by BMP, TGF-β, and proliferating cell nuclear antigen, which are all similar to OPLL.[112]

Genetic Factors. Patients with OPLL are most commonly found in Asian populations, so genetic factors are considered to be a factor in OPLL development. Tanabe et al.[119] reported a case of OPLL in the thoracic spine; this patient had a brother with the same disease, also in the thoracic spine. Genetic factors are believed to contribute to OPLL development. Many collagen genes have been studied, including human collagen α2 gene *(COL11A2)*. Koga et al.[61] showed that this gene, located on chromosome 6p close to the human leukocyte antigen region, is strongly associated with OPLL. Retaining exon 7 together with removal of exon 6 observed in intron 6(-4A) in the *COL11A2* gene could play a protective role in the ectopic ossification process.[70] Maeda et al.[71] reported a sex-specific association of the *COL11A2* haplotype with OPLL in male patients. However, a recent study by Horikoshi et al.[38] could not reproduce the association between this gene and OPLL.

A single nucleotide polymorphism in intron 32(-29) in the collagen 6A1 gene *(COL6A1)* on chromosome 21q22.3 is associated with OPLL.[120,125] Kong et al.[64] studied the Han Chinese population and also found a significant association of *COL6A1* with OPLL. They demonstrated that 3 single nucleotide polymorphisms, including promoter (-572T), intron 32(-29), and intron 33(+20), are significantly associated with OPLL and OLF.

Okawa et al.[101,102] identified a mutation of the *NPPS* gene as the cause of tiptoe walking condition in the twy mouse. Nucleotide pyrophosphatase is a membrane-bound glycoprotein believed to produce inorganic pyrophosphate, a major inhibitor of calcification and mineralization. Some evidence suggests that *NPPS* gene mutation is associated with OPLL development.[65,91] In a later study by Tahara et al.,[114] the authors showed that *NPPS* and leptin receptor genes do not promote an increased susceptibility to OPLL, but are associated with the extent of heterotopic ossification. Horikoshi et al.[38] also could not demonstrate the association between the *NPPS* gene and OPLL.

Human retinoic X receptor β,[94] TGF3,[38] BMP4,[23] FF variant of vitamin D receptor gene,[58] promyelotic leukemia zinc finger gene, and Runt-related transcription factor 2 (*RUNX2*)[40,57,68] are linked to OPLL with anecdotal evidence. Angiopoietin-1, a downstream of *RUNX2*, may play an important role in ectopic calcification.[57]

Hormonal Factors. Bone morphogenetic protein, a substance with the ability to induce ectopic bone and cartilage formation, is believed to play an important role in the pathogenesis of OPLL. Bone morphogenetic protein receptors increased in ossified ligament tissue in patients with OPLL.[141] Bone morphogenetic protein-2 stimulates differentiation of ligament cells in patients with OPLL and induces ossification by increasing alkaline phosphatase activity and stimulating DNA and procollagen Type I carboxyl-terminal peptide synthesis.[63] The TC and CC genotypes in exon 3(-726) T/C in the *BMP-2* gene of male Han Chinese patients have a genetic susceptibility to OPLL in the cervical spine.[130] Wang et al.[129] demonstrated an association between the Ser37Ala (T/G) polymorphism and the occurrence of OPLL. They also showed significant linkage between the Ser87Ser (A/G) polymorphism and the extent of cervical ossification.

Transforming growth factor-β has been studied in the literature. The T869→C polymorphism of the *TGF-β1* gene is a genetic determinant of a predisposition to OPLL.[48] In a later study, Kawaguchi et al.[52] demonstrated that the *TGF-β1* polymorphism is not associated with OPLL development, but rather a factor related to the extent of ossification. Patients with the C allele frequently have OPLL in the cervical, thoracic, and/or lumbar spine.

In a study of serum biomarkers for OPLL, Eun et al.[20] showed that 8 biomarkers were upregulated in the sera of OPLL patients: 1) PRO2675, 2) human serum albumin in a complex with myristic acid and triiodobenzoic acid, 3) an unknown protein, 4) chain B of the crystal structure of deoxy-human hemoglobin β6, 5) proapolipoprotein, 6) albumin protein, 7) retinol binding protein, and 8) chain A of human serum albumin mutant R218h complexed with thyroxine, whereas α_1-microglobulin/bikunin precursor was downregulated. Matsui et al.[73] demonstrated increased serum procollagen Type I carboxyl-terminal peptide and intact osteocalcin in patients with OPLL. These markers also increased in concert with the progression of OPLL without statistical significance. Cerebrospinal fluid analysis in patients with OPLL and CSM showed high levels of interleukin-8.[42]

Non–insulin-dependent diabetes mellitus has been suggested as a risk factor of OPLL.[59] Li et al.[67] showed increased expression of insulin receptors, proliferation of rat spinal ligament cells, and induction of osteogenic differentiation through the PI3-K/Akt pathway induced by insulin. Insulin-like growth factor-I induces histological change and elevation of alkaline phosphatase activity in OPLL cell lines much more than in non-OPLL cells.[25]

OPLL is a disease that results in increased bone formation in ligament tissue, and there is some evidence showing correlation between OPLL and increased overall BMD. In several studies, patients with OPLL had higher BMD than the non-OPLL controls,[34,73,134] but BMD may decrease in patients with advancing OPLL.[87] Aita et al.[2] studied histomorphometry of the iliac bone in patients with OPLL and found no significant differences between OPLL and control groups. They speculated that stage of OPLL and disuse atrophy may be the responsible factors.

High serum levels of menatetrenone in male patients[133] and activin in male and female patients[141] have been investigated and correlated with OPLL formation. Tumor necrosis factor α–stimulated gene-6 suppresses osteoblastic differentiation induced by BMP-2 and osteogenic differentiation medium.[124] The author of this study suggested that this is a plausible target for therapeutic intervention in OPLL.

Environmental Factors. Mechanical stress in ligaments of the spine has been investigated as a cause of OPLL development and progression.[22] Prostacyclin synthase levels in ligament cells from OPLL patients have been shown to be elevated after applying mechanical stress and induced osteogenic differentiation via the PGI_2/cyclic adenosine monophosphate pathway.[97] Mechanical stress also induces mRNA expression of alkaline phosphatase, osteopontin, BMP-2, BMP-4, BMP receptors,[121] and mRNA expression of Cbfa1, Type I collagen, osteocalcin, integrin β1,[43] and endothelin-1.[47] The P2Y1 purinoceptor subtypes, intensively expressed in OPLL cells, responded to mechanical stress–induced extracellular adenosine triphosphate, which stimulated OPLL progression.[110]

Frequent consumption of pickles, nondaily consumers of rice,[100] family history of myocardial infarction, high body mass index at age 40, long working hours, and working night shifts[58] were associated with increased risk of OPLL. On the other hand, frequent consumption of chicken and soy products[100] and good sleeping habits (6–8 hours/night) in the prime of life may decrease the risk of OPLL.[131]

Natural History

Symptomatic OPLL is usually detected in elderly patients. There have been several studies that investigated the natural history of OPLL. Chiba et al.[10] described computer-assisted measurement of the size of OPLL. They reported excellent inter- and intraobserver reliability of this method with 98% accuracy for detecting OPLL progression. Thereafter, they applied this method to 131 patients with cervical OPLL who underwent posterior decompression at 13 institutions. The rate of OPLL progression was 56.5% at 2 years and was more common in younger patients with continuous- and mixed-type OPLL.[12] Murakami et al.[89] reported a case of cervical OPLL in a 67-year-old man with more than 26 years follow-up. They found that the rate of OPLL progression varied during this period. The rate of progression was 2.2, 8.8, and 2.0 mm/year from 1–4, 4–8, and 8–10 years after the first visit, respectively. After 10 years, there was no evidence of OPLL progression.

Hori et al.[36,37] investigated the progression of OPLL in both longitudinal axis and thickness in 55 patients with at least a 5-year follow-up period. They found that progression was marked in younger patients with continuous- or mixed-type OPLL, consistent with the results of Chiba et al.[12] According to progression on the longitudinal axis, the patients with continuous- or mixed-type OPLL were classified according to age. The patients 40–49 years of age showed peak progression at greater than 1 year, whereas the patients older than 50 showed peak progression during the first year of follow-up. The authors suggested that OPLL might show a rapid progression in the 4th decade of life and that the progression gradually decreases in the 5th or 6th decade. For progression in thickness, the other factor that influences the progression is C-3 involvement; the progression of OPLL was frequently observed at levels C2–4.

Long-term follow-up of 450 patients with OPLL was reported by Matsunaga et al.[77] in 2004. All patients were followed-up for at least 10 years, with a mean follow-up period of 17.6 years. Only 17% of patients without myelopathy at the first visit developed myelopathy during the follow-up period. The myelopathy-free rate in these patients was 71% after 30 years according to Kaplan-Meier analysis. The researchers suggested that prophylactic surgery in patients without symptoms of myelopathy is unnecessary. This same group of authors[76] studied predictors for development of myelopathy in 156 patients with

OPLL from 16 spine institutes with an average follow-up period of 10.3 years. They found that both static and dynamic factors were related to the development of myelopathy. All 39 patients with more than 60% spinal canal stenosis on plain radiography developed myelopathy. Range of motion was significantly greater in patients with myelopathy. Of 15 patients with trauma-induced myelopathy, 13 had mixed-type and 2 had segmental-type OPLL.

Clinical Presentation

Clinical presentation of OPLL depends on the size of the OPLL, spinal canal diameter, and range of motion of the spine. Some patients have no symptoms, but others present with neurological deficits such as radiculopathy, myelopathy, and in severe cases, bowel and bladder symptoms. The onset of symptoms is usually gradual, but there are also some reports of patients with trauma-induced sudden onset myelopathy.

Classification

The Investigation Committee on OPLL of the Japanese Ministry of Public Health and Welfare described the OPLL classification that is most widely used in the literature.[126] Based on lateral plain radiography, cervical OPLL can be classified into 4 types (Fig. 1): continuous, segmental, mixed, or circumscribed type. Continuous type is classified as a long lesion extending over several vertebral bodies. Segmental type is classified as one or several separate lesions behind the vertebral bodies. Mixed type is classified as a combination of continuous and segmental types. Circumscribed type is classified as the lesion mainly located posterior to a disc space.

Radiological Evaluation

Plain radiography is the simplest method for detecting OPLL but it has some limitations. Chang et al.[6] reported low inter- and intraobserver reliability of lateral radiography as a tool for OPLL classification, particularly for continuous-type OPLL. The inter- and intraobserver kappa values were only 0.51 and 0.67, respectively. They emphasized the importance of 2D or 3D reconstructed images to overcome this problem.

Computed tomography and/or myelography are useful tools for detecting and accurately locating OPLL. The exact dimensions and extent of cervical canal stenosis are precisely depicted on CT. Figure 2 shows CT scans of patients with OPLL. A mushroom or hill shape on an axial CT scan typifies OPLL, and a sharp radiolucent line between the posterior vertebral body and ossified ligament is a also characteristic feature.[113]

Anterior decompression of OPLL in patients with associated dural ossification is more harmful compared with those without dural ossification because the incidence of new neurological deficits and CSF leakage is higher. A CT scan can be useful for detection of dural ossification. Mizuno et al.[86] retrospectively reviewed the relationship between dural ossification and preoperative imaging. They found that bone window CT scans were the most useful method for detecting dural ossification, whereas MR imaging was ineffective in recognizing dural ossification. Of the 4 cervical OPLL types, the nonsegmental type was most likely to be associated with dural ossification. Hida et al.[31] classified bone window CT images to detect dural defect into 2 types: double- and single-layer sign. Single-layer sign was defined as a large focal mass of uniformly hyperdense OPLL. Double-layer sign was defined as anterior and posterior rims of hyperdense ossification separated by a central hypodense mass (the hypertrophied but nonossified posterior longitudinal ligament). Dural defects during surgery were detected in 10 of 12 patients with double-layer sign compared with only 1 of 9 patients with single-layer sign. Epstein[19] applied this classification to her patients and demonstrated a dural defect in 1 of 12 patients with single-layer sign and an irregular C angular configuration compared with 1 of 4 patients with double-layer sign. She concluded that double-layer sign is more pathognomonic than single-layer sign for dural penetration. Smooth-layer sign indicated a clean dural plane with a low incidence of dural defect.

Min et al.[84] studied 197 patients with cervical OPLL

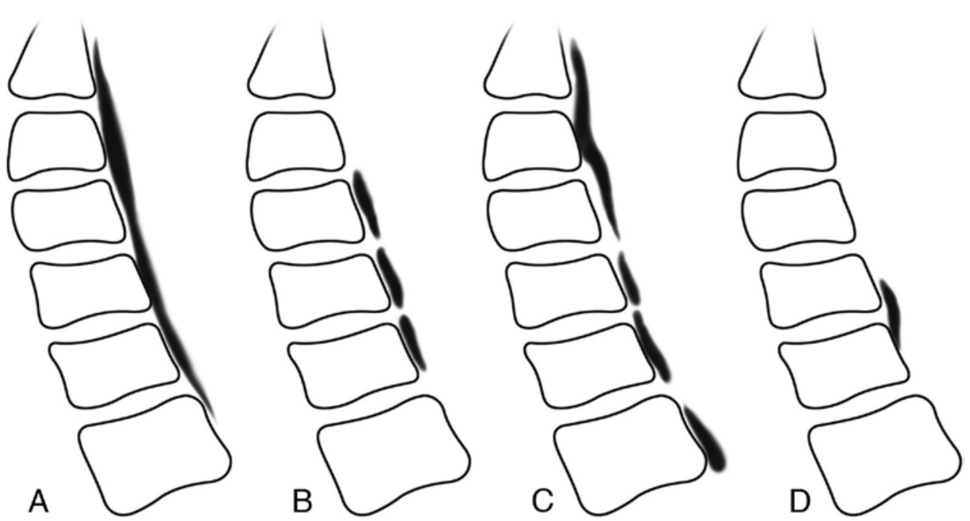

Fig. 1. Illustrations of the 4 types of OPLL: continuous **(A)**, segmental **(B)**, mixed **(C)**, and circumscribed **(D)**.

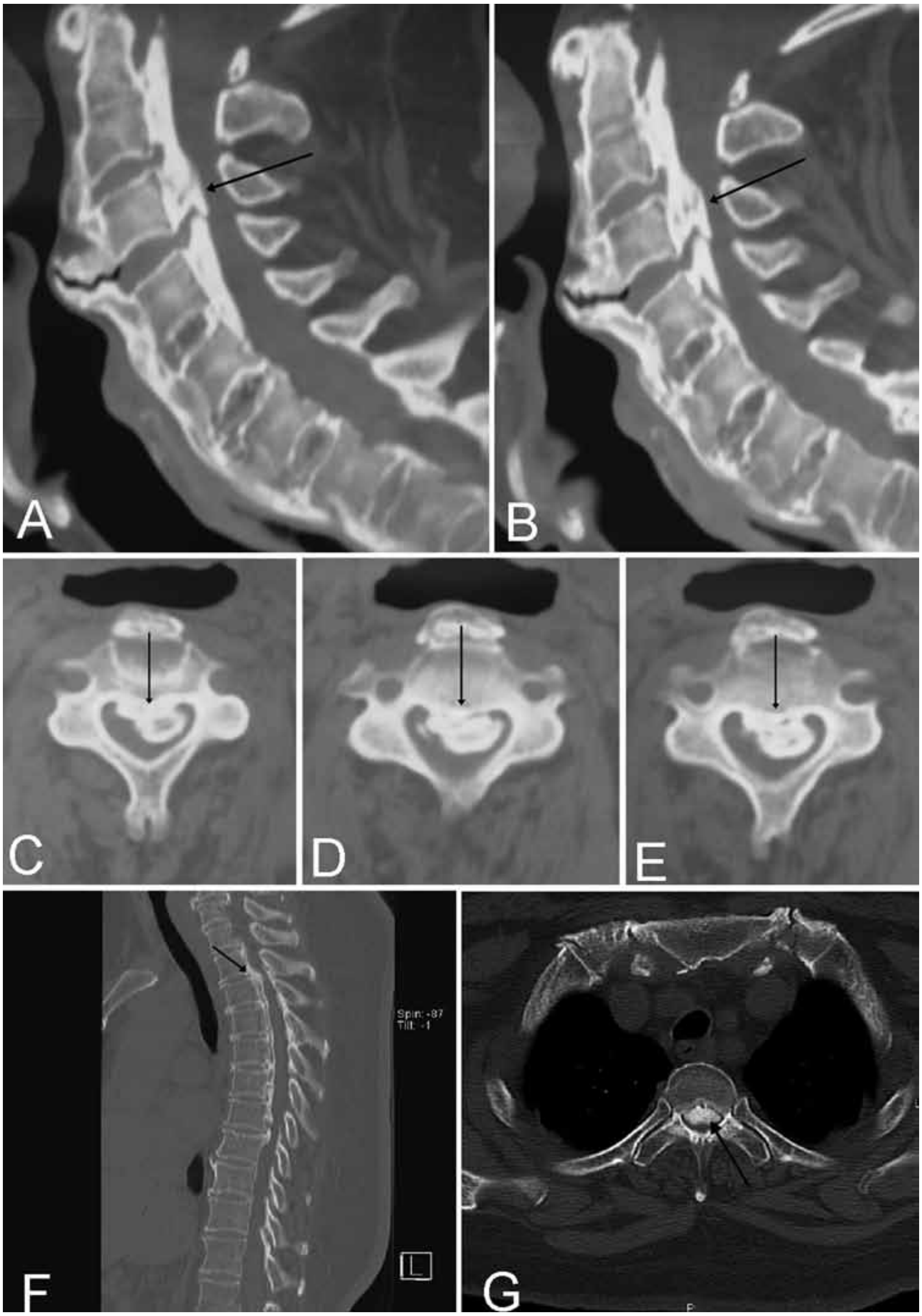

Fig. 2. Computed tomography scans showing OPLL in different locations. **A and B:** Sagittal reconstructed images show large OPLL at C2–5 *(arrow)*. **C–E:** Axial images of the cervical spine show a large OPLL occupying more than 50% of the spinal canal *(arrows)*. **F:** Sagittal reconstructed image of the thoracic spine shows a mixed-type OPLL. The spinal canal is narrowest at T2–3 *(arrow)*. **G:** Axial CT image shows large a OPLL occupying more than 80% of the spinal canal *(arrow)*.

who underwent anterior decompression and fusion. There were signs of dural penetration in 30.5% of patients. These signs were more common in nonsegmental OPLL. Dural defects were detected in 20 (52.6%) of 38 patients with double-layer sign compared with 3 (13.6%) of 22 patients with single-layer sign. They also demonstrated a positive correlation between thickness of the central hypodense mass and the possibility of a dural defect. Signs of dural ossification are even more common in thoracic OPLL. Min et al.[83] reported an 80% dural ossification rate in patients with thoracic OPLL. Dural defects were detected in 6 of 10 patients with double-layer sign and 3 of 6 patients with single-layer sign. Although most signs of dural ossification were detected in nonsegmental OPLL in the cervical spine, they were detected in both segmental and nonsegmental OPLL in the thoracic spine. The

TABLE 1: Correlation between CT images and dural defect in spinal OPLL

Authors & Year	Level of Spinal OPLL	Dural Defects
Hida et al., 1997	cervical	10/12 w/ double-layer sign; 1/9 w/ single-layer sign
Epstein, 2001	cervical	1/4 w/ double-layer sign; 1/12 w/ single-layer sign w/ irregular C shape
Min et al., 2007	cervical	20/38 w/ double-layer sign; 3/22 w/ single-layer sign
Min et al., 2007	thoracic	6/10 w/ double-layer sign; 3/6 w/ single-layer sign

studies that correlated CT images and dural defect are summarized in Table 1.

Magnetic resonance imaging is inadequate for diagnosing small ossified lesions in the spinal canal,[28] but is a sufficiently sensitive tool for detecting soft tissue abnormalities. A characteristic OPLL, signal hypointensity on both T1- and T2-weighted MR imaging, is shown in Fig. 3. In a study by Koyanagi et al.,[66] associated disc protrusion was found at maximum compression level in 60% of patients with cervical OPLL. Its presence is more common in segmental OPLL, with an incidence of 81%. The authors concluded that MR imaging is helpful for determining the actual level of spinal cord compression and for suggesting the optimal method of surgical treatment. Signal hyperintensity T2-weighted changes of the spinal cord are correlated with more severe neurological deficit.[66] Yagi et al.[132] demonstrated a positive correlation between postoperative expansion of the high signal intensity area of the spinal cord and poor neurological outcomes of patients with cervical OPLL. A risk factor for the expansion of the high signal intensity area was spinal instability.

The cross-sectional shape of the spinal cord at the level of maximum compression was classified as boomerang, teardrop, or trianglar by Matsuyama et al.[78] These investigators found that the recovery rate of patients with the triangular shape was worst, whereas the teardrop shape was best, and the boomerang shape was intermediate. After surgical intervention, triangular shape spinal cords showed the least expansion, which correlated with poor outcome.

Concurrent OPLL at multiple locations has been described. In a study of 68 patients with cervical OPLL by Park et al.,[105] thoracic tandem ossification was found in 23 cases (33.8%); 21 had thoracic OLF, 5 had thoracic OPLL, and 3 had both combined. The authors suggested performing simultaneous thoracic spine studies in patients undergoing cervical OPLL surgery.

Management

The mainstay treatment of OPLL is surgical decompression. Although there is a lot of research about OPLL formation and progression, such as genetic studies, growth factors, cytokines, and environmental factors, effective medical treatment for OPLL is still lacking. Most are only symptomatic treatments such as pain medication, topical agents, antiinflammatory drugs, antidepressants, anticonvulsants, nonsteroidal antiinflammatory drugs, and opioids.

Surgical Management of Cervical OPLL. The most common location of OPLL is at the cervical spine. There are several reports of surgical management of cervical OPLL with options including the posterior approach (laminectomy, laminectomy with fusion, laminoplasty, and open-door and double-door laminoplasty), the ante-

Fig. 3. Magnetic resonance imaging showing OPLL and signal hypointensity. **A:** Sagittal T2-weighted image of cervical spine shows signal hypointensity of OPLL most prominent at C3–4 *(arrow)*. **B–E:** Sagittal **(B and C)** and axial **(D and E)** T1- **(B and D)** and T2-weighted **(C and E)** imaging of the thoracic spine showing characteristic signal hypointensity of OPLL with severe spinal cord compression at T2–3 *(arrows)*.

TABLE 2: Summary of advantages and disadvantages of surgical procedures for cervical OPLL*

Surgical Procedure	Advantages	Disadvantages
laminectomy	simple, less operative time & blood loss, low immediate complication	risk of OPLL progression; risk of kyphotic deformity, spinal instability, & neurological deterioration due to scar tissue formation; ineffectiveness in cases w/ severe kyphotic deformity & large OPLL
laminectomy w/ fusion	relatively simple, low complication rate, decreased risk of kyphotic deformity & spinal instability	risk of OPLL progression, ineffectiveness in cases w/ severe kyphotic deformity & large OPLL
laminoplasty	relatively simple, low complication rate compared w/ ant approach, decreased risk of kyphotic deformity, spinal instability & neurological deterioration due to scar tissue formation compared w/ laminectomy alone	risk of OPLL progression, limited effectiveness in cases w/ severe kyphotic deformity & large OPLL
ant approach	direct ant decompression of OPLL	high complication rate (particularly neurological deterioration, graft complication, & CSF leakage), limitation in cases w/ long segment OPLL or OPLL involving C-2
combined ant & pst approach	direct ant decompression of OPLL	more op time & blood loss

* ant = anterior; pst = posterior.

rior approach (ACDF, anterior cervical corpectomy with fusion, open-window corpectomy, oblique corpectomy, skip corpectomy, and anterior decompression via a transvertebral approach), and the combined anterior and posterior approach. The advantages and disadvantages of each approach are summarized in Table 2.

Posterior Approach. Laminectomy is the simplest procedure used to decompress the spinal cord from the posterior approach. Progression of kyphotic deformity after cervical laminectomy for OPLL has been reported, but its presence did not affect neurological outcomes of the patients.[13,50] OPLL progression after laminectomy also rarely caused neurological deterioration. In the report from Kato et al.,[50] OPLL progression was noted in 70% of patients, but it was clearly the cause of neurological deterioration in only 1 of them. A rare case[98] of incarcerated spinal cord herniation with neurological deterioration after laminectomy in a patient with combined OPLL and OLF of the cervical spine has also been reported in the literature.

Anderson et al.[4] found that laminectomy with fusion decreases the risk of postoperative kyphotic deformity and spinal instability compared with laminectomy alone, but functional improvement is similar to laminectomy or laminoplasty. This paper contains a description of several posterior cervical fusion techniques and the lateral mass and pedicle screws that are used by many spine surgeons. One drawback of these techniques is neurovascular injury. Hasegawa et al.[29] reported higher operative duration and intraoperative blood loss in patients treated using pedicular screw fixation compared with those treated by laminoplasty. They concluded that there is no indication for cervical pedicular screw fixation in patients with typical OPLL and CSM because of the potential risk of vertebral artery or nerve injury. Recently, Epstein[18] reported good outcomes with spinous process wiring techniques. Fusion rate was 100% and complications were low, including 2 transient root injuries, 2 wound infections, 1 wound breakdown, no spinal cord injuries, and no deaths. Nerve root palsy at C-5 after cervical laminectomy and posterior fixation is correlated with increased cervical lordosis[7,9] and the main pathogenic mechanism appears to be the tethering effect.

Laminoplasty has been used for decades for posterior decompression of the spinal canal in patients with cervical OPLL. The benefits of this technique compared with laminectomy are reduced risk of postoperative kyphotic deformity and neurological deficit from scar tissue formation. There are 2 techniques of laminoplasty: open-door and double-door (Fig. 4). However, both have some limitations, including restricted access to the hinged side in open-door laminoplasty, a potential for closing of the door,[17] axial neck pain, loss of range of motion of the cervical spine, risk of OPLL progression, and limited effectiveness in cases with severe kyphotic deformity and large OPLL.

There have been some modifications of the open-door technique to prevent closing of the door, including spacer insertion at the bone gap at the open side (bone graft from spinous process or hydroxyapatite spacer),[116] titanium miniplate fixation, and the TiMesh LP (Medtronic Sofamor Danek) miniplate system.[15] Adequate longitudinal and transverse decompression of the spinal canal should be achieved because unexpectedly rapid progression of OPLL has been reported.[122] Seichi et al.[111] used intraoperative ultrasonography to evaluate adequacy of spinal cord decompression after double-door laminoplasty. They found that OPLL maximal thickness > 7.2 mm was a cutoff value for insufficient decompression, but neurological outcomes at 2 years after surgery did not correlate with adequacy of decompression.

Hirabayashi et al.[33] compared the expansion ratio of the spinal canal and the increased inclination angle of the lamina between open-door and double-door laminoplasty. Open-door laminoplasty produced a significantly larger expansion ratio at C-6 than double-door laminoplasty. The increase of inclination angle of the lamina was significantly larger in double-door than in open-door laminoplasty. They proposed the surgical indications for open-door lami-

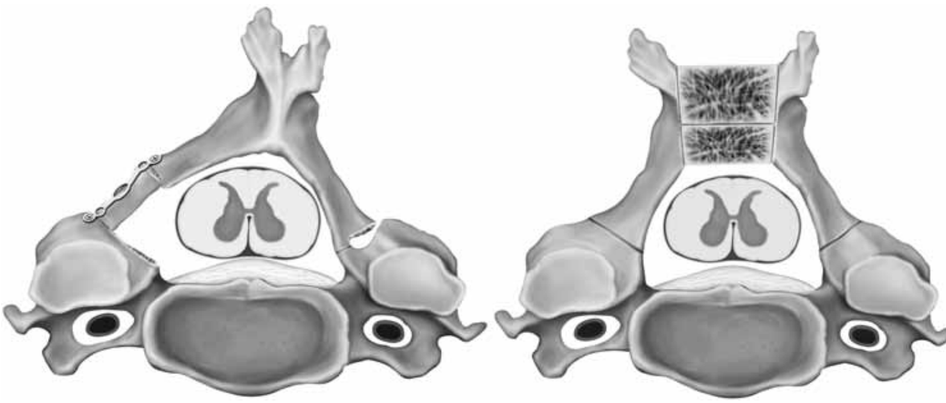

Fig. 4. Illustrations of open-door **(left)** and double-door **(right)** laminoplasty.

noplasty as CSM combined with hemilateral radiculopathy, large prominence of OPLL, and patients with a tiny spinous process who cannot undergo double-door laminoplasty. The indications for double-door laminoplasty include usual CSM, small and slight prominence of OPLL, CSM combined with bilateral radiculopathy, and cervical canal stenosis combined with instability necessitating posterior spinal instrumentation surgery.

Long-term results of open-door laminoplasty are summarized in Table 3. In studies with a long-term follow-up period (more than 5 years), the recovery rates varied from 47.9% to 63.1%.[11,21,44,45,96] Agrawal et al.[1] demonstrated the benefit of expansive laminoplasty even in patients with severe cervical myelopathy (Nurick Grade 3–5). All patients with a duration of symptoms less than 3 years, and 50% of patients with durations ranging from 3 to 6 years, improved after surgery.

Factors influencing surgical outcomes following laminoplasty included duration of myelopathy,[1,21,96] severity of myelopathy,[44,45,96] age,[21,44,45,96] preoperative kyphosis,[11] occupying ratio > 60%,[45] and hill-shaped ossification.[45] There are controversial results of some factors such as progression of OPLL and postoperative changes in cervical alignment.

The course of neurological changes following laminoplasty has been investigated.[11,95] Neurological function significantly improved after surgery, was maintained for 5 years, and then slightly declined after 5 years. Ogawa et al.[95] found that the degree of deterioration positively correlated with cervical range of motion, which is high in patients with segmental-type OPLL.

Postoperative cervical range of motion decreased after laminoplasty by approximately 32%[39,49] and did not correlate with postoperative axial neck pain. The loss of range of motion is time-dependent and plateaus by 18 months after surgery.[39]

Anterior Approach. As mentioned above, Koyanagi et al.[66] reported a high incidence of associated disc herniation in patients with cervical OPLL, and disc herniation was found at maximum compression level in 60% of patients. Anterior cervical discectomy with fusion is the procedure of choice for these patients. The recovery rate with this procedure ranges from 51% to 63.2%.[46,140] Tan et al.[118] reported on ACDF with an endoscopic approach in 5 patients with cervical OPLL. The patients' JOA scores and visual analog scale scores improved significantly. This technique has advantages in terms of cosmetic results, intraoperative visualization, and recovery course, but its application is limited to the C4–5 and C5–6 levels. At the higher levels, installation of the working channel can be blocked by the mandible. At the C6–7 level, there is a risk of damaging a thyroid vessel, as reported in 1 patient in this paper.[118] Multilevel OPLL is also a contraindication for this procedure.

Neurological improvement rates in anterior approaches to cervical OPLL are summarized in Table 4. Improvement rates varied from 51% to 71.7%. There are many varieties of techniques, bone grafts, and instrumentations for anterior approach surgery. Mizuno and Nakagawa[85] used 3 graft materials for this approach including iliac crest, vertebral body, and interbody fusion cages and found that vertebral body grafts were the most fragile. Rajshekhar and Kumar[107] performed corpectomies in poor-grade patients (Nurick Grade 4 and 5), and neuro-

TABLE 3: Long-term results of open-door laminoplasty for OPLL*

Authors & Year	No. of Patients	Minimum FU (yrs)	Mean Neurological Recovery Rate (%) at Last FU	Notes
Fujimura et al., 1998	55	5	49.3	duration of myelopathy was a factor indicating poor results
Iwasaki et al., 2002	64	10	60.0	progression of OPLL required additional op in 1 patient
Ogawa et al., 2004	72	5	63.1	progression of OPLL caused myelopathy in 2 patients
Chiba et al., 2006	80	10	47.9	OPLL patients w/ preoperative kyphosis had lower recovery rates
Iwasaki et al., 2007	66	5	58.0	outcome was significantly poorer in patients w/ occupying ratio >60%

* FU = follow-up.

TABLE 4: Summary of outcomes for anterior approach surgery in cervical OPLL

Study	No. of Patients	Mean Improvement Rate	Notes
Mizuno & Nakagawa, 2001	107	not described	89% excellent or good outcome
Onari et al., 2001	30	not described	study in patients who underwent ant interbody fusion w/o decompression; 24 patients improved in functional score
Goel & Pareikh, 2005	4	not described	study in patients who underwent oblique corpectomy; all patients showed clinical improvement
Rajshekhar & Kumar, 2005	12	not described	study in poor-grade patients (Nurick Grades 4 & 5); 76% improvement in Nurick grade
Nakase et al., 2006	12	67.4%	none available
Chacko & Daniel, 2007	3	not described	study in patients w/ combined OALL & OPLL who underwent oblique corpectomy; all patients showed clinical improvement
Iwasaki et al., 2007[46]	27	51%	study in patients w/ OPLL who underwent ant decompression & fusion
Chen et al., 2009	19	63.2%	study in patients w/ severe OPLL w/ preop CT scans showed narrowing rate 50–78%
Kim et al., 2009	17	71.7%	ant fusion w/ autologous bone grafts from vertebral bodies & bioabsorptive screws (Williams-Isu method)
Ozer et al., 2009	15	mean JOA score improved from 9.0 to 12.7	study in patients who underwent open-window corpectomy
Dalbayrak et al., 2010	29	mean JOA score improved from 13.44 to 16.16	study in patients w/ CSM or OPLL who underwent skip corpectomy

logical improvement was achieved in 76% of patients. They concluded that early decompressive surgery should be offered to poor-grade patients.

Onari et al.[103] described long-term (mean 14.7 years) follow-up results of anterior interbody fusion without decompression in patients with cervical OPLL. Twenty-four of the 30 patients improved after surgery. These investigators found that this procedure was more effective for the patients with segmental or nodular type OPLL than for those with continuous or mixed type. These data indicate that a dynamic factor is an important factor contributing to myelopathy in patients with cervical OPLL.

The open window corpectomy technique has been described in the literature. This technique creates a more stable construct with 3-point fixation and offers better load sharing among implants and healthy vertebrae. Ozer et al.[104] reported satisfactory clinical and radiological outcomes in patients with cervical OPLL after using this technique.

Oblique corpectomy preserves the ventral half of the vertebral body, so fusion and stabilization are not required. Anecdotal reports of using the oblique corpectomy technique for cervical OPLL exist in the literature, including Goel and Pareikh,[24] who reported 4 cases successfully treated with this technique. Wide exposure for resection of OPLL was achieved and stability of the spine was also preserved. Chacko and Daniel[5] applied this technique in 3 patients with combined OALL and OPLL. All patients showed clinical improvement. Asymptomatic OALL provided an intrinsic stability to the spine and was preserved in all patients. Intraoperative ultrasonography provided real-time imaging during surgery. Moses et al.[88] evaluated the accuracy of intraoperative ultrasonography in patients who underwent oblique corpectomy. They concluded that it is helpful in identifying the vertebral artery and determining the trajectory of approach, but there are limitations in OPLL cases due to artifacts from residual ossification.

The skip corpectomy technique (C-4 and C-6 corpectomy with preservation of C-5 vertebral body) was reported by Dalbayrak et al.[14] in 29 patients with multilevel CSM and cervical OPLL. The mean JOA score improved from 13.44 to 16.16 after surgery. There was only 1 case with complications from instrumentation (C-7 screw pull-out). The preservation of the C-5 vertebral body improved screw purchase and strengthened the construct.

A wide transvertebral approach and a ceramic insertion for patients with cervical degenerative disease were reported by Kim et al.[55] The advantage of this technique is preservation of the intervertebral disc, so movement of the spine is retained. The successful outcomes were achieved in patients with segmental-type OPLL. Because of the narrow visual field, this approach should not be used in patients with segmental instability, continuous or combined OPLL, and kyphosis.

Park et al.[106] described a prevascular extraoral retropharyngeal approach to the upper cervical spine, including a case of C2–4 OPLL. They reported that this approach is relatively safe. In a series of 15 patients, there was only 1 permanent and 2 transient dysphagia cases. There were no complications related to the marginal branch of the facial nerve or submandibular gland.

Surgical Treatment of Thoracic OPLL. The surgical results of thoracic OPLL are poorer than those of cervical OPLL. There are several factors that limit the effectiveness of thoracic OPLL decompression:[99,142] 1) natural kyphosis of the thoracic spine restricts the backward shift of the spinal cord after posterior decompression; 2) the thoracic segment of the spinal cord is relatively avascular compared with the cervical segment, therefore it is more vulnerable to ischemic injury during surgical manipulation; and 3) the ribcage restricts the surgical approaches to this area of the spine.

Surgical options for treatment of thoracic OPLL include posterior decompressive laminectomy or laminoplasty, posterior decompression and fusion, anterior decompression through an anterior approach, circumspinal decompression through a posterior approach, and 2-stage posterior and anterior decompression.[115] Posterior decompressive laminectomy is indirect and the simplest method for thoracic OPLL decompression, but postoperative paraparesis is the main drawback of this technique. Thoracic laminectomy causes disruption of the posterior tension band of the spine, which may lead to instability and neurological deterioration. Two cases have been reported of patients with thoracic OPLL who underwent laminectomy and suffered postoperative neurological deterioration.[135,138] Both patients underwent reoperation with posterior instrumented fusion and neurological functions gradually improved. The authors recommended simultaneous posterior instrumented fusion after laminectomy for thoracic OPLL. Nakanishi et al.[92] demonstrated a case of extensive cervicothoracic OPLL in which the patient underwent thoracic laminectomy with electrophysiological monitoring of the spinal cord evoked potential. The amplitude of evoked potential decreased after laminectomy, but recovered after posterior instrumented fusion. This finding emphasizes the importance of a dynamic factor and progression of kyphosis as the causes of neurological deterioration after laminectomy. In the study of factors related to outcomes of thoracic OPLL surgery, Matsumoto et al.[74] also recommended instrumented fusion after posterior decompression. Beak-type OPLL has higher risk of neurological deterioration after posterior approach surgery than flat-type OPLL.[80] Beak-type and flat-type OPLL are shown in Fig. 5.

Komagata et al.[62] studied the effectiveness of open-door laminoplasty in 13 patients with myelopathy from cervicothoracic OPLL with an average follow-up period of 75 months. According to the Hirabayashi method, the mean recovery rate was 54.5% without restenosis of the opened lamina and marked progression of kyphosis, but there were 2 cases of transient motor paralysis of both legs after the operation. A multiinstitutional study by Matsumoto et al.[74] showed that laminoplasty can be used safely to treat thoracic OPLL at the nonkyphotic upper thoracic spine (T1–4).

Posterior decompression with fusion generally has lower complication rates and neurological deterioration compared with both posterior decompression alone and OPLL extirpation. Yamazaki et al.[136] treated patients with thoracic OPLL by 1 of 3 approaches: posterior decompression alone (18 patients), posterior decompression and fusion (17 patients), and OPLL extirpation (16 patients). Three patients who underwent posterior decompression alone and 3 patients who underwent OPLL extirpation developed postoperative paralysis. Seven patients in the posterior decompression only group developed late neurological deterioration. There were 8 patients with CSF leakage and 2 patients with hydrothorax in the OPLL extirpation group. There were no cases of postoperative paralysis or late neurological deterioration in patients who underwent posterior decompression and fusion. Recovery of neurological function after posterior decompression and fusion is another challenge because the natural curve of the thoracic spine is kyphosis and posterior decompression may be ineffective. Yamazaki et al.[137] performed posterior decompression with in situ instrumented fusion in 24 patients with thoracic OPLL. The mean follow-up period was 4 years and 5 months, the mean recovery rate was 58.1%, and the median time to point of maximal recovery was 9 months. Only 1 patient developed transient paralysis. Despite persistent impingement of the spinal cord by OPLL, considerable neurological improvement is expected with this technique and takes about 9 months before reaching maximal recovery.

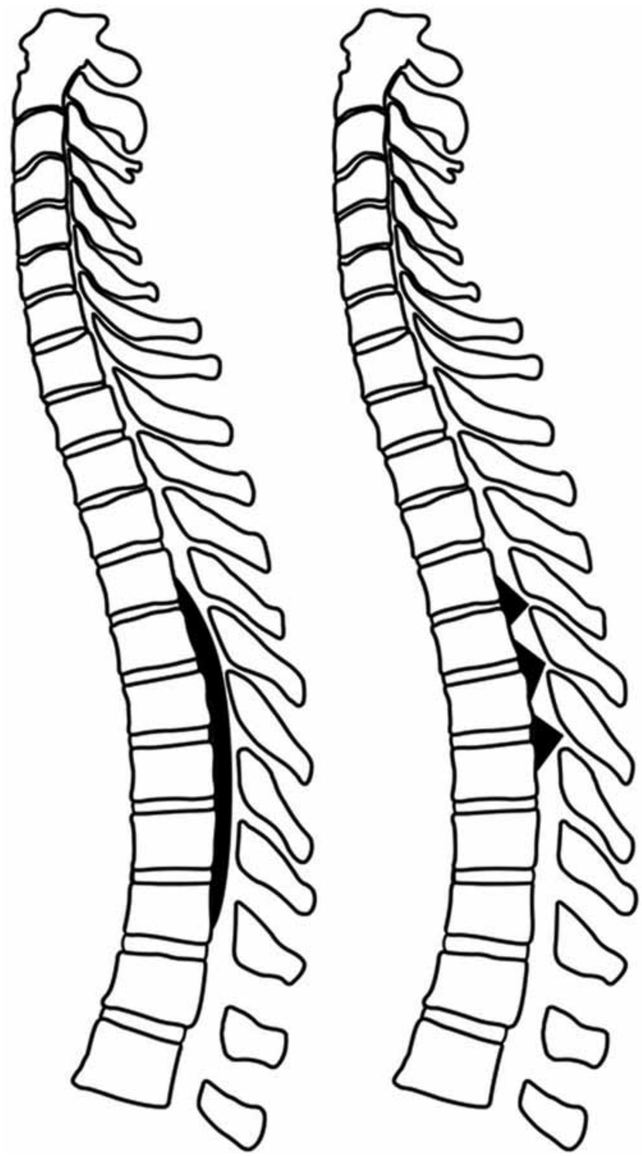

Fig. 5. Illustrations of flat-type **(left)** and beak-type **(right)** thoracic OPLL.

Posterior decompression with kyphosis correction has been studied. The recovery rate varied from 56% to 68%.[79,143] Zhang et al.[143] performed posterior decompression with 5°–15° kyphosis correction with instrumented fusion in 11 patients. Postoperative MR imaging showed backward shift of the spinal cord and complete decompression in all cases without aggravated myelopathy. Matsuyama et al.[79] used intraoperative ultrasonography to evaluate backward shift of the spinal cord and intraoperative compound muscle action potential to determine correlation with the final outcomes. There was no significant difference in recovery rate between adequate and inadequate decompression detected by ultrasonography, but patients with decreased compound muscle action potential had significantly poorer recovery rates.

Tokuhashi et al.[123] tried to determine the critical ossification-kyphosis angle that affects surgical outcome in patients who underwent posterior decompression of thoracic OPLL. At the decompression site, 23° is the critical cut-off point. All patients with an ossification-kyphosis angle > 23° had no echo-free space detected by intraoperative ultrasonography, whereas all patients with < 23° had echo-free space.

The anterior approach to OPLL resection has the benefit of direct OPLL removal, but it is technically demanding and the surgical results are poor, particularly in patients who already had severe spinal cord compression before surgery. In 2008, Min et al.[82] reported high rates of complications of anterior approach decompression in 19 patients with thoracic OPLL. Two patients (10.5%) developed neurological deterioration and 6 patients (31.6%) developed CSF leakage. They also demonstrated that poor outcomes of this approach were associated with poor preoperative JOA scores and immediate postoperative neurological deterioration.

The largest benefit of circumspinal decompression through the posterior approach is immediate anterior and posterior decompression and/or stabilization with only 1 operation. Yang et al.[139] reported satisfactory outcomes in a case with T10–11 OPLL surgically treated using this technique. Takahata et al.[115] reported on 30 patients who underwent this type of surgery with a mean follow-up period of 8 years. The JOA score improved in 24 patients (80%). Surgical complications included 40% with a dural tear, 10% with a deep infection, and 33% with postoperative neurological deterioration. Patients who underwent decompression of 5 or more vertebral levels had poorer outcomes.

Anatomical factors inhibiting posterior shift of the spinal cord after posterior decompression were described by Tsuzuki et al.[127] Longitudinal factors are anterior pulling effects of spinal cord segments above and below OPLL and restraining effects of dorsal dura. These factors can be eliminated by extensive cervicothoracic laminoplastic decompression with or without posterior longitudinal durotomy. Axial factors are anterior adhesion of dura to OPLL, dural ossification, and an anterior tethering effect of thoracic roots and dentate ligaments. These factors can be eliminated by root release with total laminofacetectomy and anterolateral dural release with or without OPLL resection. These investigators used staged posterior approach surgery to address these problems. The advantage of this staged operation is its safety, by preparing the severely compressed spinal cord by a first-stage operation before undergoing extensive manipulation by a second-stage surgery. The first stage consisted of extensive cervicothoracic laminoplastic decompression with or without posterior longitudinal durotomy to eliminate the longitudinal factors. If the decompression was inadequate, the axial factors were eliminated by the above mentioned techniques. In their series of 17 patients with a mean follow-up period of 42 months, neurological improvements were comparable to those from a successful anterior approach decompression. Only 1 case of late neurological deterioration was encountered, caused by an arachnoid cyst compressing the dorsal spinal cord.

A case report of circumspinal decompression was presented by Hioki et al.[32] Their case involved a woman with OPLL extending from C-3 to T-2 and OLF at T-2. She presented with paraparesis and numbness in both legs. After C3–T1 laminoplasty and T2–3 laminectomy, her neurological symptoms improved immediately. However, symptoms recurred after sitting or standing. A second operation was performed by anterior decompression, which improved her symptoms. Spinal instability or progression of kyphosis might have been the cause of neurological deterioration after the first surgery. Kawahara et al.[53] reported on a series of 11 patients who underwent circumspinal decompression with dekyphosis stabilization. The mean JOA score improved from 4.0 to 9.1 after the operation. There were 3 patients with CSF leakage and 1 patient with postoperative neurological deterioration due to spinal cord compression by the swelling of paravertebral muscle.

Surgical outcomes of patients with thoracic myelopathy were correlated with preoperative duration of symptoms and degree of myelopathy. Patients with shorter duration of symptoms and milder myelopathy experienced better surgical outcomes.[3] To date, there are no definitive guidelines for surgical treatment of thoracic OPLL. The choice of operation should be selected on a case-by-case basis, depending on the patient's condition, level of pathology, type of OPLL, and experience of the surgeon. Advantages and disadvantages of surgical procedures for thoracic OPLL are summarized in Table 5.

Surgical Management of Lumbar OPLL. There are some reports of surgical treatment of lumbar OPLL, but the definitive procedure has not been established. Most of the cases were approached posteriorly. Symptomatic lumbar OPLL is usually located at the upper lumbar spine because the posterior longitudinal ligament is broader at the upper level. Patients may present with cauda equina syndrome. Tamura et al.[117] reported on a patient with lumbar OPLL who underwent an operation using the anterior approach and another patient who underwent a combined anterior-posterior approach. The authors recommended combined surgery in patients with OPLLs occupying large parts of the spinal canal.

Conclusions

OPLL is a common cause of myelopathy in Asian

TABLE 5: Summary of advantages and disadvantages of surgical procedures for thoracic OPLL

Surgical Procedure	Advantages	Disadvantages
pst decompression	simple, less op time & blood loss	high risk for postop paralysis & late neurological deterioration
pst decompression w/ fusion	less op time & blood loss compared w/ ant or combined approach, low risk of postop paralysis	persistent ant impingement of spinal cord by OPLL
ant decompression through ant approach	direct removal of OPLL	high risk for postop paralysis & CSF leakage, technically demanding, more op time & blood loss
circumspinal decompression through pst approach	immediate ant & pst decompression & stabilization w/ only 1 op	technically demanding, more op time & blood loss
2-stage pst & ant decompression	complete ant & pst decompression	technically demanding, more op time & blood loss

populations. While the pathogenesis of this disease is still unclear, genetic, hormonal, environmental, and lifestyle factors are believed to cause OPLL formation and progression. Occurrence of myelopathy in patients with OPLL is related to both static and dynamic factors. Radiological evaluation of OPLL includes plain radiography, CT, and MR imaging. Preoperative images should be meticulously evaluated to detect the maximal area of spinal cord compression and dural calcification, which is rather accurately demonstrated by a double-layer sign on CT scans. Surgical management of OPLL remains controversial; each approach has its own limitations, advantages, and disadvantages. The choice of operation should be made on a case by case basis, depending on the patient's condition, level of pathology, and type of OPLL, as well as the experience of the surgeon. Most published papers in the literature are case series and retrospective studies, but more prospective studies and improvement of genetic studies will be key to more thoroughly understanding the pathogenesis, OPLL progression, myelopathy progression, and optimal treatment of patients with OPLL.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: Saetia, Cho. Acquisition of data: Saetia, Cho, Lee, SD Kim. Analysis and interpretation of data: Saetia, Cho, Lee. Drafting the article: Saetia, SD Kim. Critically revising the article: Saetia, SD Kim. Reviewed final version of the manuscript and approved it for submission: DH Kim. Administrative/technical/material support: Saetia, Lee. Study supervision: DH Kim.

Acknowlegements

The authors would like to thank Lara Richards, a medical editor, for her hard work and careful editing; without her help, this paper could not be successful. The authors also wish to thank Mijin Jung, a medical illustrator, for her help. All of the great illustrations in this paper were drawn and edited by her.

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Manuscript submitted November 15, 2010.

Accepted November 24, 2010.

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Neurosurg Focus 30 (3):E2, 2011

Conservative management of ossification of the posterior longitudinal ligament

A review

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Object. Ossification of the posterior longitudinal ligament (OPLL) can result in significant myelopathy. Surgical treatment for OPLL has been extensively documented in the literature, but less data exist on conservative management of this condition.

Methods. The authors conducted a systematic review to identify all reported cases of OPLL that were conservatively managed without surgery.

Results. The review yielded 11 published studies reporting on a total of 480 patients (range per study 1–359 patients) over a mean follow-up period of 14.6 years (range 0.4–26 years). Of these 480 patients, 348 (72.5%) were without myelopathy on initial presentation, whereas 76 patients (15.8%) had signs of myelopathy; in 56 cases (15.8%), the presence of myelopathy was not specified. The mean aggregate Japanese Orthopaedic Association score on presentation for 111 patients was 15.3. Data available for 330 patients who initially presented without myelopathy showed progression to myelopathy in 55 (16.7%), whereas the other 275 (83.3%) remained progression free. In the 76 patients presenting with myelopathy, 37 (48.7%) showed clinical progression, whereas 39 (51.5%) remained clinically unchanged or improved.

Conclusions. Patients who present without myelopathy have a high chance of remaining progression free. Those who already have signs of myelopathy at presentation may benefit from surgery due to a higher rate of progression over continued follow-up. *(DOI: 10.3171/2011.1.FOCUS10273)*

Key Words • **posterior longitudinal ligament** • **myelopathy** • **ossification** • **conservative management**

Ossification of the posterior longitudinal ligament is an ectopic ossification that can cause a significant amount of chronic pressure on the spinal cord, resulting in myelopathy. It generally occurs in patients over 40 years of age and is considered a rare entity if it appears earlier than the third decade of life.[32] The frequency of OPLL has varied between 0.8% and 3.2%.[17]

Managing OPLL can involve either surgical or conservative treatments. Patients with severe progressive myelopathy due to OPLL have generally been considered definitive candidates for surgical treatment.[35] Current indications for surgical management of patients with OPLL include severe progressive myelopathy and MR imaging evidence of increasing cord edema.[6] Several factors found to correlate with progression of OPLL-induced myelopathy can also be used as indications for surgical management. These include a C1–7 range of motion greater than 35°, segmental-type OPLL, and the presence of high signal intensity changes in the spinal cord on T2-weighted MR images.[35] Surgical therapy for OPLL includes either direct removal of the ossified mass via an anterior approach or decompression via a posterior approach.[32] Patients who have a segmental type of OPLL will benefit more from an anterior approach.[1,18,33] Those with extensive OPLL affecting more than 3 levels of the spine will benefit more from a posterior approach and laminoplasty.[32]

When patients present without myelopathy or with only mild myelopathic signs and symptoms, the question arises as to optimal subsequent management. Current suggested indications for conservative management of patients with OPLL include minimal neurological

Abbreviations used in this paper: JOA = Japanese Orthopaedic Association; OPLL = ossification of the posterior longitudinal ligament.

symptoms or significant medical risk factors for surgery. Patients with irreversible neurological deficits, evidenced by findings of myelomalacia on MR imaging and atrophy on clinical examination, should also be considered for nonsurgical management.[6] Conservative treatment can involve regular clinical follow-up, application of a neck brace for cervical immobilization, decreased activity levels, or physical therapy.[22,46] Inpatient management can consist of bed rest and a period of cervical traction as well.[11] Such conservative treatment has been reported to be an effective therapeutic option, especially for patients with mild myelopathy from cervical spondylosis.[21,39,40] Management of patients who have OPLL without myelopathy still remains controversial, however, considering the propensity for these patients to develop subsequent enlargement of OPLL or possible severe neurological deficits following minor trauma.[5,10,20,32,34,35]

In this paper we provide a literature review on the conservative management of OPLL. Although the literature is rich regarding various surgical treatments, there are fewer studies reporting data regarding outcome of conservatively managing these patients. To our knowledge, this is the first attempt to aggregate all known articles regarding the conservative management of OPLL.

Methods

English literature was identified using the MEDLINE database. Several combinations of "ossification posterior ligament," "OPLL," "conservative," "natural history," "observation," and "nonsurgical" were searched from January 1975 to October 2010. In addition, "OPLL" and "surgery" were used to search for surgical series that may have included conservatively managed patients as well. References were also searched for relevant literature. This process was conducted by 3 independent authors.

Inclusion criteria were: 1) that a study included OPLL patients who were conservatively managed without surgical intervention upon initial diagnosis, and 2) that there was clinical follow-up regarding the progression of myelopathy. Exclusion criteria were: 1) any study reporting a group of conservatively managed patients who were included in a later study that met our primary inclusion criteria, and 2) any study in which OPLL patients were being conservatively managed due to an acute injury. Data were then extracted for number of patients conservatively managed, mean duration of follow-up in the study, clinical presentation, type of conservative management reported, clinical change on follow-up, and radiological change on follow-up. Three authors independently reviewed all studies that provided any details in these categories, and any discrepancies were resolved by consensus after re-review of primary data before inclusion for analysis. We considered any nonoperative treatment and/or observational follow-up as conservative management in this review.

The authors of several papers used the JOA score to evaluate the severity of myelopathy (highest score, 17 points).[14] The JOA score quantifies cervical myelopathy by evaluating upper-extremity function (4 points), lower-extremity function (4 points), sensation (6 points), and bladder function (3 points).

Results

Published Studies

Eleven studies detailing the conservative management of OPLL met the criteria for discussion in this review (Table 1). Of the 11 included articles, 7 were primarily clinical studies, 3 were primarily radiological studies, and 1 was a case report. There were a total of 480 patients (range per study 1–359), with a mean per-patient follow-up of 14.6 years (range 0.4–26 years). Matsunaga et al.[27] had the largest study, with 359 patients, accounting for 74.8% of this aggregate population. In addition to

TABLE 1: Studies included for this review*

Authors & Year	Study Type	No. of Pts w/ OPLL†	FU (yrs)‡	Reported Conservative Management
Harsh et al., 1987	clinical	1	1.25	clinical FU
Maiuru et al., 2000	clinical	1	3.0	bed rest, neck immobilization
Matsumoto et al., 2000	radiological	11	3.0	cervical brace with mandibular support (8+ hrs for 1st 3 mos, then wean), restriction of daily activities; inpatient traction
Matsunaga et al., 2004	clinical	359	17.6	clinical FU
McAfee et al., 1987	clinical	1	0.4	clinical FU
Mochizuki et al., 2009	clinical	21	4.5	clinical FU
Morio et al., 1999	radiological	23	3.0	clinical FU
Murakami et al., 2010	case report	1	26.0	skull traction × 3 wks
Takatsu et al., 1999	radiological	56	7.8	clinical FU
Trojan et al., 1992	clinical	4	1.9	observation, short duration of dexamethasone treatment, skull traction, bed rest, neck brace, or rehabilitation
Yu et al., 1988	clinical	2	1.1	neck collar

* FU = follow-up; Pts = patients.
† Whose cases were conservatively managed.
‡ For studies involving more than 1 patient, the mean value is given.

TABLE 2: Studies initially considered for review and subsequently excluded

Authors & Year	Study Type	No. of Pts w/ OPLL*	Reason for Exclusion
Jayakumar et al., 1996	clinical	17	incomplete FU
Koyanagi et al., 2004	radiological	22	incomplete FU
Matsunaga et al., 1994	clinical	207	same patients already included in another study
Matsunaga et al., 1996	radiological	101	incomplete FU; same patients already included in another study
Matsunaga et al., 2001	clinical	126	incomplete FU; same patients already included in another study
Matsunaga et al., 2002	clinical	167	same patients already included in another study

* Whose cases were conservatively managed.

regular clinical follow-up, reported types of conservative management included cervical brace or immobilization (4 studies), cervical traction (3 studies), a reduction in daily activities including bed rest (3 studies), and physical therapy (1 study).

Six other studies that were initially considered for inclusion in this review were subsequently excluded. Those studies can be found in Table 2. Reasons for exclusion were: incompletely documented clinical follow-up or absence of documented clinical follow-up (4 studies) and presence of overlapping patients in studies already included in this review (4 studies).

Presentation

Of all 480 conservatively managed patients across these 11 studies, 348 patients (72.5%) presented without any signs of myelopathy (Table 3). This is in comparison with 76 patients (15.8%) who presented with signs of myelopathy (Table 4). Status specifically regarding myelopathy could not be determined in 56 patients (11.7%). Reasons for nonsurgical intervention in the 76 patients presenting with myelopathy were: refusal of surgery (39 patients), myelopathy determined to be mild (28 patients), patient not medically stable for surgery (1 patient), and undetermined (8 patients).

Four studies reported initial JOA scores in their conservatively managed patient population (Table 5). In a series of 11 patients, all of whom had mild myelopathy, Matsumoto et al.[24] reported a mean JOA score at initial presentation of 14.3 ± 1.6. Mochizuki et al.[35] and Takatsu et al.[43] reported mean initial JOA scores for a mixed nonmyelopathic/myelopathic population with 15.6 ± 0.9 and 15.1 ± 2.7, respectively. Morio et al.[36] specified a mean JOA score in their myelopathic population as 12.9; altogether, however, their total population of 23 patients, including those without signs of myelopathy, had a mean initial score of 16.1. Based on these 4 studies, the mean aggregate JOA score on presentation of 111 OPLL patients who were subsequently managed conservatively was 15.3.

TABLE 3: Patients who presented without myelopathy and their clinical progression*

Authors & Year	No. of Pts w/o Myelopathy	Findings at FU	
		No Change	Myelopathy
Matsunaga et al., 2004	323	268	55
Mochizuki et al., 2009	6	6	0
Morio et al., 1999	18	NR	NR
Trojan et al., 1992	1	1	0

* Overall, 348 patients with conservatively managed OPLL were described as initially presenting without myelopathy. No change was reported in 275 (83%) of the 330 cases for which follow-up data were reported and progression to myelopathy in 55 (16.7%). Abbreviation: NR = not reported.

Clinical Progression

Of 330 patients with clinical follow-up data who initially presented without myelopathy, 275 patients (83.3%) remained progression free while 55 patients (16.7%) developed signs of myelopathy. In 76 patients who already had signs of myelopathy on presentation, 39 patients (51.3%) either remained unchanged or improved, whereas 37 patients (48.7%) showed clinical aggravation or worsening of their myelopathy on follow-up.

Follow-up JOA scores were available in only 3 of the 11 studies (Table 5). In a study of 56 conservatively managed OPLL patients, Takatsu et al.[43] showed a final mean JOA score of 14.8 ± 3.1 after a mean follow-up period of 7.8 years. This was slightly decreased from a mean JOA score of 15.1 ± 2.7 on initial presentation, but they reported this to be a nonsignificant change. For their 11 mildly myelopathic patients treated conservatively, Matsumoto et al.[24] reported a final mean JOA score of 13.8 ± 1.7 during a mean follow-up period of 3 years. This was decreased from 14.3 ± 1.6 on initial presentation. Mochizuki et al.,[35] however, demonstrated an improvement in their population of 21 patients. In their group of 6 nonmyelopathic and 15 mildly myelopathic patients, a mean JOA score of 16.4 ± 1.0 was achieved after a mean follow-up period of 4.5 years—an improvement from an initial mean JOA score of 15.6 ± 0.9.

Discussion

Ossification of the posterior longitudinal ligament is an important cause of spinal cord disease. Chronic compression of the spinal cord is believed to be the mechanism for myelopathy and may contribute to significant neurological disability.[26] Although the majority of cases (92%) affect the cervical spine, OPLL can also appear at the thoracic (4%) and lumbar (4%) spinal levels.[37]

Good results from the surgical treatment of patients

TABLE 4: Patients who presented with myelopathy and their clinical progression*

Authors & Year	No. of Pts w/ Myelopathy at Presentation	Findings on FU		
		No Change	Improvement	Worsening
Harsh et al., 1987	1	1		
Maiuru et al., 2000	1	1		
Matsumoto et al., 2000	11	5†		6
Matsunaga et al., 2004	36	13†		23
McAfee et al., 1987	1	1		
Mochizuki et al., 2009	15	6	8	1
Morio et al., 1999	5	0	0	5
Murakami et al., 2010	1			1
Trojan et al., 1992	3	2	1	0
Yu et al., 1988	2	1	0	1

* Overall, 76 patients with conservatively managed OPLL initially presented with myelopathy. Improvement or no change was reported in 39 (51.3%) and worsening in 37 (48.7%).
† No change or improvement (not categorized separately).

with OPLL have been reported throughout the literature.[8,23,27,42,47] In several high-volume series of over 100 cases,[4,13,33] rates of neurological improvement have been reported as ranging between 86.5% and 89.4%. Major concerns with respect to an anterior approach revolve around inadequate decompression, dural loss or laceration, CSF leak, or neurological injury of the compressed spinal cord.[3,7,9,12] Vertebral instability with pseudarthrosis has also been reported with anterior approaches, with rates ranging from 4%–6% for 1-level fusions to as high as 17% for 3-level fusions.[2,7,31] Posterior approaches may run into continued progression of OPLL. Other complications resulting from posterior approaches include postsurgical kyphosis and C-5 palsies. Symptomatic neurological deterioration, however, occurs only rarely and has been cited as occurring in less than 1% of cases.[16,45]

It has been suggested that conservative treatment be pursued for patients with a JOA score of at least 14 points. This suggestion was based on a study by Mochizuki et al.,[35] who reported a mean JOA score improvement from 15.6 ± 0.9 to 16.4 ± 1.0 over a mean follow-up period of 4.5 years. When Matsumoto et al.[24] managed their 11 myelopathic patients conservatively, however, they saw a decline in mean JOA score from 14.3 ± 1.6 to 13.8 ± 1.7 over a mean follow-up period of 3 years. Our review showed that nonmyelopathic patients had a 16.7% chance of showing myelopathic progression over an aggregate mean follow-up period of 14.6 years. If a patient already had myelopathy on initial presentation, the chance of further progression increased to 48.7% with conservative management.

Over a mean follow-up period of 17.6 years, Matsunaga et al.[27] showed that only 55 (17%) of the 323 patients who presented without myelopathy symptoms or signs had developed myelopathy by final follow-up. The cumulative myelopathy-free survival rate in patients presenting without myelopathy was 71% after 30 years. This suggests that prophylactic surgery in the absence of signs and symptoms may not be necessary in light of this benign course. In contrast, 23 (64%) of the 36 patients who had presented with myelopathy but declined surgery, experienced progression. The majority of this progression occurred in patients who had at least moderate myelopathy at initial presentation (Nurick Grades 3, 4, and 5).[41] On the other hands, patients who initially had mild myelopathy (Nurick Grades 1 and 2) had the same functional outcome whether they were managed conservatively or surgically.

A long-term observational study[44] of OPLL demonstrated progression of ossification longitudinally in 60% of patients and transversely in 52%. This radiographic progression, however, did not necessarily correlate with the appearance of myelopathy in in patients who had previously shown no signs of spinal cord disease. Likewise, Matsunaga et al.[29] demonstrated similar findings in their observational study of 207 patients followed up for a mean period of 10.25 years. Although 32% of the 65 patients who had an increase in ossification thickness showed aggravation of myelopathy, there were cases in which patients had no worsening of myelopathy in the face of marked ossification, as well as those in which patients experienced worsening myelopathy in the presence of only slight ossification. They determined that the onset and aggravation of myelopathy could not be attributable to the development of ossification alone and pointed to

TABLE 5: Studies reporting mean JOA scores in conservatively managed patients*

Authors & Year	No. of Pts w/ OPLL†	Mean JOA Score at Initial Presentation	Mean JOA Score at FU
Matsumoto et al., 2000	11	14.3 ± 1.6	13.8 ± 1.7
Mochizuki et al., 2009	21	15.6 ± 0.9	16.4 ± 1.0
Morio et al., 1999	23	16.1	NR
Takatsu et al., 1999	56	15.1 ± 2.7	14.8 ± 3.1

* Based on the available data, the overall mean JOA scores were 15.3 at initial presentation (4 studies) and 15.05 at follow-up (3 studies).
† Including asymptomatic patients and those with myelopathy.

incidence of cardiovascular disease and dynamic range of motion factors as well. An increase in the extent of OPLL in addition to these other factors may be needed to induce myelopathy. In our review of these 11 studies, only Murakami et al.[38] commented on radiographic progression; in their case report, they noted an increase in ossification that coincided with the appearance of myelopathy 26 years after their patient's initial presentation.

There are significant caveats for this review. Data gathered were partly based on retrospective series that included conservatively managed cases as part of a larger report of surgical treatments. Patients who were chosen for conservative management typically had presentations that were more benign than their surgically managed counterparts.[43] This may represent a selection bias that may underestimate the severity in progression of OPLL's true natural history should higher grades of OPLL be managed without surgery. In addition, the clinical and radiological progression of OPLL is not linear. Studies have shown that patients with moderate to severe myelopathy will experience faster progression than those with only mild myelopathy.[27] Therefore, the simple presence of myelopathy on initial examination without a descriptor of its severity is not enough to predict outcome. Because many studies did not report a particular grade or score of presenting myelopathy and because several studies aggregated their conservatively managed patients, it may be difficult to predict a true slope of progression. Last, because the study of Matsunaga et al.[27] study from one Japanese center constituted the majority of this review's patient population, the conclusions reached here may not be completely applicable to all patients with OPLL.

To the best of our knowledge, this is the first attempt to review the clinical course of all OPLL patients reported on in the literature who were conservatively managed without surgery. It is hoped that our findings will provide continued guidance as to deciding the appropriate treatment in patients with this condition.

Conclusions

The indications for conservatively managing patients with OPLL remain vaguely defined. Patients who present without myelopathy have a high chance of remaining progression free. Those who present already with symptoms or signs of myelopathy may benefit from surgery due to a higher rate of progression over continued follow-up.

Disclosure

Dr. Hsieh reports being a consultant for DePuy Spine and Medtronic, and receives support from DePuy Spine for non–study-related clinical or research effort.

Author contributions to the study and manuscript preparation include the following. Conception and design: Pham, Attenello, Stapleton, Hsieh. Acquisition of data: Pham, Lucas, He. Analysis and interpretation of data: all authors. Drafting the article: Pham, Lucas. Critically revising the article: Pham, Attenello, Hsieh. Reviewed final version of the manuscript and approved it for submission: Pham, Attenello, Hsieh. Administrative/technical/material support: Stapleton. Study supervision: Hsieh.

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Manuscript submitted November 15, 2010.

Accepted January 12, 2011.

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Surgical management of cervical ossification of the posterior longitudinal ligament: natural history and the role of surgical decompression and stabilization

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Object. Ossification of the posterior longitudinal ligament (OPLL) is a complex multifactorial disease process combining both metabolic and biomechanical factors. The role for surgical intervention and choice of anterior or posterior approach is controversial. The object of this study was to review the literature and present a single-institution experience with surgical intervention for OPLL.

Methods. The authors performed a retrospective review of their institutional experience with surgical intervention for cervical OPLL. They also reviewed the English-language literature regarding the epidemiology, pathophysiology, natural history, and surgical intervention for OPLL.

Results. Review of the literature suggests an improved benefit for anterior decompression and stabilization or posterior decompression and stabilization compared with posterior decompression via laminectomy or laminoplasty. Both anterior and posterior approaches are safe and effective means of decompression of cervical stenosis in the setting of OPLL.

Conclusions. Anterior cervical decompression and reconstruction is a safe and appropriate treatment for cervical spondylitic myelopathy in the setting of OPLL. For patients with maintained cervical lordosis, posterior cervical decompression and stabilization is advocated. The use of laminectomy or laminoplasty is indicated in patients with preserved cervical lordosis and less than 60% of the spinal canal occupied by calcified ligament in a "hill-shaped" contour. *(DOI: 10.3171/2010.12.FOCUS10283)*

Key Words • **cervical stenosis** • **cervical spondylitic myelopathy** • **ossification of the posterior longitudinal ligament** • **laminoplasty** • **corpectomy**

Ossification of the posterior longitudinal ligament (OPLL) is a pathological process whereby the PLL becomes progressively calcified, often leading to symptomatic spinal canal or foraminal stenosis.[11,29,31] It is a complex disease process, and patients often present to the spine surgeon in an advanced stage requiring surgical intervention. There is a great deal of evidence that OPLL is a multifactorial process resulting not only from inherent biological factors but also from environmental and biomechanical factors.[11,29,30,33] Each of these competing factors plays a role in the natural history of the disease process and ultimately in the role of surgical intervention. With that in mind, there are various potential surgical options available to the spine surgeon, each with its own risks, benefits, and accompanying pitfalls. In this manuscript, we discuss the various types of OPLL in the cervical spine and the advantages and disadvantages of different surgical strategies as supported by our institutional experience.

The prevalence of OPLL has been shown to be higher in East Asian countries, most significantly in Japan (1.9%–4.3%), Korea (3.6%), and Taiwan (2.8%).[11] The prevalence of OPLL in the North American Caucasian population has been reported as only 0.12% historically,[11] but more recently, Epstein[5] has reported that as many as 25% of patients who present with cervical myelopathy have some evidence of OPLL. While there is evidence of a genetic predisposition for OPLL there are also underlying associated metabolic comorbidities. Both adult-onset and non–insulin-dependent diabetes mellitus have been shown to be independent risk factors for OPLL and are believed to be related to an increase in insulin production and its upregulating effect on osteoprogenitor cells leading to OPLL.[1,11,20,27] Ossification of the PLL can also be seen in as many as 50% of cases of diffuse idiopathic skeletal hyperostosis (DISH).[5,7]

Abbreviations used in this paper: BMP = bone morphogenetic protein; DISH = diffuse idiopathic skeletal hyperostosis; JOA = Japanese Orthopaedic Association; OPLL = ossification of the PLL; PLL = posterior longitudinal ligament.

Four types of OPLL have classically been described:[10,25] 1) segmental—confined to the area posterior to the vertebral bodies without crossing the disc spaces; 2) continuous—extending from vertebral body to vertebral body including the disc space and spanning multiple levels; 3) mixed: combined aspects of both segmental and continuous types that maintains some skipped areas; and 4) other: limited to area behind the disc space with some extension to the posterior vertebral body endplate or focal punctate areas of hypertrophy/calcification of the posterior longitudinal ligament.

Although OPLL is the result of multiple processes, there have been numerous studies addressing the genetic and metabolic basis of this disease. While the details of those studies are beyond the scope of this manuscript, there are a few details that bear mentioning. The role of repeated mechanical stress to the cervical spine has been proposed as an agent in the formation of OPLL. Studies looking at the importance of dynamic repeated stress have demonstrated an increase in BMP-2, BMP-4, prostaglandin I2 synthase, and osteoblast specific transcription factors in patients with OPLL compared with those without OPLL.[11,12] The increase in these cytokines suggests, as the authors point out, that the mechanical stress induces a biochemical response that leads ultimately to osteogenic induction in the ligament cells leading to OPLL. The importance of this finding with respect to surgical intervention is important to point out in terms of the role of surgical stabilization as opposed to decompression alone.

Matsunagra et al.[22] studied the natural history of untreated OPLL and found that 17% of patients who were found to have OPLL without signs of myelopathy went on to progress to the development of myelopathy. Likewise, 64% of patients with signs of myelopathy at the time of presentation who did not undergo surgery experienced neurological deterioration. This clinical study helps to highlight the fact that the development and progression of OPLL is a dynamic process. Epstein[5] describes OPLL as part of a continuum that begins with increased vascular fibrosis of the PLL and progresses to focal calcification, proliferation of periosteal cartilage, and ultimately ossification. Early ossification is often seen in patients in the 5th decade of life in the area posterior to the disc space alone, making it difficult to distinguish from degenerative spondylosis. The rate of ossification is variable among different patient groups but Harsh et al.[8] found an annual growth rate of 0.67 mm in the anterior-posterior direction and 4.1 mm in the cranial-caudal direction. In another study, Matsunaga et al.[21] confirmed these findings, demonstrating that nearly 20% of patients with untreated OPLL experienced an increase of 2 mm or more in PLL thickness and 86% experienced an increase in the cranial-caudal extent of the disease. Murakami et al.[26] likewise report a case of a patient who progressed from asymptomatic segmental OPLL to a mixed-type OPLL as his neurological condition deteriorated, developing myelopathy over the course of 4 years. The progressive nature of OPLL suggests that most patient will ultimately require some sort of surgical intervention.

Surgical Management

Nonoperative management of OPLL is reserved for patients who have few neurological symptoms or for those whose overall medical health precludes them from surgical treatment. Pharmacological pain management with the guidance of multidisciplinary pain specialists is recommended. Nonsteroidal antiinflammatory medications and steroid injections are the mainstays of nonoperative therapy. Unfortunately, despite the inflammatory nature of the disease, there have been few pharmacological advances in the specific antiinflammatory agents designed for OPLL, as compared with other inflammatory disease such as rheumatoid arthritis or ankylosing spondylitis.

Nearly 70% of cases of OPLL involve the cervical spine.[5] Most patients with cervical OPLL come to the attention of spine surgeons because of clinical findings of myelopathy, radiculopathy, or both and thus require surgical intervention. The questions that often face the surgeon involve the appropriate surgical approach: anterior versus posterior and decompression alone versus decompression and stabilization. The location of the OPLL, in conjunction with the patient's clinical symptoms, guides the surgeon in formulating a surgical plan. There are different treatment options available for OPLL of the cervical spine, compared with OPLL of the thoracic or lumbar spine. In the cervical spine, the anterior spinal column is much more accessible and often carries less morbidity than the thoracotomy that would be required for anterior access to the thoracic spine. Many patients with OPLL harbor other medical comorbidities or are of advanced age such that thoracotomy is not an ideal choice. On the other hand, older patients undergoing multilevel cervical corpectomy have been shown to have an increased rate of significant dysphagia postoperatively. Posterior decompression via laminectomy or laminoplasty is an option at any level of the spine. The need for stabilization is often greater in the cervical spine than in the thoracic spine, the latter being supported by the thoracic cage. However, kyphosis of the thoracic spine may increase the need for instrumented stabilization to minimize the risk of a progressive kyphotic deformity in the setting of a disrupted posterior tension band. There are many factors that influence the surgical plan for OPLL, and in this manuscript we analyze our single-institution experience with surgically treated cervical OPLL.

Methods

After obtaining institutional review board approval, we retrospectively analyzed our own patient experience with cervical OPLL. Individual surgeon case logs and billing records were reviewed for the previous 10 years (2000–2010). We retrospectively identified 18 patients (Table 1) who underwent surgery for symptomatic cervical myelopathy secondary to radiographically confirmed OPLL. The different types of OPLL as classified by Hirabayashi et al.[10] were evenly distributed among our patients: continuous in 6, segmental in 6, and mixed in 6. Twelve patients underwent laminectomy and instrumented stabilization (Figs. 1 and 2), 3 patients underwent 2-level corpectomy, 2 patients underwent 1-level corpectomy (Figs. 3 and 4), and 1 patient underwent 1-level corpectomy with adjacent-level anterior cervical discectomy and fusion. Medical record chart review was performed

TABLE 1: Summary of demographic and clinical characteristics in 18 patients*

Case No.	Age (yrs), Sex	Type of OPLL†	Procedure
1	62, F	continuous	C5–6 corpectomy, C4–7 ASF
2	60, M	continuous	C5–6 corpectomy, C4–7 ASF
3	51, F	continuous	C-4 corpectomy, C5–6 ACD, C3–6 ASF
4	79, M	continuous	C-5 corpectomy, C4–6 ASF
5	59, F	continuous	C3–7 laminectomy, C3–T2 PSF
6	86, M	continuous	C4–7 laminectomy, C3–T2 PSF
7	58, M	mixed	C3–6 laminectomy, C3–6 PSF
8	84, M	mixed	C3–5 laminectomy, C3–5 PSF
9	74, M	mixed	C3–7 laminectomy, C3–T2 PSF
10	59, M	mixed	C4–7 laminectomy, C4–T2 PSF
11	51, F	mixed	C3–6 laminectomy, C3–6 PSF
12	42, M	mixed	C4–6 laminectomy, C3–T2 PSF
13	31, F	segmental	C-6 corpectomy, C5–7 ASF
14	64, F	segmental	C3–7 laminectomy, C3–7 PSF
15	68, F	segmental	C3–6 laminectomy, C3–7 PSF
16	56, M	segmental	C3–5 laminectomy, C3–T2 PSF
17	42, F	segmental	C5–6 corpectomy, C4–7 ASF
18	54, M	segmental	C3–7 laminectomy, C3–7 PSF

* There was no CSF leak or postoperative neurological deficit. Abbreviations: ACD = anterior cervical discectomy; ASF = anterior spinal fusion; PSF = posterior spinal fusion.
† As classified by Hirabayashi et al.

to obtain both preoperative and postoperative neurological examination status as well as presenting complaints. The type of procedure was recorded as well as findings of pre- and postoperative neurological examinations and follow-up imaging. Any intraoperative or postoperative complications documented in the medical record were also recorded. The average follow-up time was calculated. Any change in neurological examination findings documented in the medical record was recorded.

Results

Follow-up data were available in 16 cases. One patient suffered a massive pulmonary embolus 1 month after surgery and died as a result. In another case, there was no record of the patient's ever returning to clinic after discharge and the patient was thus classified as lost to follow-up. Of the 16 patients for whom follow-up data were available, 31% demonstrated a significant improvement in strength on objective physical examination; 69% remained neurologically stable; and 12.5% experienced some transient weakness in 1 or more muscle groups during the immediate postoperative period. The average duration of follow-up was 9 months (range 1–36 months). There was no radiographic evidence of instrumentation loosening or failure in the short term for any patients 3 months after surgery. There was no evidence of CSF leak.

Fig. 2. Case 5. Postoperative images. Anterior-posterior **(left)** and lateral **(right)** radiographs obtained after C3–7 laminectomy and C3–T2 instrumented posterior spinal fusion.

Discussion

When evaluating patients with OPLL, preoperative planning is essential. Careful assessment of the imaging studies includes determining the extent of ossification and the direction of the surgical approach (anterior vs posterior). Diagnostic imaging in OPLL is usually multimodality. Typically, when patients present for neurosurgical evaluation, an MR imaging study has already been performed for evaluation of neck pain or arm pain. The

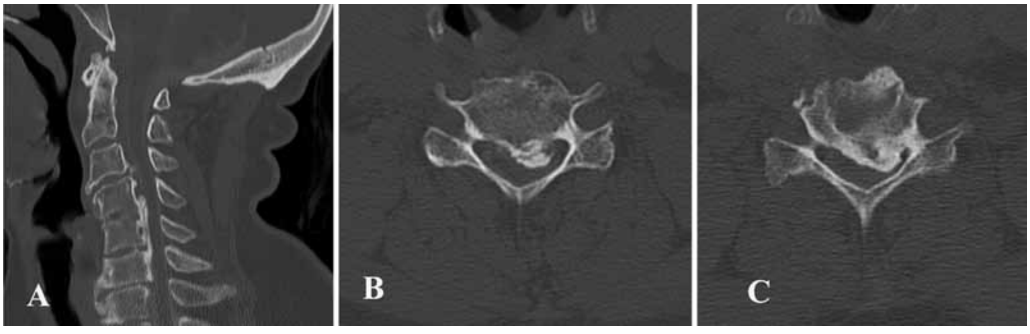

Fig. 1. Case 5. Preoperative images. This 59-year-old woman was found to have cervical spondylitic myelopathy and OPLL. **A:** Sagittal CT reconstruction demonstrating continuous OPLL at the C4–6 levels. **B and C:** Axial CT images revealing severe spinal canal stenosis due to OPLL at multiple levels. There is also evidence of DISH on the sagittal and axial images.

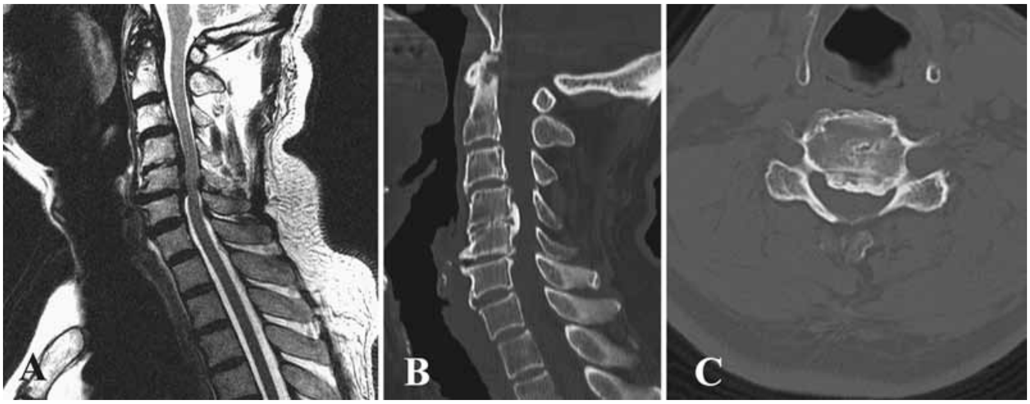

Fig. 3. Case 4. Preoperative images. This 79-year-old man with gait difficulties was found to have cervical spondylitic myelopathy secondary to continuous OPLL as seen on sagittal T2-weighted MR imaging **(A)**, sagittal CT reconstruction **(B)**, and axial CT **(C)**.

appearance of OPLL on MR imaging differs depending on the extent of progression of the ossification process. For example, early OPLL is often confined to the area behind the disc space with some extension to the adjacent vertebral bodies or end plates; in such a case, OPLL appears very similar to spondylosis or disc herniation. Hypertrophied and calcified ligament appears hypointense on unenhanced MR images, but following the administration of gadolinium, ossified PLL enhances. Disc herniations do not enhance. In fact, particularly advanced cases of OPLL will display evidence of fat deposition and signs of bone marrow production. Advanced continuous OPLL may demonstrate the development of a Haversian canal system within the calcified ligament.[5] Wang et al.[34] studied T2 signal intensity ratios between intramedullary areas posterior to compressive ossified PLL compared with the intramedullary signal behind the C7–T1 disc space where there was no compression in patients with myelopathy prior to laminoplasty. They concluded that patients with low signal-intensity ratios had better surgical outcomes than those with high signal-intensity ratios and evidence of pyramidal signs.[34] Given the likely progression of untreated OPLL we advocate for early surgical intervention.

Fig. 4. Case 4. Postoperative images. Anterior-posterior **(left)** and lateral **(right)** radiographs obtained after C-5 corpectomy and C4–6 anterior spinal fusion.

Computed tomography can help to confirm OPLL first suspected on MR imaging; CT can often help to better define the extent of disease seen on MR imaging and identify any foraminal component or the degree of stenosis. Likewise, OPLL in its early stages may be missed on CT sagittal reconstructions and these images should be correlated with axial imaging. Ossification of the ligamentum flavum can also be associated with OPLL and can be seen best on CT.[5] The longitudinal extent and circumferential location of both anterior and posterior ossification and subsequent canal or foraminal stenosis aid in formulating the appropriate surgical plan. CT myelography often helps to define the extent of spinal cord compression and the urgency of surgical intervention. Dynamic flexion-extension imaging can also play a role when the surgeon is considering stabilization. It is important to point out the importance of utilizing CT reconstructions in assessing OPLL to best understand the 3D anatomy of the disease. Chang et al.[2] have demonstrated the increased intra- and interobserver reliability of CT reconstructions compared with plain radiographs or even axial CT alone.

Patient age and medical comorbidities also influence the decision to use an anterior or posterior approach and whether to perform stabilization. Epstein[5] reports that in comparison to stand-alone posterior procedures, anterior procedures produce better short- and long-term improvement in neurological outcomes. The work of Kawano et al.[18] provides support for this notion, demonstrating improved outcomes in the short-term and long-term for patients undergoing anterior corpectomy compared with those undergoing posterior procedures. Anterior decompression of the spine seems to be the definitive surgical approach for a compressive lesion ventral to the spinal cord. However, OPLL can often present as segmental or continuous type of lesion spanning multiple levels. Good results have been reported for 1- and 2-level cervical corpectomies; however, corpectomies of 3 levels or more are fraught with complications including graft fracture, graft pistoning, graft dislodgement, instrumentation failure, and pseudarthrosis.[4] Dalbayrak et al.[4] have introduced the idea of the "skip" corpectomy, whereby the C-5 vertebral body is left intact and C-4 and C-6 corpectomies are performed for cervical spondylitic myelopathy and OPLL. They conclude that the C-5 body adds additional stability to the anterior cervical construct and the procedure still provides adequate decompression. The biomechanical complications are compounded by high rates of postoperative dysphagia in patients who have undergone multilevel cervical corpectomy.

Anterior corpectomy has been shown to have significant benefits for these patients, but many surgeons are concerned about the risk of durotomy and postoperative CSF leak due to the adherent ossified PLL and the potential for continued neurological deterioration due to insufficient decompression.[3,6,23,28,35] In the series reported by Chen et al.,[3] only 4 patients suffered a CSF leak, and there was no evidence of neurological decline in patients who underwent anterior corpectomy. The authors conclude that these outcomes are the result of a lack of traumatic manipulation of the spinal cord and protection of the epidural vascular plexus. They used specially designed microdissectors to separate the ossified PLL from the dura and they also used the popular "floating" technique when there was evidence of dural ossification. Hida et al.[9] studied the CT characteristics of patients with OPLL and demonstrated some key findings that help determine the amount of dural ossification and thus the potential risk of durotomy and CSF leak at the time of surgery. They studied 21 patients with radiographic evidence of OPLL and correlated their findings with intraoperative evidence of dural defect. They describe double- and single-layer OPLL. Twelve patients were found to have a double layer of ossification on CT at the level of the thickest ossified PLL and 10 patients were found to have a single calcified layer. Of the 12 patients with double-layer OPLL, 10 of them were found to have dural defects, whereas 9 of the 10 patients with single-layer OPLL had intact dura.[9] Utilizing these findings on preoperative CT can help determine which areas of the ossified PLL should be left in place at surgery. In our experience, calcified ligament can be removed safely. When removing the calcified ligament, one must be careful to dissect in the appropriate plane. That plane can often be found by sliding a blunt nerve hook under the lateral aspect of the ligament. Utilizing the appropriate plane minimizes the risk of neurological injury, CSF leak, and injury to the engorged epidural venous system. In the event that the ligament is adherent to the dura, certain "bone islands" can be left in place. If the area of adherent calcified ligament is totally disconnected circumferentially, then it is unlikely to impose any compression on the spinal cord. Repair of an anterior durotomy can be challenging, particularly in the setting of calcified dura. If a CSF leak occurs it should be repaired immediately. If CSF drains from the thecal sac, the engorged epidural venous plexus will likely bleed significantly, making the procedure even more technically challenging.

Although in our experience anterior decompression and reconstruction can be done effectively and safely for 2-level disease, 3-level corpectomies are often not well tolerated due to postoperative dysphagia as well as the biomechanical challenges of such a large construct. With that in mind, we find that the most important factor in choosing an anterior or posterior approach is cervical lordosis. In particular, patients who lack cervical lordosis may benefit from an anterior approach when possible. In cases in which posterior decompression is required, however, we typically perform a stabilization procedure in our institution due to concern about progression of OPLL as a result of dynamic instability or progression of sagittal deformity. Posterior decompression alone has been shown to accelerate progression of OPLL ventrally. Takatsu et al.[32] demonstrated an increase in the rate of deterioration of patients who underwent posterior decompression alone—laminectomy or laminoplasty—compared with those who did not undergo any surgical intervention for OPLL. Likewise, when the decompression extends to the cervical-thoracic junction, stabilization should extend across the cervical-thoracic junction to T-2 to minimize the risk of a junctional kyphosis.

In the US, most cases of OPLL are treated using a posterior approach, as it can be a less technically than an anterior corpectomy. However, the need for posterior stabilization is controversial. Laminoplasty has been used to achieve posterior decompression while preserving motion, but patients with a straight or kyphotic cervical spine are at risk for progression of cervical kyphosis, and laminoplasty is contraindicated in this population. Patients with reversal of cervical lordosis who undergo laminoplasty have been shown to experience progression of kyphotic deformity as well as progression of ligamentous ossification postoperatively.[3,13,17,22]

Laminectomy without stabilization or laminoplasty can be an effective surgical option in specific circumstances. Iwasaki et al.[14,15] have studied long-term outcomes in patients who underwent cervical laminoplasty for OPLL and concluded that the most significant predictors for poor neurological outcome following laminoplasty are "hill-shaped" ossification, lower preoperative JOA score, postoperative change in cervical alignment, and older age at time or surgery. Likewise, they report worse neurological outcomes for patients with an occupying ratio of 60% or greater.

Matz et al.[24] performed a detailed analysis of the literature and concluded that there is Class III evidence to support the use of laminoplasty in cervical spondylitic myelopathy or OPLL. They report 55%–60% JOA score improvement compared with nonoperative therapy. Furthermore, while the most common complication of laminoplasty is the development of a C-5 nerve palsy due to cord shift and nerve root stretch, there is preserved range of motion and Class III evidence of equivalence in functional improvement between laminoplasty, anterior cervical decompression and fusion, and laminectomy with arthrodesis.[24] For our patient population, laminoplasty or laminectomy alone are rarely used due to the concern about progression of OPLL or development of cervical kyphosis. Many patients with OPLL also have DISH. The combination of OPLL and DISH may provide some anterior stability to the construct and thus reduce the risk of developing progressive kyphosis in the setting of laminoplasty or laminectomy. However, we have not had that experience at our institution, and thus all patients with multilevel cervical decompression in the setting of a straight or kyphotic cervical spine also undergo stabilization.

The technique we employ for posterior cervical decompression typically involves an en bloc laminectomy. Using a high-speed drill, bilateral troughs are created at the junction of the lamina and lateral mass or lamina-facet line, thus releasing the lamina from the lateral mass. Once the troughs are drilled, a nerve hook is used to define the epidural space. Disconnection of the osteoligamentous structures is performed by using Kerrison punches to systematically complete the disassociation of lamina from the facets. Similarly, disconnection of the osteoligamentous structures must also be performed at the cephalad and caudal ends to remove the lamina en bloc. This process of removing the ligamentum flavum must be done carefully to avoid any tearing of the dura. Both the ligamentum and the dura may be calcified or adherent to one another. The lamina can later be used as autograft for fusion. Throughout the procedure, the mean arterial blood pressure is maintained above 80 mm Hg to provide appropriate spinal cord perfusion. Instrumentation is typically placed prior to decompression using a modified Magerl technique[16] for placement of lateral mass fixation and the free-hand technique described by Lenke[19] is used for thoracic pedicle screw placement when necessary. Complete arthrodesis of the facet complex is essential to optimize fusion. The use of osteobiologic agents is a controversial topic and is left to the discretion of the surgeon. While osteobiologics can enhance fusion rates in the posterior cervical spine, their use in the anterior cervical spine is not recommended due to the intense inflammatory response generated and the concern for compromising the patient's airway. The fusion rate in our case series is high and likely on a par with other institutions' series in large part due to the inflammatory nature of OPLL and high propensity for calcification and fusion.

Overall, the decision to use an anterior or posterior approach is a complicated one involving many factors. In our series, 67% of the patients underwent posterior decompression and fusion. Posterior stabilization is often a less technically demanding procedure that can be done safely and effectively. Chen et al.[3] retrospectively studied radiographic and clinical outcomes in 75 patients with severe OPLL as defined by 3 or more levels of OPLL with at least a 40% compromise of the cervical canal. The patients underwent anterior corpectomy and reconstruction, laminectomy and posterior instrumented stabilization, or laminoplasty. In this study they demonstrated a few important points. First, patients who underwent anterior corpectomy or laminectomy and instrumentation maintained a significantly greater cervical lordosis compared with those who underwent laminoplasty. Also, Chen et al.[3] demonstrated that neurological improvement measured by the JOA scale was significantly greater in patients who underwent anterior corpectomy than in those who underwent laminoplasty. For example, the mean JOA improvement percentage (± SD) for those in the 3 groups was as follows: anterior corpectomy 63.2 ± 15.2, laminectomy and stabilization 43.5 ± 12.7, and laminoplasty 25.1 ± 8.5. None of the patients in the anterior corpectomy group or the laminectomy and fusion group experienced neurological deterioration postoperatively, but 4 of 25 patients who underwent laminoplasty suffered neurological deterioration and progressive kyphotic deformity. The fact that some of the patients in the laminoplasty group experienced worsening neurological deficits helps support the idea that there is indeed an impact from a repeated mechanical stress and potential instability that may contribute to development of OPLL. The patients in this study who underwent instrumented stabilization did not suffer the same neurological decline. Whether the deterioration was from progressive kyphosis or from OPLL progression is not completely clear, but may be due to both processes leading to continued or worsening stenosis/compression. Although the literature suggests improved outcomes for anterior decompression and reconstruction, both groups of patients in our series who underwent anterior or posterior procedures did well neurologically. The decision to use an anterior or posterior approach was based on the number of levels involved, cervical lordosis, medical comorbidities, and patient age.

Conclusions

Ossification of the PLL is a complex multifactorial disease process that requires an understanding of the etiology of the disease as well as the role for surgical intervention. Most patients who present with symptomatic OPLL will eventually require surgery. The natural history of OPLL is that of progressive neurological decline resulting from enlargement of the ossified ligament and resulting stenosis. Clinical myelopathy is further worsened by a dynamic process whereby mechanical stress is transferred into reactive inflammation. The role of surgery is to decompress and stabilize the spine. For patients who demonstrate appropriate lordosis, laminoplasty or laminectomy may be a viable option. However, studies suggest that despite preservation of cervical lordosis, patients with myelopathy secondary to OPLL require stabilization. The decision to use an anterior or posterior approach is left to the discretion of the surgeon. Both anterior and posterior approaches have been shown to be safe and effective in our experience. Due to the ability to create lordosis in the cervical spine, outcomes from anterior decompression and reconstruction have been shown in the literature to be superior to the posterior decompression and stabilization. We have demonstrated successful decompression and fusion from both an anterior and a posterior approach. The choice of which approach to use is based on a number of factors that influence patient outcomes.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: Sugrue, McClendon, Liu, Koski, Ganju. Acquisition of data: Sugrue, McClendon. Analysis and interpretation of data: Sugrue, McClendon. Drafting the article: Sugrue, McClendon. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: all authors.

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Manuscript submitted November 16, 2010.
Accepted December 20, 2010.
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Neurosurg Focus 30 (3):E4, 2011

Ossification of the posterior longitudinal ligament in non-Asians: demographic, clinical, and radiographic findings in 43 patients

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Object. Ossification of the posterior longitudinal ligament (OPLL) is a disorder afflicting as many as 2% of East Asians. However, reports of OPLL in non-Asians have been sporadic in the medical literature. This study describes clinical and radiographic findings with OPLL in non-Asians at a tertiary care center treating a diverse multiethnic population.

Methods. Over a 6-year period, 43 patients not of East Asian descent presented to an urban tertiary medical center with OPLL. Patient data, including ethnicity, spinal cord function, Nurick grade, radiographic findings, OPLL subtype, and degree of cervical stenosis, were recorded.

Results. The average patient age was 59 years (range 32–92 years) with 18 women and 25 men. There were 22 Caucasian patients, 17 Hispanic patients, and 4 Black patients. With respect to the radiographic findings, OPLL morphology was continuous in 19, segmental in 17, mixed in 6, and other in 1. Average canal diameter was 7.6 mm (range 4.2–9.0 mm) at the most stenotic points. The mean Nurick grade was 2.95 at presentation, but 7 of the patients had OPLL identified incidentally and with early or minimal symptoms and signs of myelopathy.

Conclusions. Ossification of the posterior longitudinal ligament in non-Asians demonstrates similar demographic and radiographic characteristics as in East Asians. The representation of different ethnic groups mirrors the demographics of the medical center population in general, showing no specific predilection for particular ethnic groups. Surgical decompression in appropriately selected patients results in similar rates of improvement when compared with the Japanese literature. *(DOI: 10.3171/2010.12.FOCUS10277)*

Key Words • **ossification of the posterior longitudinal ligament** • **Asian** • **demographics** • **ethnicity**

Ossification of the posterior longitudinal ligament is characterized by growth of the posterior longitudinal ligament followed by ossification and the growth of this ectopic bone formation. While relatively uncommon, this disease results in progressive degeneration and increasing spinal stenosis. The final result of disease progression is severe cervical spinal cord dysfunction with its attendant neurological sequelae.

Ossification of the posterior longitudinal ligament was first reported in 1838 in Europe,[14] but the disorder received recognition in the 1960s by Japanese spine surgeons. As disease reports proliferated, it became apparent that this disease was significantly different from cervical spondylotic myelopathy, a disease more common in non-Asians. It is now generally believed that OPLL has a prevalence of 1.9%–4.3% in the Japanese population.[18] As such, it became associated with a higher frequency of occurrence in Asian populations, and it is now recognized that OPLL represents a significant public health problem in Japan.

Whereas the exact causes of OPLL remain elusive, specific genetic and environmental factors have been associated with this disease. Mutations in the gene for nucleotide pyrophosphatase have been associated with an OPLL variant in rodents (tiptoe walking mouse), as well as with a higher frequency in patients with OPLL.[20] Environmental factors such as exposure to high concentrations of fluoride have also been implicated in the pathogenesis of OPLL, but genetic links to the disease are concordant with what appears to be a propensity for afflicting specific ethnic groups.[6]

In the last half-century the bulk of scientific and clinical reports on OPLL have originated from Japan. This increased attention to OPLL in East Asia was suspected as a potential contributor to higher reported incidences in East Asian populations. In 1980, Izawa[12] reported on a radiographic survey of patients in Japan, Korea, Hawaii, Minnesota, and Germany. Using plain radiographs to make the diagnosis, thousands of patients were studied. While the incidence of degenerative disease was similar between groups, OPLL among asymptomatic Japanese adults was found to be 2.0%, compared with 0.95% in

Abbreviation used in this paper: OPLL = ossification of the posterior longitudinal ligament.

Koreans and 0.17%–0.20% in Caucasians. Corroborative evidence emerged from a US study of 1000 plain cervical radiographs by Firooznia et al.;[5] in that report, OPLL was identified in 0.7% of New Yorkers in general.

While most North American spine surgeons have observed sporadic cases of OPLL in non-Asians, there have been few reports of OPLL in non-Asian populations, and these have generally been limited to small case series or pooled populations from multiple centers.[1,7,8,10,15,19,22] This report from a tertiary academic medical center serving a diverse ethnic population was directed at elucidating the presentation, clinical findings, and radiographic characteristics in non-Asian North American patients with OPLL.

Methods

Study Population

Over a 6-year period, 43 patients with OPLL who were not of East Asian descent presented to an urban tertiary medical center in Southern California. The center services a diverse population composed of approximately 50% Hispanic, 15% Black, 15% Caucasian, and 10% Asian patients.[24] Patients presented through either the outpatient clinic or the emergency department. Patient data, including ethnicity, spinal cord function, Nurick grade,[21] radiographic findings, OPLL subtype, and degree of cervical stenosis were recorded. Ethnicity was determined by patient self-report.

Imaging Protocol

All patients underwent cervical imaging, including flexion-extension radiographs, CT scanning, and MR imaging, which was the standard protocol evaluation process for these patients. The degree of stenosis was determined by measuring the sagittal canal diameter at the most stenotic cervical level on high-resolution axial MR images. Measurements in millimeters were determined at the midline.

Diagnosis of OPLL

The diagnosis of OPLL was made if 3 conditions were met: 1) clinical symptoms consistent with cervical spinal cord compression were responsible for presentation to the clinician; 2) MR imaging evidence of cervical stenosis as defined by a minimal midsagittal canal measurement of 9 mm or less; and 3) CT demonstrated that the stenosis was due primarily to a calcified mass consistent with the morphology of OPLL. Ossification of the posterior longitudinal ligament morphology was classified according to the scheme by Hirabayashi et al.[9] (Fig. 1).

Results

Patient Demographics

Patient demographic data are shown in Table 1. The average patient age was 59 years, with a range of 32 to 92 years. There was a slight male predominance with 18 women and 25 men. Thirty-six patients presented with signs and symptoms of myelopathy, and the mean Nurick grade was 2.95 at presentation (Figs. 2 and 3). However, 7 patients had OPLL identified in its early stages with minimal symptoms and no reflex changes. These patients typically had upper extremity numbness or presenting symptoms of radiculopathy due to cervical nerve root compression. With respect to ethnicity there were 22 Caucasian patients, 17 Hispanic patients, and 4 Black patients. The mean follow-up was 13

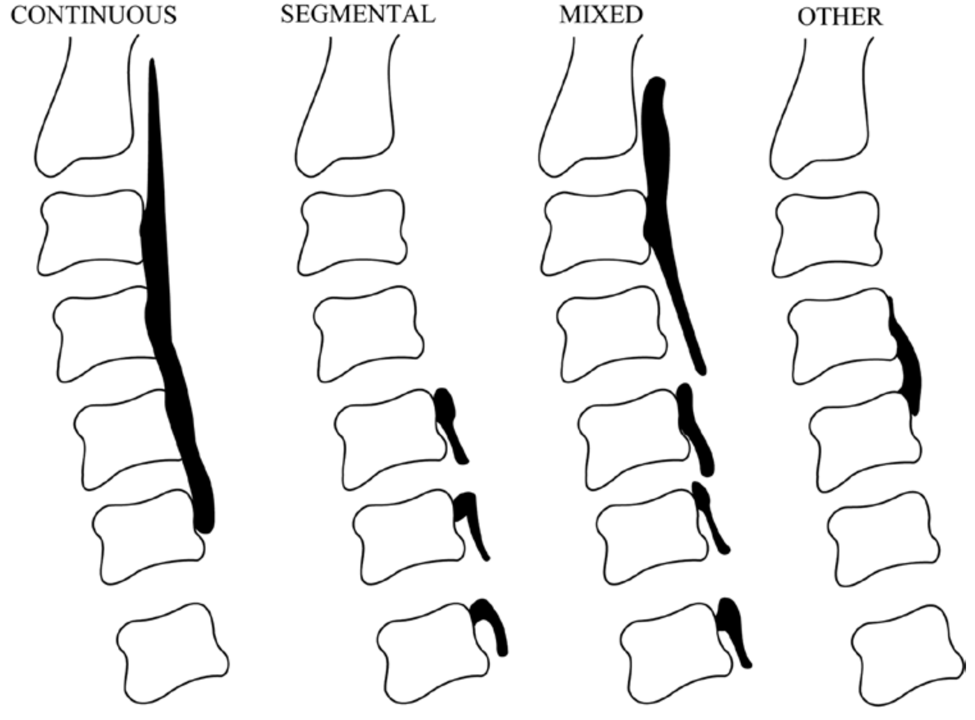

Fig. 1. Illustration of the 4 types of OPLL morphology as described by Hirabayashi et al.[9]

TABLE 1: Patient demographics

Variable	Value
mean age in yrs (range)	59 (32–92)
no. of women/men	18:25
ethnicity	
Caucasian	22
Hispanic	17
Black	4
OPLL morphology	
continuous	19
segmental	17
mixed	6
other	1
mean sagittal canal diameter in mm (range)	7.6 (4.2–9.0)
mean Nurick score at presentation	2.95

± 4.7 months for those undergoing operative intervention. For the 8 patients who did not undergo operative intervention (at our institution), mean follow-up was 3.2 months. Four of these patients had only 1 clinic visit.

Characteristics of OPLL

Ossification of the posterior longitudinal ligament morphology was determined based on axial CT and sagittal reconstruction images. The morphology of OPLL was continuous in 19 patients, segmental in 17, mixed in 6, and other in 1. The average canal diameter was 7.6 mm (range 4.2–9.0 mm) at the most stenotic points. The ossification spanned a mean of 2.2 spinal segments (range 1–6 segments). There was no association between the OPLL morphology and patient ethnicity. Two cases had an associated thoracic involvement with OPLL.

Surgical Intervention

With respect to surgical treatment, 35 patients underwent decompression. An anterior approach for corpectomy, fusion, and plating was performed in 7 patients, laminectomy with instrumented fusion in 15, laminoplasty in 9, nonoperative management in 24, and combined anterior-posterior surgery in 4. Expectant nonoperative management was applied in 8 patients. These patients had minimal symptoms and did not desire operative treatment given the risks of surgery. Of the 35 patients treated operatively, 29 showed an improvement in their Nurick grades, resulting in a mean improvement of 1.3 points for the entire surgical cohort.

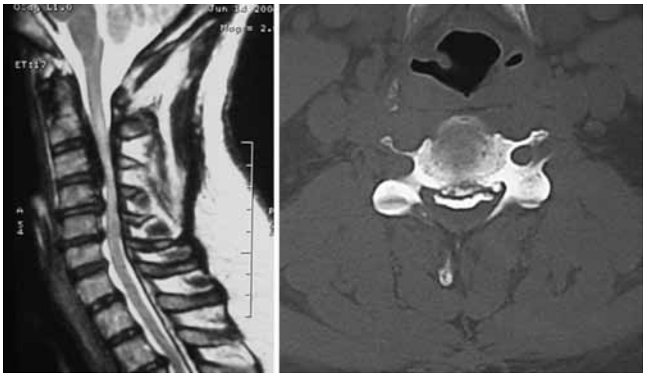

Fig. 2. Images obtained in a 43-year-old woman of Mexican Pima Indian descent with severe cervical stenosis presenting with signs and symptoms of myelopathy. Sagittal MR imaging **(left)** demonstrates mixed type OPLL, with confirmation of ossified masses on an axial CT scan **(right)**.

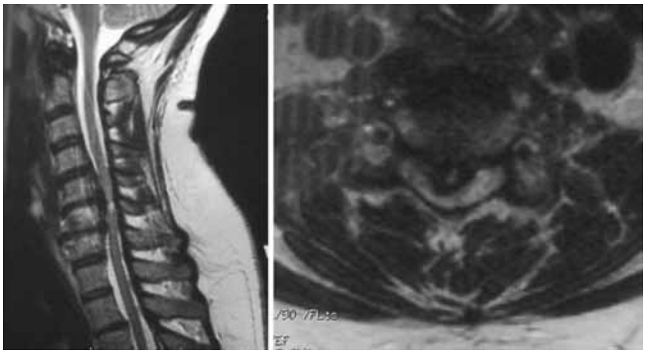

Fig. 3. Images obtained in a 49-year-old Black woman initially misdiagnosed with cervical spondylotic myelopathy. Sagittal **(left)** and axial **(right)** MR imaging shows morphological characteristics suggestive of continuous type OPLL from C-5 to C-7.

There was no significant difference in neurological improvement between the anterior, posterior, and anterior-posterior surgical cohorts; the mean improvement in Nurick grade for these groups was 1.2, 1.4, and 0.8 points, respectively. However, 2 patients experienced neurological worsening. Both of these patients had severe preoperative stenosis and were not ambulating independently prior to intervention, and both patients underwent anterior decompressive surgery (Fig. 4). Surgical complications included dural tears in 5 patients who underwent anterior surgery, with 3 requiring additional surgical intervention; C-5 nerve root palsy in 4 patients (75% from posterior surgery); persistent dysphagia in 3 patients (100% from anterior or combined anterior/posterior surgery); and wound infection or breakdown in 2 patients (100% from posterior surgery).

Discussion

In this report we describe our experience with a series of 43 non-Asian patients with OPLL. In our series the clinical and radiographic presentation of OPLL was similar to previous series from East Asia. We found a varied distribution of OPLL morphologies, with a predominance of continuous and segmental forms, similar to that reported in series with Japanese patients. This study builds on several previous reports of OPLL in non-Asians. In Trojan et al.'s review[23] of 73 cases of OPLL in non-Asians, several similarities were found with reports from the Japanese literature. These findings included: 1) male predominance, 2) peak age of symptoms in the 6th decade of life, 3) varied clinical presentations, 4) predominance for the cervical spine, and 5) association with other enthesopathies such as diffuse idiopathic skeletal hyperostosis. In the series of Jayakumar et al.,[13] 47 symptomatic Asian Indian patients of Caucasoid origin were studied. Sixty-five percent of these patients were found to have continuous-

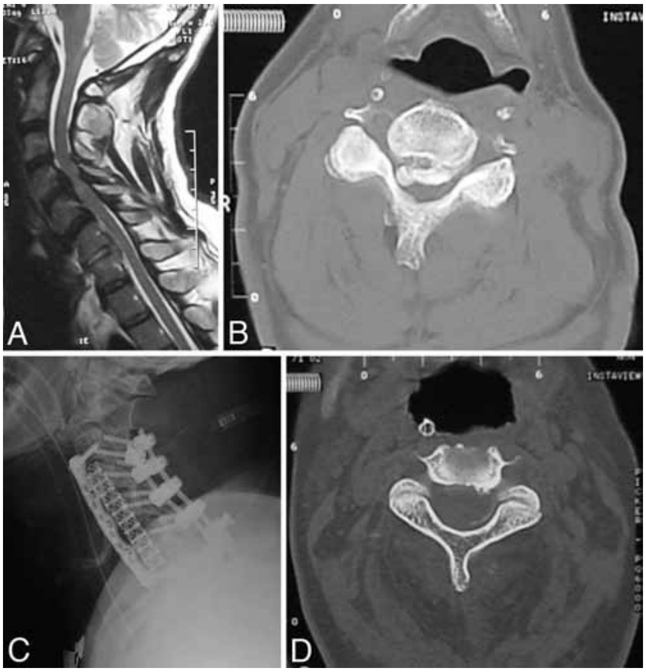

Fig. 4. Images obtained in a 63-year-old Caucasian man who presented confined to a wheelchair with severe tetraparesis. Sagittal MR imaging **(A)** and axial CT **(B)** demonstrated severe stenosis to less than 4 mm at the widest (sagittal diameter) point. The patient underwent a combined anterior-posterior surgery for decompression and stabilization **(C)**. An intraoperative dural tear resulted in an anterior neck pseudomeningocele noted on CT **(D)**, which required subsequent surgery involving patching and the application of a fibrin sealant.

type OPLL, and the disease predominantly affected the upper cervical spine. Epstein[2–4] has reported the largest series of patients with OPLL in the US, but the reports have provided little information on patient ethnicity.

Surgical Interventions

Our selection of surgical approach was based upon the guidelines of Hirabayashi et al.,[9] favoring posterior indirect decompressive approaches (laminectomy with instrumented fusion and laminoplasty) for longer segment and continuous-type OPLL, and anterior approaches for younger patients with more focal lesions. Furthermore, anterior corpectomies were favored when more that 60% of the spinal canal was compromised, given the higher rates of improvement compared with indirect through posterior approaches.[11,16] Thus, there were preoperative differences between the patients who underwent different surgical treatments, with a bias toward worsened clinical status for anterior surgery.

Both of the cases with neurological worsening also occurred with anterior or combined anterior/posterior surgery. This may have been due to this selection bias as these patients had more severe radiographic spinal cord compression and worse neurological status at presentation. However, all cases of dural penetration were also associated with anterior surgery, and these events may have been correlated with direct iatrogenic mechanical injury to the spinal cord. Other surgical complications were as expected from previous patient series, with higher rates of dysphagia following anterior surgery and C-5 nerve root palsy from posterior decompression.

Complications

The higher incidence of complications in patients with OPLL compared with cervical spondylotic myelopathy has been well described. Dural tears, unusual associated with anterior surgery for cervical spondylosis, are common in patients with OPLL given the adherence and/or penetration of the dura mater by the osseous overgrowth. In many instances of advanced disease it may be impossible to separate the dura from the offending lesion. In our more recent practice we have adopted the “floating corpectomy” technique advocated by Japanese authors.[25] This approach leaves a thin shell of OPLL adherent to the dura, but frees it from the vertebral body, allowing it to migrate en bloc into the ventral corpectomy defect. This maneuver can save time and blood loss by avoiding much of the microdissection when stripping the OPLL away, and offers the additional advantage of keeping the drilling at the lateral margins of the spinal canal, where the ventral epidural space is commonly patent.

Higher rates of neurological worsening can be due to numerous factors, including: 1) iatrogenic spinal cord or anterior spinal artery injury due to the absence of dura; 2) the profound compromise of the spinal canal space, rendering drilling and bone removal more treacherous; and 3) a compromised spinal cord more susceptible to spinal cord injury from ischemia and hypotension. We pay particular attention to the vulnerability of the spinal cord in patients with OPLL, ensuring fiberoptic intubation, maintenance of a mean systolic pressure greater than 85 mm Hg, and using motor evoked potential monitoring.

Postoperative dysphagia and dysphonia are also more common in this population given the presence of anterior vertebral osteophytes and diffuse idiopathic skeletal hyperostosis. In addition, the need for anterior exposures at C-2 and C-3 are more likely to jeopardize normal swallowing function. In our practice we minimize this risk by careful, sharp, anterior neck dissection so that retractor pressure and stretching of soft tissues are minimized. Prolonged surgeries are also managed with periodic retractor loosening.

Nerve root palsies at C-5 are also more common given the severity of spinal cord compression. This risk is managed by careful electromyographic monitoring of the biceps muscle during surgery. Any aberrant electromyographic activity may be indicative of C-5 nerve root irritation from stretching. This is managed with the addition of a C4–5 foraminotomy if a posterior decompression is used.

Classification by Ethnicity

This report is the largest series of OPLL cases from a single institution focused on ethnicity. The case series is derived from the diverse Southern California population, which has a high representation of Caucasians, Asians, Blacks, and White and Black Hispanics. In our series we were unable to identify a predominance of OPLL in any particular non-Asian group. However, classification of patients by ethnicity remains problematic and artificial. While it remains undisputed that there are distinct phenotypic characteristics within populations that can be attributed to the concept of race or ethnicity, the number and types of subcategories can be quite varied and disputed. The typical Linnaean variety of classification relies on a partitioning of individual patients into distinct ethnic groups. Other methods of classification, such as a cladistic or clinal approach, may eventually prove more useful for ethnic designations, avoiding the need for discrete and separate groups.[17] In addition, this methodology more closely models the genetic variations found within human populations and likely provides more reliable predictive information. In this study we classified patients according to self-report, which is problematic as the patient's self-assigned identity may bear no relation to physical traits or genetic constitution.

Another major drawback of this study is that our patient cohort was not population-based. Whereas our patients were drawn from a cohort of approximately 2.5 million patients, complete capture of all patients with OPLL in the area, as well as the lack of a clinical or radiographic screening program, leave us without a "denominator" for determining disease incidence or prevalence.

Conclusions

This report describes our experience treating cervical OPLL in a diverse US population. While the clinical presentation, radiographic characteristics, and treatment were similar to that of East Asian patients, it is important for neurosurgeons working with less diverse populations to recognize that OPLL occurs with some frequency in non-Asian ethnic groups. Preoperative CT scanning can be useful when OPLL is suspected to assist in surgical planning and reduce the risk of complications.

Disclosure

Dr. Wang serves as a consultant for DePuy Spine, Biomet Spine, Aesculap Spine, and Globus Spine. He also holds a patent with DePuy Spine.

Author contributions to the study and manuscript preparation include the following. Conception and design: Wang. Acquisition of data: Wang. Analysis and interpretation of data: Wang. Drafting the article: both authors. Critically revising the article: Thambuswamy. Reviewed final version of the manuscript and approved it for submission: both authors.

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Manuscript submitted November 15, 2010.

Accepted December 20, 2010.

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Ossification of the posterior longitudinal ligament in the cervical spine: an 11-year comprehensive national epidemiology study

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Object. This study aimed to calculate the incidence and prevalence of ossification of the posterior longitudinal ligament (OPLL) in the cervical spine with its comorbid disability.

Methods. Using an 11-year nationwide database in Taiwan (National Health Insurance Research Database), this retrospective study cohort analyzed the incidences of cervical OPLL causing hospitalization. All patients admitted for the diagnosis of OPLL, regardless of surgery, were identified. Age- and sex-specific incidences, Poisson regression, and multivariate logistic regression analysis were conducted.

Results. Between 1997 and 2007 covering 241,800,725.8 person-years, 1651 patients were admitted for OPLL. The overall incidence of OPLL-related admission was 6.1 per 1 million person-years. Specifically, male sex and older age were associated with higher OPLL incidences (both $p < 0.001$). Among the 1651 OPLL patients, 542 (32.8%) received conservative management, 612 (37.1%) had anterior only surgery, 353 (21.4%) had posterior only surgery, and 144 (8.7%) had anterior and posterior surgery. Eighty-five patients were moderately to severely disabled (5.2% cumulative incidence rate). The incidences of disability varied by age, in a decreasing trend, except for the 60- to 69-year-old age group ($p = 0.05$). Patients who received posterior-only surgery were more likely to have disability.

Conclusions. In a large cohort of the Chinese population, the incidence of cervical OPLL-related admission is 6.1 per 1 million person-years, and the prevalence rate is 7.7 per 100,000 person-years. Higher incidences are observed in elderly and male patients, which implies the disease's degenerative nature. After adjustments for demographics, the incidences and trends of OPLL-related comorbid disability are associated with age and surgical approaches. *(DOI: 10.3171/2010.12.FOCUS10268)*

Key Words • ossification of posterior longitudinal ligament • incidence • spinal cord injury • national health insurance

Ossification of the posterior longitudinal ligament is an uncommon disease that may cause cervical radiculopathy and myelopathy of varying severity. It is reported mostly in literature from Japan, where prevalence rates are extraordinarily high compared with other ethnic groups.[4–6] The prevalence reportedly ranges from 1.9% to 4.3% among individuals older than 30 years in investigations conducted in Japan.[8,12,14,15] Some epidemiological studies reported slightly lower or similar prevalence to that of the Japanese population among East Asians and definitely lower in the Caucasian population, suggesting genetic involvement.[4,16] However, reported data are often institution-based, which implies some bias. A population-based epidemiological investigation has not been published in English-language literature. If the disease is genetically relevant, neighboring countries in East Asia with a close geographic and anthropological relationship to Japan could share similar epidemiological features.

The NHIRD, provided by the NHRI of Taiwan, is a national database containing 26 million administered insurants accumulated between January 1997 and December 2007. The extremely high coverage, more than 99% of the population, yields a unique system that finances health care for the entire population and offers unrestricted access to any health care provider of the patient's choice. Therefore, the statistics gathered represent a sound epidemiological investigation of incidences of diseases and utilization of medical interventions because of universal coverage.

Abbreviations used in this paper: NHIRD = National Health Insurance Research Database; NHRI = National Health Research Institutes; OPLL = ossification of the posterior longitudinal ligament; SCI = spinal cord injury.

This study used the nationwide data to estimate, from a large population, the incidence of cervical OPLL and its comorbid disability. Age- and sex-specific incidences were also analyzed. To date, this is the largest cohort study to investigate such an issue, and it can provide a better depiction of the disease course.

Methods

Database

The NHIRD included all claims data from Taiwan's National Health Insurance program. This study was exempted from full review by the institutional review board because the NHIRD consisted of deidentified secondary data released to the public for research purposes.

Study Sample

In the entire 11 years between January 1, 1997, and December 31, 2007, all inpatient data from NHIRD were collected for analysis. The total enrollees consisted of 26,750,807 people, and the total observation span included 241,800,725.8 person-years.

Identification of OPLL

Diagnosis of every admission was recorded in the NHIRD using the International Classification of Disease, 9th Version (ICD-9). All hospitalizations discharged with the diagnostic code of OPLL of the cervical region (723.7) were identified. Accompanying surgical procedures coded with cervical laminectomy, laminoplasty, discectomy, corpectomy, and fusion (03.09, 03.09, 80.51, 80.99, and 81.02, respectively) were considered as receiving the surgery for OPLL during the specific admission. The surgical procedures were subsequently classified into anterior approach only, posterior approach only, or combined anterior and posterior procedures (front-and-back surgeries).

The incidences of hospitalization for cervical OPLL were identified as patients who underwent follow-up for more than 1 year and newly hospitalized with the aforementioned discharge code between January 1, 1998, and December 31, 2007. The incidence rates in the study were calculated by the incidence density.

Disability

The registry of patients with catastrophic illnesses (HV1997–2007) of the NHIRD was used to identify patients with cervical myelopathy or SCI causing moderate and severe disabilities. All newly diagnosed cervical myelopathy or SCI comorbid with OPLL were identified. By assumption, patients with severe neurological deficits such as paraplegia, tetraplegia, and incontinence were all included.

Statistical Analysis

All data were calculated using SPSS software for descriptive statistics and contingency tables (SPSS, Inc.). Poisson regression and multivariate logistic regression were used. A probability value of 0.05 was considered statistically significant.

Results

Incidence and Prevalence

During the study period, 1651 patients admitted for cervical OPLL were identified (1204 men [72.9%] and 447 women [27.1%]). There were 485 patients (29.4%) between 50 and 59 years old, 379 (23.0%) between 60 and 69 years old, 365 (22.1%) 70 years old or older, 359 (21.7%) between 40 and 49 years old, 52 (3.1%) between 30 and 39 years old, and only 11 (0.7%) younger than 30 years old. The overall incidence of cervical OPLL was 6.1 per 1 million person-years. There was an age-related increase in incidence at 0.2, 1.1, 8.7, 18.2, 22.9, and 22.8 for ages 20–29, 30–39, 40–49, 50–59, 60–69, and ≥ 70 years old, respectively. Higher incidences were also found in men than in women in every age group. The incidences of men and women were 0.3 versus 0.1, 1.6 versus 0.6, 11.3 versus 6.1, 25.2 versus 11.3, 35.2 versus 11.1, and 36.6 versus 7.9 for ages 20–29, 30–39, 40–49, 50–59, 60–69, and ≥ 70 years old, respectively (Table 1).

After adjustments for age and sex, the fitted Poisson regression model showed that men had more than a 2-fold higher risk of OPLL than women (incidence rate ratio 2.65 [95% CI 2.38–2.96], $p < 0.001$). The incidence of OPLL increased by a rate of 80% for every 10-year increase in age ($r = 1.79$ [95% CI 1.74–1.85], $p < 0.001$) (Fig. 1).

The overall prevalence rate was 7.7 per 100,000 person-years. There was an age-related increase in prevalence in each age group at 0.1, 0.6, 5.1, 15.5, 20.5, and 22.8 per 100,000 person-years for ages 20–29, 30–39, 40–49, 50–59, 60–69, and ≥ 70 years old, respectively. Moreover, in each specific age group, men had a higher rate of prevalence than women, at 0.3 versus 0, 0.8 versus 0.4, 6.6 versus

TABLE 1: Age- and sex-specific incidence of cervical OPLL

	No. of Patients w/ OPLL (%)			Incidence Rate (per 10^6 person-years)		
Age Group (yrs)	Female	Male	All	Female	Male	All
20–29	3 (0.7)	8 (0.7)	11 (0.7)	0.1	0.3	0.2
30–39	15 (3.4)	37 (3.1)	52 (3.1)	0.6	1.6	1.1
40–49	124 (27.7)	235 (19.5)	359 (21.7)	6.1	11.3	8.7
50–59	150 (33.6)	335 (27.8)	485 (29.4)	11.3	25.2	18.2
60–69	94 (21.0)	285 (23.7)	379 (23.0)	11.1	35.2	22.9
≥70	61 (13.6)	304 (25.2)	365 (22.1)	7.9	36.6	22.8
all	447 (100.0)	1204 (100.0)	1651 (100.0)	3.3	9.0	6.1

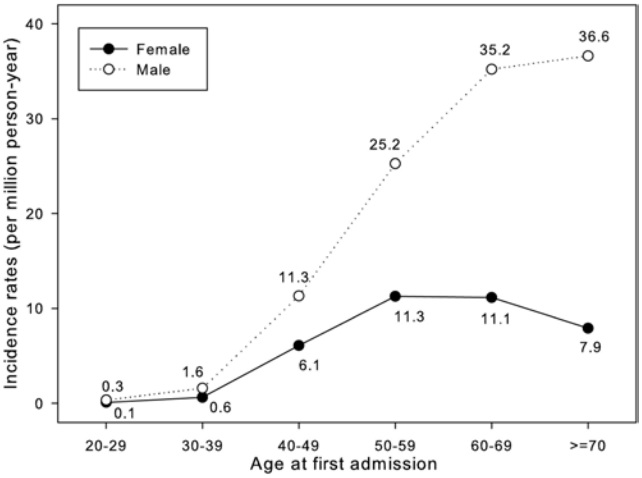

Fig. 1. Age- and sex-specific incidences of cervical OPLL-related admission.

3.6, 21.6 versus 9.4, 28.0 versus 13.5, and 37.7 versus 8.2 per 100,000 person-years, respectively (Fig. 2; Table 2).

Incidence of Neurological Deficits

Eighty-five patients (5.2% of all OPLL cases) were moderately or severely disabled due to related cervical myelopathy or SCI (Table 3). The incidences of disability varied by age, in a decreasing trend, except for the 60- to 69-year-old group (p = 0.05, chi-square test for trend; Fig. 3). Although male patients with OPLL appeared to have higher risk of developing SCI-related disability, this trend did not reach statistical significance (p = 0.18, test for proportion).

Surgical Treatment

A total of 542 patients (32.8%) in the cohort were conservatively treated, while 1109 (67.2%) underwent surgical treatment. Of those who received surgery, 612 (55.2%) underwent an anterior-only approach, 353 (31.8%) underwent a posterior-only approach, and 144 (13.0%) underwent a combined anterior and posterior approach.

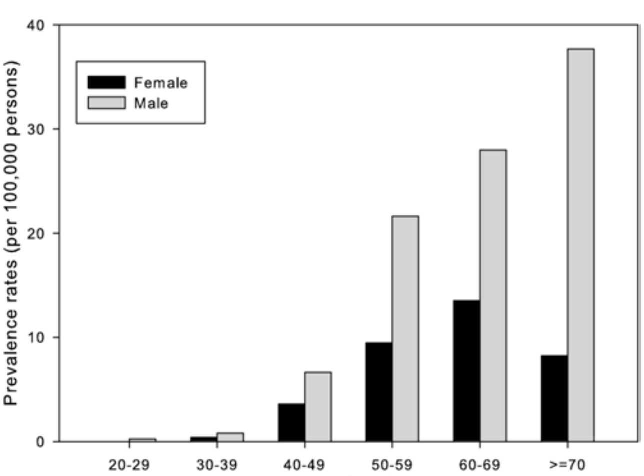

Fig. 2. Age- and sex-specific prevalences of cervical OPLL-related admission.

TABLE 2: Age- and group-specific prevalence of OPLL

	Prevalence Rates (per 10^5 person-years)		
Age Group	Female	Male	All
20–29	0.0	0.3	0.1
30–39	0.4	0.8	0.6
40–49	3.6	6.6	5.1
50–59	9.4	21.6	15.5
60–69	13.5	28.0	20.5
≥70	8.2	37.7	22.8
all	4.3	11.2	7.7

Incidence of Neurological Deficits by Surgical Approach

The incidence of disability varied with surgical approach. The majority of patients who had OPLL (67.2%) underwent surgery during their admission, and more than half (55.2%) underwent an anterior-only approach, whereas almost one-third (31.8%) had a posterior-only approach. A minority (13.0%) had the combined anterior and posterior approach. After adjustments for demographic features and comorbidities such as diabetes, hypertension, and cerebro- and cardiovascular diseases, patients with cervical OPLL who underwent posterior-only surgery were more likely to have related disability (adjusted OR 2.19, p = 0.01; Table 4). There were no other significant differences among the groups.

Discussion

The present report is, to date, the largest series of cervical OPLL in a span of a decade to investigate the incidence, prevalence, hospitalization, and surgical treatment of OPLL. All previously reported prevalence rates, varying from 0.1% to 4.6% in different ethnic groups including Caucasian and Japanese, have been calculated from institutional databases. Furthermore, most are radiographic prevalence rates, which should not be considered representative of endemic reality. Data from patients, whether symptomatic, who underwent imaging studies of the cervical spine for various reasons at certain institutions, inherently had selection bias. Therefore, data in the literature are overestimated when considering the epidemiological status of cervical OPLL. Comparisons of prevalence rates among these hospital-based studies are thus pointless since they have different inclusion cri-

TABLE 3: Disabilities in patients as stratified by age and sex

	No. of OPLL Patients w/ Disability/Total (%)		
Age Group (yrs)	Female	Male	All
30–39	1/15 (6.7)	3/37 (8.1)	4/52 (7.7)
40–49	5/124 (4.0)	19/235 (8.1)	24/359 (6.7)
50–59	5/150 (3.3)	17/335 (5.1)	22/485 (4.5)
60–69	5/94 (5.3)	16/285 (5.6)	21/379 (5.5)
≥70	1/61 (1.6)	13/304 (4.3)	14/365 (3.8)
all (≥20)	17/447 (3.8)	68/1204 (5.6)	85/1651 (5.1)

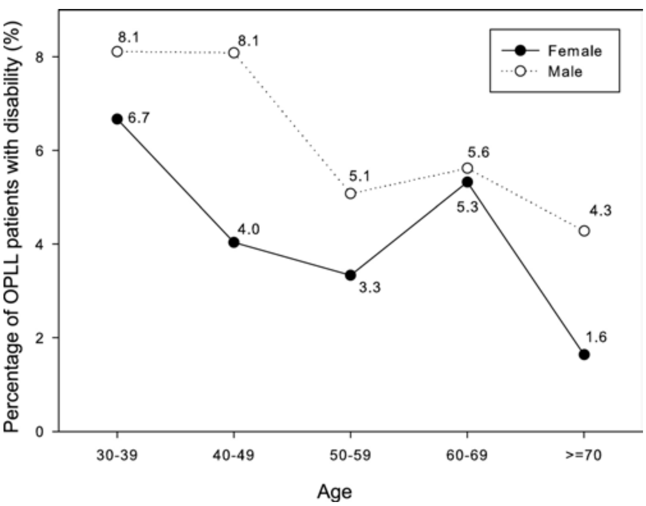

Fig. 3. Age- and sex-specific percentages of cervical OPLL-related moderate to severe disability.

teria of the sample populations. The selection bias from institution-based data becomes more prominent considering the rarity of the disease. In the current study, the incidence of cervical OPLL-related admissions, calculated from the nationwide retrospective cohort, is 6.1 per 1 million person-years. The differences in each age and sex category also provide a better understanding of the endemic nature and natural history of the disease.

Very few epidemiological investigations on OPLL come from authors outside Japan. Even in endemic regions of Japan, where there are reports, there is a paucity of cross-sectional epidemiological studies for the actual prevalence rate. Some literature report higher incidences of OPLL in middle-aged patients.[5,18] In 1984, Tsuyama[16] reported the highest incidence among patients 50–59 years old in Japan. In Korea, Kim et al.[5] reported the highest prevalence rate of 1.36% in the age group of 50–59 years old from 11,774 patients who underwent radiographic examinations of the cervical spine. Aside from East Asian countries, Harsh et al.[2] reported on 20 patients from North America with a mean age of 47.5 years old. For the first time, data from the present study clearly demonstrate that older age correlates with higher incidence and prevalence rates of cervical OPLL (Fig. 1). This fact also implies the degenerative nature of the disease.

Ossification of the posterior longitudinal ligament has been reported to be more common in male patients. In the literature, the male/female ratio ranges from 1.1 to 3.0 in different reports, including those from outside Japan.[6,11,18] On the other hand, there are reports that state the opposite. For example, Hiramatsu and Nobechi[3] reported that women were affected 3 times more than men. The discrepancy can again be attributed to the use of an institutional database rather than population-based data. The data in the current study also demonstrate clearly, for the first time, the sex-specific incidences and prevalence of cervical OPLL. Overall, men are almost 3 times more commonly affected than women, and the gap between sexes increases with age. In the male population, incidence and prevalence rates escalate drastically as age increases. Despite a similar increase in women, the actual numbers are smaller, and the increase does not change until they are older than 70 years (Fig. 2).

Cervical OPLL can cause severe adverse effects on spinal cord function. There is no practical treatment other than surgery. However, a large portion of patients with cervical OPLL remain asymptomatic for prolonged periods.[7] Therefore, numerous reports address the best timing of surgery, as well as the choices of surgical approaches.[1,9,10,13,17] In the current cohort, 67.2% of patients received surgical treatment, of whom more than half (55.2%) were

TABLE 4: Demographic factors, co-morbidities, cumulative incidence rates, and adjusted odds ratios of OPLL patient with disability, stratified by surgical approach*

		Approach		
Parameter	Conservative Treatment (542 patients)	Anterior-Only (612 patients)	Posterior-Only (353 patients)	Anterior + Posterior (144 patients)
demographic factor				
female sex	136 (25.1)	199 (32.5)	80 (22.7)	32 (22.2)
mean age (± SD)	60.8 ± 13.7	57.4 ± 11.6	57.5 ± 11.1	58.2 ± 11.1
comorbidity				
diabetes	64 (11.8)	80 (13.1)	46 (13.0)	23 (16.0)
hypertension	107 (19.7)	115 (18.8)	62 (17.6)	26 (18.1)
cerebrovascular disease	31 (5.7)	16 (2.6)	4 (1.1)	5 (3.5)
heart diseases	39 (7.2)	28 (4.6)	17 (4.8)	6 (4.2)
disability (moderate to severe SCI)				
no. of patients w/ disability	21	24	29	11
cumulative incidence rate of disability (%)	3.9	3.9	8.2	7.6
adjusted OR (95% CI)	reference	0.99 (0.54–1.81)	2.19 (1.17–3.77)†	1.93 (0.90–4.14)

* Unless indicated otherwise, values are presented as the number of patients with percentages in parentheses.
† Significant ($p < 0.05$) after adjustments for sex, age, and comorbidities.

via an anterior-only approach, 31.8% were via a posterior-only approach, and 13.0% had a combined anterior and posterior approach. It has always been a classic debate regarding the best surgical approach for such patients with regard to fewer complications and better outcomes. Data in the current study show higher disability rates after posterior surgery. However, this finding should not be misinterpreted as posterior surgery posing more risk on patients. Due to lack of clinical parameters, the analysis is underpowered to compare options for surgical treatment. Nonetheless, it serves as a survey for disease outcomes in epidemiology.

This study also shows a trend of the decreasing risk of disability as the patient ages. This holds true with all age groups with the exception of the 60- to 69-year-old age group. There are still insufficient data to determine the timing of surgical intervention. However, the surge of risk in the 60- to 69-year-old age group implies a potential benefit of intervention in asymptomatic patients belonging to this age group or symptomatic patients reaching this age group. The best timing, as well as choice of surgical approach, requires confirmation in future studies. No conclusion can be made in the present report.

The current study has limitations. First, diagnoses in the national health insurance claims primarily serve administrative billing purposes, and as such, do not undergo verification for scientific purposes. Nonetheless, individuals with cervical OPLL are ascertained by hospitalization and surgical procedures in most cases, which are therefore reliable. Second, the disability outcome of the study is determined by the registry of patients with catastrophic illnesses of the NHIRD, which also serves billing and social welfare benefits, and thus, is under prudent internal monitor. The study individuals are also blinded to the investigator, and mild disability or minor SCI is not included. There is, therefore, a lack of differentiation of degrees of neurological outcome. Third, although demographic data and comorbidities, such as diabetes, hypertension, cerebrovascular disease, and diseases of the heart, have been included in the multivariate logistic regression analysis, personal habits such as smoking, body mass index, and the condition of the anatomical level of the disease are not available from the NHIRD. Additional large-scale studies with detailed clinical parameters will be helpful in further understanding the disease.

One critical caveat of this report is the source of the incidence. The data are collected from OPLL-related admissions, which inheritably underestimated the actual value, due to possible exclusion of asymptomatic or mildly symptomatic patients. Furthermore, since the asymptomatic or mildly symptomatic patients who would not be hospitalized are not included in this database, the data presented in this paper are likely to underestimate the incidence and prevalence of OPLL of asymptomatic or mildly symptomatic patients. The advantages of this study are the nationwide database, which provides a large patient number on a rare disease, and the validity of diagnosis ascertained by admissions. On the other hand, because the hospitalization database of NHIRD used in this study does not include patients who underwent follow-up in the outpatient clinic, there is a bias toward identifying more symptomatic patients who require hospitalization. In addition, the surgical rate in this group is rather high compared with other published series,[10] indicating that there are more symptomatic patients in this cohort leading to a higher rate of surgery. Interestingly, the study raises the importance of the rate of disability. The most symptomatic patients who are disabled from the OPLL are likely to be captured in the database with a high accuracy rate. The relative proportion of patients who are disabled from OPLL, in respect to the overall number of OPLL patients, cannot be determined by this method.

The natural history of cervical OPLL is critical, especially in the management of young or mildly symptomatic patients. However, very few reports address this issue due to the rarity of the disease. Compared with the incidence of cervical disc diseases receiving anterior cervical discectomy and fusion in Taiwan, 98 per 1 million person-years, also calculated by NHIRD, cervical OPLL is indeed an uncommon disease of the cervical spine in the Chinese population. The results of this study can be deemed as indirect evidence indicating the degenerative nature of cervical OPLL. This degenerative process more obviously affects males and the severity of its comorbid disability is related to age and surgical approach. These findings add to literature as a regional, nationwide overview.

Conclusions

In this large cohort of the Chinese population, the incidence of cervical OPLL is 6.1 per 1 million person-years, and its prevalence rate is 7.7 per 100,000 person-years. Higher incidences are observed in elderly and male patients, which implies the degenerative nature of the disease. After adjustment for demographics, the incidences and trends of OPLL-related comorbid disability are associated with age and surgical approaches.

Disclosure

This study was based partly on data from the NHRI database provided by the BNHI, Department of Health, and managed by NHRI in Taiwan. The interpretation and conclusions contained herein do not represent those of the BNHI, the Department of Health, or NHRI.

Author contributions to the study and manuscript preparation include the following. Conception and design: YC Chen, Wu, Liu. Acquisition of data: YC Chen. Analysis and interpretation of data: YC Chen, Wu. Drafting the article: YC Chen, Wu, Liu. Critically revising the article: Wu. Reviewed final version of the manuscript and approved it for submission: YC Chen, Wu. Statistical analysis: YC Chen. Administrative/technical/material support: YC Chen, Huang, TJ Chen, Cheng. Study supervision: Huang, Cheng.

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Manuscript submitted November 14, 2010.
Accepted December 8, 2010.
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Ossification of the posterior longitudinal ligament: genetics and pathophysiology

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Ossification of the posterior longitudinal ligament (OPLL) is a disease of progressive ectopic calcification of the PLL of the spine. It occurs most frequently in the cervical spine, followed by the thoracic spine. The disease was first described in the Japanese population, and the prevalence of OPLL is highest in Japan at a rate of 1.9%–4.3%. Note, however, that OPLL is also seen and is a known cause of cervical myelopathy in other Asian countries and in the white population. Research into the underlying cause of OPLL over the past few decades has shown that it is a multifactorial disease with significant genetic involvement. Genetic studies of OPLL have revealed several gene loci that may be involved in the pathogenesis of this disease. Genes encoding for proteins that process extracellular inorganic phosphate, collagen fibrils, and transcription factors involved in osteoblast and chondrocyte development and differentiation have all been implicated in the pathophysiology of OPLL. In this paper, the authors review current understanding of the genetics and pathophysiology of OPLL. *(DOI: 10.3171/2010.12.FOCUS10271)*

Key Words • ossification of the posterior longitudinal ligament • enthesopathy • cervical myelopathy • diffuse idiopathic skeletal hyperostosis

Ossification of the posterior longitudinal ligament is a disorder of progressive ectopic calcification and ossification of the cervical and thoracic segments of the PLL that results in a compressive myelopathy and/or radiculopathy.[4] Belonging to the same pathological entity as diffuse idiopathic skeletal hyperostosis,[18] OPLL was first described in detail by Tsukimoto and colleagues in 1960 and has a reported prevalence of 1.9%–4.3% in the Japanese population.[1,12] Despite a longstanding predominance in Japan, this disease has also been recognized in other geographic regions and ethnicities, although its prevalence in the US and Europe is only 0.01%–1.7%.[12] In both males and females, the average age at onset is approximately 50 years, and the reported male/female ratio is roughly 2:1. Ossification of the PLL is classically observed and categorized into 4 separate subtypes: segmental; continuous; mixed; and localized, circumscribed, or bridged, with segmental being the most common subtype.[14] A diagnosis is typically made using either plain film radiographs or CTs, on which calcification of the PLL is noted in the appropriate clinical setting.

Early clinical and epidemiological studies conducted in Japan have suggested that the underlying cause of OPLL is multifactorial in nature, reflecting the interplay of numerous genetic and environmental factors.[21,25] Over the past several decades, however, a variety of genetic investigations, including pedigree studies, twin studies, and detailed molecular analyses, have documented many genes or gene loci of interest involved in mediating the molecular and genetic pathobiology of OPLL.[2,5–7,9–11,13,15,17,22,23] Although a host of gene products has been implicated as the root cause, several genes and proteins have emerged over the years as promising targets for future investigation and intervention: *NPPS*, *COL11A2* and *COL6A1*, and BMP-2 and *TGFβ* (Table 1). As OPLL is believed to arise because of endochondral bone formation,[7] each of the aforementioned genetic targets have been shown to critically regulate a crucial step in chondrogenesis, osteogenesis, or bone mineralization.

Abbreviations used in this paper: BMP-2 = bone morphogenic protein–2; NPPS = nucleotide pyrophosphatase; OPLL = ossification of the posterior longitudinal ligament; PPi = inorganic pyrophosphate; SNP = single-nucleotide polymorphism; TGFβ = transforming growth factor–β; *ttw* = tip-toe walking.

TABLE 1: Summary of notable genes, transcription factors, and cytokines implicated in OPLL pathogenesis

Gene	Protein	Chromosome	Physiological Function
NPPS	nucleotide pyrophosphatase	6	regulates soft-tissue calcification & bone mineralization via the production of PPi, a known inhibitor of calcification
COL11A2	α2 chain, Type XI collagen	6	associates w/ Type II collagen & is responsible for forming the size, diameter, & growth rate of fibril networks; forms extracellular matrix scaffolds & may contribute to the formation of ectopic bone by enhancing endochondral ossification
COL6A1	α1 chain, Type VI collagen	21	forms extracellular matrix scaffolds & may contribute to the formation of ectopic bone by enhancing endochondral ossification
BMP-2	BMP-2	20	stimulates proteoglycan formation & alkaline phosphatase activity in chondroblasts & osteoblasts & directs cellular differentiation
TGFβ	TGFβ1	19	mediates bone development & metabolism

Current treatment strategies for patients with myelopathic or radiculopathic symptoms due to OPLL are multifold and often dictated by the subtype of OPLL present, the extent of disease, and the duration of symptoms. Common surgical interventions include decompressive laminoplasty or laminectomy via a posterior approach or direct resection of the OPLL segment with spinal fusion through an anterior approach.[14] However, as neurological surgeons obtain a deeper understanding of the genetic and molecular pathogenesis of OPLL, therapies targeted at preventing the initial formation and progression of OPLL may be pursued further. In the present report, we discuss the role of *NPPS*, *COL11A2, COL6A1*, BMP-2, and *TGFβ* in the pathophysiology of this progressive and debilitating disease entity.

Genetics and Pathophysiology

NPPS

The *ttw*, or tip-toe walking, mouse harbors a natural recessive mutation that results in progressive, ectopic spinal ligament calcification and ossification strikingly similar to that in human OPLL as well as in the ossification of other cartilaginous structures and peripheral ligaments.[10,22] Naturally occurring mutants, the *ttw* mice show spontaneous OPLL, which results in a myelopathic syndrome with an insidious motor disability as the most common manifestation of the disease.[16,17] In 1998 Okawa et al.[16,17] performed genetic analyses on *ttw* mice and discovered a single-base mutation in the *NPPS* gene, which results in a shortened gene product with the loss of more than one-third of the native NPPS enzyme. Physiologically, NPPS is a Type II transmembrane metalloenzyme and regulates soft-tissue calcification and bone mineralization via the production of PPi, a known inhibitor of calcification.[3] In humans, at least 3 isoforms of NPPS exist and are known to be involved in bone mineralization, ligament and joint capsule calcification, and cell motility. The NPPS subtype implicated in OPLL pathogenesis, NPP1 is the main enzyme that generates PPi in osteoblasts and chondrocytes and regulates bone mineralization by decreasing hydroxyapatite crystal deposition.[3] For reasons that have yet to be entirely elucidated, when extracellular PPi levels are low, pathological calcification of ligaments and joints occur.

To investigate the association between NPP1 and OPLL, Koshizuka et al.[10] screened the human *NPPS* locus for SNPs in a case-control association study involving 180 patients with OPLL and 265 without. Their study demonstrated that a T→C substitution in intron 15 at position 14, upstream from the start of exon 16, was significantly associated with OPLL susceptibility and severity. However, a base-pair deletion in intron 20 at position 10, upstream from the start of exon 21, did not display a significant difference in allelic distribution between patients with OPLL and controls. In a prior case-control study in 323 patients with OPLL and 332 without, Nakamura et al.[15] found a T deletion at 11 nucleotides upstream from the splice acceptor site of intron 20 that was significantly associated with OPLL susceptibility, suggesting again that NPP1 may be important in OPLL pathophysiology. Tahara et al.[22] performed a similar case-control association study and likewise noted an association between certain SNPs in the *NPPS* gene and OPLL. Moreover, Tahara and colleagues discovered that other SNPs were strongly associated with disease severity when comparing patients with cervical OPLL versus those with both cervical and thoracic disease. Despite the important associations between these NPP1 sequence variants and OPLL disease susceptibility, these genetic studies did not examine NPP1 activity within the study participants. As a result, whether the expression and function of NPP1 is altered in these OPLL cohorts remains unknown. In 2001 Rutsch et al.[19] did describe the case of 2-year-old boy with a documented deficiency of NPP1 and a syndrome termed "idiopathic infantile arterial calcification," a disease in which patients experience early, pathological arterial and articular calcification. Ossification of the PLL was not noted in the boy, however. On the whole, while the phenotype of the *ttw* mouse and the numerous case-control studies demonstrating an association between certain SNPs in *NPP1* and OPLL susceptibility suggest a role for NPPS in the pathogenesis of OPLL, further molecular and functional studies are necessary to show a causative link.

COL11A2 *and* COL6A1

COL11A2 encodes the α2 chain of Type XI collagen, a minor collagen that associates with Type II collagen and is responsible for forming the size, diameter, and growth rate of fibril networks.[4,11] Sakou et al.[21] performed genetic linkage analyses on 90 sibling pairs from 53 families with a history of OPLL and deduced that genetic abnormalities in the *COL11A2* gene were significantly associated with a predisposition to OPLL. Further gene mapping studies by this group demonstrated that the observed genetic mutations resulted in an aberrant N-propeptide of the $\alpha 2$ chain of Type XI collagen, and thus affecting the size and conformation of the resulting fibril structures.[20] Physiologically, the N-propeptide of the $\alpha 2$ chain is purported to alter the conformation and shape of Type II collagen, which is responsible for bone and cartilage formation, and to mediate the interaction between extracellular matrix proteins and cell surface molecules. Moreover, Maeda et al.[11] studied 195 patients with OPLL and 187 without and discovered an SNP on intron 6 of the *COL11A2* gene that results in altered splicing in the region containing exons 6 through 8 with preservation of exon 7, which seems to confer a protective advantage in the development of OPLL. On the other hand, Koga et al.[7] identified SNP variants of the *COL11A2* promoter and intron 6 that were positively associated with OPLL susceptibility in their group of 124 sibling pairs from 53 families. Although the specific role of Type XI collagen in the pathogenesis of OPLL remains undefined, its role in the formation of extracellular matrix scaffolds may contribute to the formation of ectopic bone by enhancing endochondral ossification.[4] Further, while the aforementioned studies do not provide a mechanistic link or explanation for Type XI collagen's function in OPLL, the positive and negative association of various SNP variants with disease susceptibility supports the theory that *COL11A2* is in fact important in the disease pathogenesis. In addition to *COL11A2*, *COL6A1* is a gene that encodes the $\alpha 1$ chain of Type VI collagen and has also been implicated in OPLL susceptibility.[9] Tanaka et al.[23] performed a genome-wide study on 142 affected sibling pairs and discovered a high level of evidence of linkage on chromosome 21, localizing to the *COL6A1* gene. Ultimately, future genetic, molecular, and functional studies focusing on the role of Types VI and XI collagen in OPLL may yield novel therapies for this progressive disease process.

Bone Morphogenic Protein–2 and TGFβ

Bone morphogenic proteins are multifunctional transcription factors that are members of the TGFβ superfamily of proteins and are involved in regulating cartilage and bone formation.[8,28] During development, BMPs stimulate proteoglycan formation and alkaline phosphatase activity in chondroblasts and osteoblasts and direct cellular differentiation.[21] In vitro studies indicate that BMP-2 is capable of augmenting osteoblast maturation and inducing mesenchymal cells to differentiate into osteoblasts.[24] Moreover, BMP-2 has been shown to induce ectopic bone formation in rats.[26,27] In 1997 Kon et al.[8] examined the effect of recombinant BMP-2 in primary cultures of fibroblast cells derived from OPLL tissue and non-OPLL ligamentous cells. The authors demonstrated that the BMP-2 was capable of preferentially inducing alkaline phosphatase activity in OPLL cell lines as opposed to non-OPLL cell lines, indicating that BMP-2 is critically important in regulating osteogenic differentiation and function. Moreover, Yonemori et al.[28] discovered that BMP receptors are expressed to a significantly greater degree in the ossified ligament of OPLL specimens than in non-OPLL tissue. In addition, the nonossified segment of the PLL in patients with OPLL also expressed the BMP receptors to an extent greater than non-OPLL tissue but less than ossified OPLL segments. This finding suggests either that observable molecular changes may precede the development of OPLL or that patients with OPLL have a genetic and molecular susceptibility to OPLL via the expression of the BMP receptors. Although BMP-2 and its respective receptors have not been the subject of such rigorous genetic studies as *NPPS*, *COL11A2*, and *COL6A1*, detailed molecular biological and functional studies have confirmed its role in the pathogenesis of OPLL and thus rendered it a promising therapeutic target.

Transforming growth factor–β, specifically TGFβ1, is an important mediator of bone development and metabolism and has been found in chondrocytes of the ossified cartilage in OPLL specimens.[6] Transforming growth factor–β1 has been the subject of both genetic and molecular biological studies, and recent findings have highlighted its importance in the pathogenesis of OPLL. In a series of 46 patients with OPLL and 273 without, Kamiya et al.[5] identified the association between a T869→C polymorphism in the *TGFβ1* gene and susceptibility to OPLL in the Japanese population. Kawaguchi et al.[6] further examined this SNP to determine if there was an association with the radiological appearance of OPLL. Ultimately, the group found that the T→C transition in the signal sequence did not predict a difference in the radiographic appearance of the ossified segment of PLL, but the difference in distribution of the SNPs was associated with the location of OPLL within the spinal column. While the physiological function of TGFβ1 hints at a potential role in the pathobiology of OPLL, additional genetic and functional studies are necessary to provide a true mechanistic link.

Over the past several decades, a host of genes, cytokines, and growth factors have emerged as potential factors underlying the molecular pathobiology of OPLL. While several studies have demonstrated an association between certain gene mutations and OPLL susceptibility and others have pointed to a functional role in OPLL pathogenesis, future detailed molecular and functional studies of these gene products are necessary to verify their appropriateness for therapeutic intervention.

Conclusions

Ossification of the PLL is a progressive and debilitating disease of spinal cord compression. While the underlying genetics and molecular pathobiology of the disease is currently under study, several genes, transcription factors, and cytokines have emerged as potential molecular causes and therapeutic targets. Although an array of factors have been studied and implicated over the years, NPP1, Types VI and XI collagen, BMP-2, and TGFβ have been identified by several groups and probably represent key proteins in the molecular pathogenesis of OPLL. As further discoveries are made in the field of molecular biology, targeted therapies can be implemented in the neurosurgical arena to complement and augment the current anterior and posterior surgical approaches to the management of this insidious disease process.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: Stapleton. Drafting the article: Hsieh, Stapleton, Pham. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: Hsieh. Administrative/technical/material support: Attenello, Pham. Study supervision: Hsieh.

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Manuscript submitted November 15, 2010.
Accepted December 17, 2010.

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The genetics of ossification of the posterior longitudinal ligament

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Object. Ossification of the posterior longitudinal ligament (OPLL) is a pathological process of ectopic calcification with a preponderance for the cervical spine. Epidemiological and familial studies have both indicated predisposition; however, the genetic inheritance pattern and responsible genes for OPLL are still uncertain. The aim of this study was to evaluate and summarize the current understanding of the genetics underlying OPLL.

Methods. The authors reviewed epidemiological and genetic studies surrounding OPLL, with a particular focus on inheritance patterns and potential genes responsible for OPLL, using a PubMed database literature search.

Results. Despite an unclear inheritance pattern, there appears to be a strong familial link in patients with OPLL. Examination of these patterns using linkage analysis has shown multiple candidate genes that could be responsible for the inheritance of OPLL. Genes for collagen, nucleotide pyrophosphatase, transforming growth factors, and the vitamin D receptor have all been implicated. Additionally, multiple cytokines and growth factors, including bone morphogenetic proteins as well as other proteins and interleukins involved in bone development, have been shown to be abnormally expressed in patients with OPLL. In addition, multiple mechanical and metabolic factors such as hyperinsulinemia and obesity have been shown to be linked to OPLL.

Conclusions. Ossification of the posterior longitudinal ligament has a complex inheritance pattern. It does not appear that OPLL follows a simple, single-gene Mendelian inheritance pattern. Development of OPLL is more likely multifactorial in nature and develops in patients with a genetic predisposition from a variety of different mutations in various genes on various chromosomes. Additionally, environmental factors and interaction by other pathological disease processes, such as obesity and diabetes mellitus, may play a role in the development of OPLL in susceptible individuals. *(DOI: 10.3171/2010.12.FOCUS10275)*

Key Words • **ossification of the posterior longitudinal ligament** • **genetic analysis** • **review**

Ossification of the posterior longitudinal ligament refers to pathological mineralization. This ectopic ossification is slowly progressive, and patients with OPLL can range from asymptomatic to severely myelopathic.[7,27] The most common location of OPLL is the cervical spine[43] followed by the thoracic spine,[34] but it can also occur anywhere in the spinal axis. Ossification of the posterior longitudinal ligament is more frequently noted in male patients by a ratio of 2:1,[19] and is more common in East Asian populations, particularly in the Japanese[7] where it was first described.[27] The incidence increases with age, with most cases occurring after 40 years of age.[43] Previously, the inheritance patterns of OPLL were confined to familial studies and large-scale epidemiological studies to discern predisposing risk factors and possible Mendelian inheritance patterns.[3,7,33,34,38,43] However, with the recent advances in genetic laboratory technology as well as the understanding and sequencing of the human genome, more specific studies to determine gene mutations involved in, predisposing to, and causing OPLL have been pursued.[2,12,14–16,18–22,25,26,28,30,32,36,39] Analysis of contributing factors such as growth factors, transcription factors, and cytokines have also become possible with advances in cytochemical laboratory techniques.[1,4,9–11,23,29,35,40–42] Taken together, this is a new era of understanding not only the inheritance of OPLL, but also its pathogenesis, natural history, and exacerbating factors.

Abbreviations used in this paper: BMP = bone morphogenetic protein; HLA = human leukocyte antigen; NPPS = nucleotide pyrophosphatase; OPLL = ossification of the posterior longitudinal ligament; SNP = single nucleotide polymorphism; TGF-β = transforming growth factor–β; ZFR = Zucker fatty rat.

Methods

A comprehensive literature search was performed using the PubMed database for all journal articles published until October 2010. Key words used in the search included "ossification of the posterior longitudinal ligament," "genetics," "OPLL," and "epidemiology;" terms were searched individually or in combination. The appropriate articles for our review were selected based on scientific investigations surrounding the genetic inheritance and susceptibility patterns of OPLL in humans and animal models. We limited our results to articles only in the English language.

Results

Familial Inheritance Pattern Studies

Initial inheritance studies of OPLL were limited to epidemiological investigations of the disease with a focus on familial prevalence. Overall, OPLL is considered to be more common in East Asian populations with a prevalence between approximately 2% and 4%, which is markedly more common than in the US and Europe, where prevalence is roughly 0.01%–2%.[14] Studies in twins have shown that OPLL tends to involve analogous types of pathological ossification, and point toward genetic rather than environmental factors as influencing development of OPLL.[33] Furthermore, the prevalence of OPLL has been shown to be much greater among family members of patients with OPLL.[3,38] Terayama[38] studied 347 patients with OPLL and their families, and found that OPLL was found in approximately 26% of the patients' parents and in 28% of the patients' siblings, indicating a strong familial predisposition to OPLL. This finding was troubling, given that the inheritance patterns were not consistent with either a classic autosomal dominant or recessive pattern of inheritance. The authors concluded that OPLL was likely explained by a single gene inheritance, and that given the late-onset of OPLL, the most likely mode of inheritance was actually autosomal dominant inheritance with incomplete penetrance. In contrast, Hamanishi et al.[3] examined a single family in detail and determined that OPLL inheritance in this family was consistent with autosomal recessive inheritance patterns. From such familial studies, it is clear that OPLL has a strong genetic inheritance; however, the pattern of genes responsible for this inheritance is uncertain.

Association of OPLL to HLA Haplotypes and Examination of Chromosome 6

In 1991, Sakou et al.[28] studied 33 families of patients with OPLL and examined the HLA haplotypes of these families. They found that there were 6 HLA haploytpes that were observed frequently in that population, and 3 of these haplotypes were found to be exceedingly rare in the general Japanese population, suggesting an association of OPLL and these rare haplotypes. Moreover, it was found that the relatives of patients with OPLL who also had OPLL tended to have both identical HLA haplotypes, whereas relatives without OPLL had only 1 shared HLA haplotype. This study indicated that OPLL inheritance was genetic, given that an individual inherits 1 HLA gene set from each parent, and the relatives of patients with OPLL who also had OPLL tended to have identical HLA haplotypes. Furthermore, the authors concluded that the gene responsible for OPLL would likely fall on the same chromosome that coded HLA (chromosome 6). These results were later confirmed in a study of 24 patients and 61 sib-pairings, in which relatives with 2 HLA haplotypes had greater than a 50% chance of having OPLL, and those with only 1 identical strand were shown to have less than a 25% chance.[20]

Following these findings, a search for the gene responsible for OPLL on chromosome 6 was undertaken. Koga et al.[14] analyzed 91 affected sib-pairs using genetic linkage and found that the gene for collagen 11A2 (*COL11A2* encoding the α_2 chain of type XI collagen), near the HLA complex, showed a strong linkage. Of the 19 gene variants found, 4 revealed a statistically significant likelihood of association with OPLL. These findings were supported by further research by the same group in which they found that a polymorphism of intron 6 (-4A) resulted in an alteration of the splicing of the *COL11A2* transcript, offering more evidence that *COL11A2* was in fact the gene responsible for OPLL. Specifically, they found that retention of certain exons (exon 7) combined with loss of another exon (exon 6) within this intron was associated with a lower probability of OPLL, perhaps conferring a protective role.[18] Another study examining the *COL11A2* gene from 161 patients with OPLL revealed 5 frequent SNPs from which likelihood ratios were able to construct potential haplotypes. Of these, the most commonly noted haplotype was found to be more frequent in male patients. The authors believed this to be congruous with the known prevalence of OPLL in males (at a 2:1 ratio to females in epidemiological studies), and concluded that this demonstrated further evidence that *COL11A2* was the gene behind OPLL.[19]

Large-Scale Screening Studies for Candidate Genes in OPLL

Despite all the evidence that pointed toward *COL11A2* as a gene responsible for OPLL, several groups continued to search for additional and alternative genes responsible for OPLL. Tanaka et al.[36] conducted a genome-wide linkage analysis of 142 sib-pairs and detected linkage on 6 different chromosomes, with the strongest linkage on 21q, far away from the locus of *COL11A2*. In total, 4 genes were identified in the linkage area noted. Single nucleotide polymorphism linkage disequilibrium testing was performed, revealing that *COL6A1* (encoding the α_1 chain of type VI collagen) was the gene that was most closely related to OPLL. Polymorphisms of this gene were further found to be related to diffuse idiopathic skeletal hyperostosis in the Japanese population (another related disease process of pathological ossification),[39] as well as OPLL in the Chinese (and not just the Japanese) population.[15] These studies provided additional evidence that *COL6A1* not only played a strong role in OPLL, but in pathological ectopic ossification in general. Likewise, Furushima et al.[2] studied 88 candidate genes, including

COL11A2 and multiple genes known to be involved in the ossification process, and found no association with OPLL with any except *BMP4*, which itself was only weakly linked.

Further study of genes near the HLA locus was pursued by the same team that described the initial linkage distal to the HLA complex. Numasawa et al.[22] examined the retinoic X receptor β (*RXRβ*) locus in 134 patients, as this gene was noted to be adjacent to *COL11A2* in the murine and human genomes on chromosome 6 near the HLA locus. They discovered 3 variants, 2 of which showed a strong association with OPLL, suggesting that this gene and its location on chromosome 6 may be associated with the inheritance of OPLL.

Other groups have investigated the vitamin D receptor gene as a potential link to OPLL. One group found that the B allele occurred much less frequently in patients with ossification of spinal ligaments in general than controls, implicating that 1) the vitamin D receptor gene *(RXRβ)* could play a role in inheritance of OPLL, and 2) that the B allele may act as an inhibitor of ossification.[30] Along the same lines, another group noted that a certain SNP of the vitamin D receptor gene (F*ok*I variant) was connected to OPLL in comparison with controls. They found that the FF genotype was strongly associated with OPLL (while the F allele is protective), further suggesting a role for the vitamin D receptor gene in the inheritance of OPLL.[12]

Animal Models of OPLL: Insight Into Inheritance and Pathogenesis of OPLL

Since Hosoda et al.[5] first described the tiptoe walking *(twy)* mouse, it has been used as an animal model for OPLL. This naturally occurring mutant mouse has pathological ossification of the spinal ligaments similar to OPLL that results in progressive myelopathy and paresis.[16,21,25,26] In an effort to determine the human locus of a gene responsible for OPLL, several groups attempted to find the murine gene responsible for *twy*. Okawa et al.[25] first localized the gene to a small segment on murine chromosome 10, and then they were able to determine that the gene responsible was *NPPS*, a gene encoding NPPS, which was mutated in *twy* resulting in a stop codon.[26] Since NPPS was known to be an inhibitor of calcification, the gene encoding this enzyme seemed a plausible candidate gene for not only *twy* but also OPLL. Therefore, 323 patients with OPLL were screened for SNPs of *NPPS*, and 2 SNPs were found solely in patients. After further study, Nakamura et al.[21] were able to determine that a deletion in the viz allele occurred in a significantly greater percentage of OPLL patients than in controls, indicating that human NPPS and the gene encoding it *(NPPS)* likely played a strong role in the genetics of OPLL. Furthermore, it has been shown that a different SNP in human *NPPS* resulted in not only increased propensity toward OPLL, but also increased severity of OPLL.[16]

The ZFR is a murine model that was originally used for obesity, hyperinsulinemia, hypercholesterolemia, and hyperlipidemia. However, it was noted that these mice had orthotopic ossification of spinal ligaments and that this ossification is histopathologically similar to human OPLL.[24] Therefore, ZFRs have been proposed as, and subsequently used as, a model for OPLL. Since the leptin receptor gene is known to be the mutated gene in the ZFR model,[6] serum leptin levels were analyzed in patients with spinal ligament ossification and compared with controls. It was found that females with ossified spinal ligaments (such as OPLL) had significantly higher serum leptin levels and insulin levels than controls,[31] suggesting that leptin and the leptin receptor gene may play a role in the inheritance and pathogenesis of OPLL. Further study has shown that SNPs of NPPS and the leptin receptor gene are not necessarily related to OPLL, but rather that polymorphisms of the genes for NPPS and the leptin receptor are associated with greater severity of OPLL.[32]

Exogenous Factors May Contribute to OPLL

While the aforementioned studies point toward a strong genetic component in the development of OPLL, multiple studies have shown that various exogenous and modifiable risk factors may also contribute to the development of OPLL. Kobashi et al.[13] administered questionnaire forms to 69 patients with OPLL and found that obesity, diabetes mellitus, and lumbago were independent risk factors for OPLL. Additionally, a family history of myocardial infarction, limited intake of vegetables and salads, and even long working hours have been noted as independent risk factors.[12] The role of hyperinsulinemia itself was studied by Li et al.,[17] who noticed that high concentrations of insulin promoted BMP-2 to induce alkaline phosphatase expression/activation, which could in turn indirectly induce osteogenic differentiation.

Mechanical stretch has also been proposed as a contributing factor in the pathogenesis of OPLL; however, that mechanism has not been well described. Tanno et al.[37] demonstrated that cyclic stretching on cultured spinal ligaments increased expression of alkaline phosphatase, osteopontin, and several BMPs and BMP receptors. A similar study by Iwasawa et al.[8] showed that endothelin and alkaline phosphatase expression was increased with mechanical stress in OPLL specimens, but not in non-OPLL specimens, suggesting that mechanical stress may promote ossification in susceptible cells.

Cytokines and Transcription Factors

With the development of better histochemical laboratory studies, multiple growth factors, cytokines, and transcription factors have been implicated in the inheritance and pathogenesis of OPLL.[7] Kawaguchi et al.[10] initially showed that BMP-2 and TGF-β were present in the ossified matrix of the posterior longitudinal ligaments of patients with OPLL and thus suggested that BMP-2 and TGF-β were important initiators in the ossification process in OPLL. Tanaka et al.[35] later confirmed that the *BMP-2* gene was expressed in spinal ligaments of patients with pathological ectopic ossification of the spinal ligaments (such as OPLL). Furthermore, they proved that BMP-2 presence activated alkaline phosphatase, which suggested that BMP-2 could have a direct causal role in ossification of spinal ligaments. Likewise, Kamiya et al.[9] confirmed that an SNP in the *TGF-β1* gene was more likely to be found in patients with OPLL. Others have shown that polymorphisms of the *BMP-2* gene are associated with severity[11,40] as well as prevalence of OPLL.[40] Horikoshi et al.[4] demonstrated that an alternative TGF gene, *TGFB3*, was found to have a significant association to OPLL (while many other previously implicated candidate genes, such as *COL11A2*, did not show significant association). Other growth factors, cytokines, and genes that have been shown to have increased expression or different polymorphisms between patients with OPLL and those without included purinoceptors,[29] osteopontin,[1] CTGF/Hcs24,[42] the estrogen receptor, and interleukin-1.[23]

Discussion

Since the original studies demonstrating a strong familial tie to OPLL,[3,14,38] the genetic contribution to the development of OPLL has been undeniable. The conflicting reports from these studies, with some suggesting that OPLL follows autosomal dominant inheritance[38] while others suggest it follows autosomal recessive inheritance,[3] point toward a complex inheritance pattern for OPLL. It seems most likely that OPLL follows neither classic autosomal dominant or recessive inheritance patterns.

A link between HLA and OPLL[20,28] appears to be present, but an association of HLA with OPLL does not implicate causation. Many pathological disease processes are noted to be more frequent with a certain HLA type (diabetes, ankylosing spondylitis, and others). Similarly, the HLA haplotypes associated with OPLL in Sakou and Matsunaga's studies[20,28] may not be responsible for OPLL. Rather, it seems more likely that the HLA haplotypes noted to be associated with OPLL are only that—associated with an increased likelihood of a patient having OPLL.

While many groups have implied that *COL11A2* is the gene responsible for OPLL,[14,18,19] other groups have failed to find an association of *COL11A2* with OPLL in their series,[4] thus calling into question the role of *COL11A2* in the inheritance of OPLL. It makes sense theoretically that a collagen gene could be responsible for OPLL, given collagen's intimate relationship to bone formation. Therefore, it makes just as much sense that *COL6A1* may be a contributing gene in OPLL, as is implicated in multiple other studies.[15,36,39] This gene's association does, however, negate the idea that the gene responsible for OPLL lies on chromosome 6 near the HLA locus.[14] This idea assumes, however, that there is only 1 responsible gene for OPLL, an idea that seems less likely given the multitude of other genes implicated in various studies as being associated with OPLL inheritance (*BMP-4*,[2] *RXRβ*,[22] *NPPS*,[16,21] and leptin receptor gene[32]). Therefore, it seems most likely that OPLL has many potential genes involved in its inheritance, pathology, and expression. This would then also explain the inability of familial studies to explain the type of autosomal inheritance pattern (autosomal dominant vs recessive), as these studies also assumed a single gene inheritance pattern.

Additionally, it seems clear that multiple growth factors,[4,9–11,35,40,41] cytokines,[23,42] and transcription factors[1,29] are involved in the pathogenesis, inheritance, and development of OPLL. Multiple polymorphisms in multiple genes of multiple bone modulating proteins have been linked to OPLL. It seems that with so many and so varied mutations noted, it is unlikely that there is only 1 growth factor gene responsible for OPLL. Rather, it seems most likely that any number of mutations in a variety of genes for growth factors, cytokines, and transcription factors may be associated with OPLL, and therefore predispose a patient for developing OPLL, even if there is no direct causation.

Finally, the interactions of both mechanical components as well as other disease pathologies have been linked to OPLL. Hyperleptinemia,[31] hyperinsulinemia,[17] obesity, and diabetes mellitus[13] have all been linked to OPLL in both humans and mice (ZFR model).[24] It is unclear, however, whether these states cause formation of OPLL, or whether they merely predispose patients to the development of OPLL. For example, not all patients with diabetes have OPLL, and not all patients with OPLL have diabetes. Therefore, it is difficult to associate a causation of diabetes to OPLL.

Likewise, mechanical stretch has been shown to induce expression of BMPs[37] and endothelins[8] to contribute to bone synthesis in susceptible OPLL cells, but not in controls. Again, direct causation cannot be attributed, as only susceptible cells (OPLL cells) show induced expression of BMPs with stretch. Rather, it seems that all these exogenous factors may contribute to the development of OPLL in susceptible individuals, but not in those without a predetermined susceptibility.

Ossification of the posterior longitudinal ligament likely demonstrates multifactorial inheritance. From the large number of genes that have been associated with OPLL (from many conflicting studies), it seems only logical that there are likely multiple genes involved in not only the inheritance, but also the pathogenesis of OPLL. Furthermore, varied exogenous factors have been noted to contribute to the development of OPLL. In all likelihood, there are in fact multiple exogenous factors that are not mutually exclusive contributing to development of the underlying disease process in susceptible individuals over a course of many decades before they actually develop symptoms.

Conclusions

The inheritance patterns of OPLL are extremely complex, given that very likely multiple genes are involved in the development of pathological ectopic ossification. There are also multiple exogenous factors that likely contribute to the pathogenesis of OPLL, but only in genetically susceptible individuals. Therefore, the inheritance of OPLL is best described as a multifactorial genetic inheritance.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: Stetler. Analysis and interpretation of data: Park, Stetler. Drafting the article: Stetler. Critically revising the article:

Park. Reviewed final version of the manuscript and approved it for submission: Park, La Marca. Study supervision: Park, La Marca.

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Manuscript submitted November 15, 2010.
Accepted December 2, 2010.
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Dorsal versus ventral surgery for cervical ossification of the posterior longitudinal ligament: considerations for approach selection and review of surgical outcomes

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Ossification of the posterior longitudinal ligament is a common cause of radiculopathy and myelopathy that often requires surgery to achieve decompression of the neural elements. With the evolution of surgical technique and a greater understanding of the biomechanics of cervical deformity, the criteria for selecting one approach over the other has been the subject of increased study and remains controversial. Ventral approaches typically consist of variations of the cervical corpectomy, whereas dorsal approaches include a wide range of techniques including laminoplasty, laminectomy, and laminectomy with instrumented fusion. Herein, the features and limitations of these approaches are reviewed with an emphasis on complications and outcomes. *(DOI: 10.3171/2010.12.FOCUS10270)*

Key Words • **ossification of the posterior longitudinal ligament** • **corpectomy** • **laminoplasty** • **cervical myelopathy** • **outcome**

Ossification of the posterior longitudinal ligament in the cervical spine is a common cause of myelopathy and radiculopathy that affects mostly persons of Asian descent.[1,30,31] There has been considerable debate in recent years regarding the optimal surgical approach for addressing these compressive lesions. Ventral approaches consist of variations of the cervical corpectomy, whereas dorsal approaches include a wide range of techniques including laminoplasty, laminectomy, and laminectomy with instrumented fusion. With the evolution of surgical technique and a greater understanding of the biomechanics of cervical deformity, the criteria for selecting one approach over the other has been the subject of increased study.

Of the many factors to consider when deciding on either a dorsal or ventral approach, the degree of stenosis related to the severity of ventral compression of the spinal cord by the ossified lesion is critical to decision making as patients with greater degrees of stenosis have historically shown less improvement following either dorsal or ventral surgery.[4,36] Often spanning more than 1 vertebral level, the advantages of either approach have been described in limited retrospective case series, with each varying in the quality of outcome measures used to assess clinical outcomes following surgery. Herein, we discuss the features of each approach and review their associated outcomes.

Abbreviations used in this paper: JOA = Japanese Orthopaedic Association; OPLL = ossification of the posterior longitudinal ligament; VB = vertebral body.

Biomechanical Considerations

Determining which surgical approach will best achieve the goals of decompression while preserving regional sagittal balance requires an understanding of biomechanics and a consideration of the preexisting deformity. Although there are insufficient clinical data to suggest that correction of any preexisting deformity improves outcomes associated with OPLL, there are retrospective data indicating that patients who undergo dorsal procedures without instrumentation may worsen neurologically as a result of progressive kyphosis.[8,24] With regard to OPLL, the presence of a compressive lesion ventral to the spinal cord increases the risk of neurological deterioration during any attempt at deformity correction, particularly if a dorsal procedure is planned. For this reason, careful assessment of the presurgical sagittal alignment and the occupying volume of the ossified mass are critical to selecting the best approach as correction of deformity may not always be feasible without significant morbidity.

Cervical kyphosis may be the result of iatrogenic destabilization, trauma, degeneration, and systemic inflammatory diseases. However, it is most commonly observed after multilevel dorsal decompression, with rates of clinically significant kyphosis as high as 21%.[6,12,23]

If a kyphotic deformity is present, a flexion moment is created with the head pitched forward relative to the normal alignment of the cervical spine.[2,3] This abnormal posture shifts the normally neutral axial force of the head ventral to the instantaneous axis of rotation, thus creating a flexion bending moment. This leads to further kyphosis.[5] Thus, a vicious cycle of abnormal forces and progressive deformity is created.[2,3,6] If kyphosis becomes severe, the spinal cord may stretch over the apex of the deformity and lead to further neurological decline.[5]

Radiographic Criteria for Approach Selection

The criteria used to select either a dorsal or ventral approach should be based on a number of factors including patient age, comorbidities, severity of symptoms, previous surgery, type of OPLL, extent of OPLL, degree of stenosis, surgeon preference, and assessment of cervical deformity.

Various radiographic schemes have been proposed to help select the best approach for patients with cervical myelopathy. Gwinn et al.[14] proposed a simple straight-line method to measure effective spinal canal lordosis in patients with cervical myelopathy. In this scheme, a straight line is drawn from the dorsal-caudal aspect of the C-2 VB to the dorsal-caudal aspect of the C-7 VB (Fig. 1). Effective lordosis is maintained if no ventral bone structure such as VBs, disc-osteophyte complexes, or hypertrophic calcifications project dorsal to this line. Otherwise, effective lordosis is considered lost (Fig. 2). This straight-line method of assessing cervical lordosis was compared with traditional methods of measuring cervical alignment including the Cobb and dorsal tangent methods. It was found to be a reliable indicator of overall alignment of the cervical spine as well as compression ventral to the spinal cord. It is proposed that this loss of effective lordosis due to the presence of a compressive mass may have a role in determining the best surgical approach as ventral surgery may better achieve decompression in these patients.

In 2008, Fujiyoshi et al.[11] proposed a new concept for decision making regarding the surgical approach for cervical OPLL. They introduced a new index called the K-line to help determine the effectiveness of a dorsal approach. This line was defined as a line on a lateral radiograph drawn between the midpoints of the spinal canal at C-2 and C-7. According to this line, 2 groups of patients with OPLL were identified. In the K-line (+) group, the OPLL lies ventral to the K-line. In the K-line (–) group, the OPLL passes the line and lies dorsal to the line. In their series, 27 patients with myelopathy as a result of OPLL underwent either laminoplasty or laminectomy with instrumented fusion. Intraoperative ultrasonography was also used to evaluate the dorsal shift of the spinal cord from the OPLL. The relationship between the dorsal shift of the spinal cord and the K-line classification was made. Clinical outcomes were assessed using the JOA scores before surgery and at 1 year after surgery.

Fig. 1. In this digital radiograph, the line drawn from the dorsal caudal aspect of C-2 to the dorsal caudal aspect of C-7 is used as a reference to measure effective cervical lordosis. In this image, effective spinal canal lordosis is maintained, as no bone from the VBs or disc space is projecting dorsal to the line. Reprinted with permission from Gwinn et al: **J Neurosurg Spine 11:**667–672, 2009.

Overall, statistically significant improvement in JOA scores was found in the K-line (+) group. Complications and neurological worsening were not reported. Based on these findings, Fujiyoshi et al.[11] proposed that patients with cervical OPLL that extend dorsal to the K-line have a better chance for neurological improvement with a ventral approach, but no patients were studied to support this recommendation. Based on their outcomes and correlation with intraoperative ultrasound, it is their assertion that K-line (–) patients have kyphosis that prohibits a dorsal approach as the spinal cord has less potential to shift following decompression.

Ventral Approaches

In general, there are 2 surgical procedures for the treatment of OPLL: direct removal of the ossified ligamentum through a ventral approach, or decompression through a dorsal approach.[1,5]

The ventral approach with direct resection of OPLL and decompression of the spinal canal is well described and is an effective option with excellent results (Table 1).[28] Ventral decompression becomes more technically demanding, however, with significant narrowing of the spinal canal and ventral displacement of the spinal cord due to large ossified lesions. The risk of complications including CSF leakage and iatrogenic neurological deterioration significantly increases with the extent of OPLL as dural ossification often prohibits identifying an adequate plane of dissection.[9,10] Residual OPLL behind the VB also

Fig. 2. Digital radiograph clearly showing vertebral endplates with osteophytes projecting dorsal to the effective lordosis line indicating a loss of lordosis within the spinal canal. Reprinted with permission from Gwinn et al: **J Neurosurg Spine 11:**667–672, 2009.

requires extensive undercutting and drilling under high-power magnification to ensure adequate decompression of the spinal cord.

Several variations of the corpectomy have been reported with favorable results.[21,28,29,36] Because these ossified lesions often extend beyond the level of the endplate and behind the VB, corpectomy is essential to allow complete visualization of the compressive mass and achieve adequate decompression of the spinal cord. Reconstruction of the ventral vertebral column can then be performed using a number of different grafts including iliac crest, fibula, autogenous VB graft, and titanium.[17,25,26,30] Because the use of allograft in humans is illegal in Japan, there are few reports of allograft use for the treatment of OPLL.

Although this strategy has been shown to be highly effective for patients with short segment compression and kyphosis, historically high rates of pseudarthrosis, bone graft subsidence, and graft dislocation have been seen with long or multisegment constructs.[3,22] These complications are largely a result of suboptimal bony points of fixation, poor biomechanical constructs, and the reliance on screw fixation as the only available method of bony fixation afforded by the ventral approach.[4]

Pseudarthrosis has historically been a major concern following corpectomy. The rate of pseudarthrosis ranges from 4% to 6% for 1-level fusions and increases to 17% to 30% when 3 levels are fused.[5,10,34] Shinomiya et al.[34] found that 16 (12%) of 129 patients required a second operation for pseudarthrosis. Epstein[10] reported that 3 (4.7%) of 76 patients required supplemental dorsal fixation for pseudarthrosis. In this series, corpectomy was performed on average over 3 levels without anterior plate instrumentation, using iliac crest or fibular strut autografts. At 3 months, dynamic radiographs in 20 patients demonstrated radiographic instability consistent with pseudarthrosis. At 6 months, 10 of these patients underwent fusion and another 7 were clinically stable despite persistent evidence of lucency around the grafts. Mizuno and Nakagawa[29] found 3 cases of postoperative kyphotic deformity (6.7%) due to pseudarthrosis in patients receiving iliac crest grafts and 9 cases (24%) in patients receiving VB grafts. There were no cases of pseudarthrosis when anterior plates were used in this series.

Some of these issues may be mitigated by the use of intermediate points of fixation and by the introduction of dynamic implants, although their true effectiveness in this regard has yet to be proven.[4] With increased use of ventral cervical plates and a greater appreciation for the biomechanical implications of long multisegment vertebral grafts with flexion, extension, and load bearing, fusion rates have improved. Supplemental dorsal fixation following multilevel corpectomy has also decreased the rate of bone graft subsidence and graft dislocation in patients who had previously been immobilized in halos postoperatively.

A variation to the standard corpectomy is the technique of square-shaped corpectomy and use of autologous VB as graft for reconstruction of the ventral column as described by Williams and modified by Isu and colleagues.[17,18,25] A square-shaped corpectomy is performed rostral and caudal to the disc around which the OPLL is centered. This prevents having to perform a complete corpectomy as the square-shaped VB resection is performed to the extent of the OPLL behind the VB. The removed vertebral bone is then saved for use as a bone graft. After removal of the OPLL, the vertebral bone is stacked together and sutured with nylon. This is then placed within the VB defect.

Before the widespread use of ventral cervical plates, the main disadvantage of using the autologous VB technique was the risk of developing postoperative kyphosis. Due to the size of the VB graft relative to the corpectomy defect, this technique has a tendency to create a focal kyphosis at the level of corpectomy. In cases in which the VB graft is not large enough to fill the bony defect, a hydroxylapatite graft sandwiched between the bone grafts has been reported as an effective salvage maneuver.[35] Mizuno and Nakagawa[29] found postoperative ventral angulation more frequently in patients in whom VB grafts were implanted than those in whom iliac crest grafts were used. Isu et al.[17] reported that 4.4% of 90 patients developed postoperative ventral angulation after using this technique. Some authors have also reported using titanium threaded interbody cages instead of autogenous vertebral bone grafts in patients with OPLL with less chance of developing postoperative kyphosis.

In one of the largest published surgical series, Mizuno and Nakagawa[29] reported their experience in treating 107 patients with OPLL who underwent anterior cervical corpectomy and direct removal of the ossified mass. Iliac crest was used in 45 cases, autologous VB in 37, and titanium interbody cages in 25 cases. Forty-five patients underwent 1-level, 41 underwent 2-level, 12 underwent

TABLE 1: Review of surgical series: ventral approaches for OPLL*

Authors & Year	No. of Patients (%)							Mean Improvement	Key Findings	FU (yrs)
	Total	Pseud-arthrosis	Postop Kyphosis	Add'l Op	CSF Leak	Early (postop) Deterioration	Late Deterioration			
Abe et al., 1981	12	NR	NR	NR	NR	0	0	100.0%†	>50% stenosis had less recovery	NR
Epstein, 1998	76	3 (4)	NR	NR	NR	NR	NR	NR‡	no plating for mean 2.75 levels	3
Isu et al., 1997	40	0	1	0	4	1: C-5 palsy	0	74.0%†	VB autograft w/o plating	3
Iwasaki et al., 2007	27	4 (15)	0	7	0	2: C-5 palsy	2	57.0%‡	>60% stenosis had better outcomes compared w/ laminoplasty	6
Kim et al., 2009	17	0	0	1	0	1: arm weakness	0	71.7%‡	VB autograft w/o plating	2
Masaki et al., 2007	19	NR	NR	NR	NR	0	0	68.4%‡		1
Mizuno & Nakagawa, 2001	107	3 (2.8)	12	10	21	3: C-5 palsy	0	89.0%†	kyphosis more likely when VB autograft used	2
Mizuno & Nakagawa, 2006	111	13 (12)	NR	NR	3	0	0	89.0%‡	no revisions required for pseudarthrosis	1
Shinomiya et al., 1993	129	4 (3.1)	NR	16	NR	NR	NR	NR‡		
Tani et al., 2002	14	0	NR	1	3	0	0	58.0%‡	>50% stenosis had better outcomes compared w/ laminoplasty	4

* Add'l = additional; FU = follow-up; NR = not reported.
† Outcome was assessed using the JOA scoring system for cervical myelopathy.
‡ Outcome was assessed based on improvement noted during neurological examination.

3-level, 4 underwent 4-level, and 5 underwent 5-level procedures via the ventral approach. Ventral cervical plates were only used in 4 patients with 3-level VB grafts and 1 with a 2-level VB graft. No other patient received plating. Surgery-related outcomes were excellent or good in 89% and fair in 11%. Patients underwent follow-up for 6 months, and the overall fusion rate was 97%, with 3 patients requiring additional surgery for pseudarthrosis. Of the graft materials used in this series, VB grafts were most susceptible to pseudarthrosis. Cerebrospinal fluid leakage was the most common complication, occurring in 21 cases. Although a significant number of patients improved after surgery, it is unclear from this study how the surgical approach was selected and how these techniques affected long-term fusion rates and outcomes.

Dorsal Approaches

A number of dorsal approaches have been described including laminoplasty, laminectomy, and laminectomy with instrumented fusion.[2,6] The advantages of these approaches include familiarity, ease of decompression of multiple levels, and the ability to extend the fusion rostrally to the occiput or caudally to the thoracic spine. The major disadvantage of laminectomy and laminoplasty is the obligatory disruption of the dorsal tension band, resulting in a high rate of postlaminectomy kyphosis.[4,13] This complication has led some authors to caution against use of these procedures in patients with preexisting cervical kyphosis or even in the relative kyphosis of the "straightened" cervical spine.[3,4,15,20] Moreover, ventral compression cannot be addressed from the dorsal approach alone, and this has therefore limited the overall effectiveness of these approaches as the ossified lesions in OPLL are known to progress over time. This limited effectiveness has been associated with greater degrees of stenosis in various series (Table 2). In some cases, the use of dorsal cervical fixation, in combination with dorsal decompression, may be used to correct a mild degenerative kyphosis.[1] Although instrumented fixation may prevent and delay a loss of lordosis, it is unclear if it has any effect on the natural progression of ossification.

Laminoplasty

Cervical laminoplasty is historically one of the most widely used surgical options for OPLL. The overall recovery rate after expansive laminoplasty for OPLL has been reported to be approximately 60%.[4,13,19,32] However, several series have shown that laminoplasty in patients with OPLL may result in insufficient decompression, progression of the ossified lesion, development of kyphosis, and limited neurological improvement. Reports of paralysis following laminoplasty range from 5% to 10%. Because these dorsal approaches do not address the ossified lesion directly, these lesions may grow in length and depth over time, leading to subsequent neurological deterioration despite an early period of improvement.[15,37] In 2002, Iwasaki et al.[19] published their series of 92 patients who underwent laminoplasty for OPLL with more than 10 years of follow-up. After an initial interval of neurological improvement, there was a significant decrease in

TABLE 2: Review of surgical series: dorsal approaches for OPLL*

			No. of Pts							
Authors & Year	No. of Pts	Op	Postop Kyphosis	Revision Op	CSF Leak	Early (postop) Deterioration	Late Deterioration	Mean Improvement†	Key Findings	FU (yrs)
Baba et al., 1995	47	laminoplasty	NR	NR	1	2: C-5, C-6 palsy	0	54.6%	>50% stenosis had worse outcomes	7.3
Chen et al., 2009	83	laminectomy + fusion	0	0	0	10: C-5, C-6, C-7 palsy	0	62.4%	high rate nerve root palsy	4.8
Cho et al., 2008	14	laminectomy	13	0	0	3: C-5 palsy	0	43.5%	kyphosis not associated w/ neurological change	3.4
Iwasaki et al., 2002	92	laminoplasty	5	1	0	3: C-5, C-6 palsy	2: progression of OPLL	60.0%	kyphosis not associated w/ neurological change	12.2
Iwasaki et al., 2007	66	laminoplasty	4	0	0	6: motor paresis; 5: neuropathic arm pain	6 (3: progression of OPLL)	63.0%	>60% stenosis had worse outcomes; kyphosis associated w/ worse outcomes	10.2
Kato et al., 1998	44	laminectomy	14	NR	1	3: iatrogenic spinal cord injury	10 (1: progression of OPLL)	32.8%	kyphosis not associated w/ neurological change	14.1
Masaki et al., 2007	40	laminoplasty	NR	NR	NR	1	NR	52.4%	kyphosis associated w/ worse outcomes	1.0
Nakano et al., 1988	14	laminectomy	NR	NR	NR	NR	NR	81.1%		10.7
	75	laminoplasty	NR	NR	NR	NR	NR	81.4%		4.5
Ogawa et al., 2004	72	laminoplasty	3	0	0	5: C-5, C-7 palsy	11 (3: progression of OPLL)	63.1%	kyphosis not associated w/ neurological change	9.5
Tani et al., 2002	12	laminoplasty	NR	1	0	7: Brown-Séquard, C-5 palsy	NR	39.0%	>50% stenosis had worse outcomes	4.2

* Pts = patients.
† Outcome was assessed using the JOA scoring system for cervical myelopathy.

outcome as assessed by JOA scores. Postoperative progression of the ossified lesion was noted in 70% of the patients, and additional surgery was required in 1 patient. Postoperative progression of kyphotic deformity was also observed in 8% of the patients.

Similarly, Ogawa et al.[33] reported their series of 72 patients who underwent follow-up for more than 5 years. The mean recovery rate was 62.1% at 1 year but decreased to 41.3% after 5 years. Postoperative progression of the ossified ligament was observed in 46 patients (63.9%), and a change in the cervical alignment was observed in 28 patients (38.9%) at last follow-up. In these patients, a change from lordosis to straight was most common (12 patients), followed by a change from lordosis to kyphosis.

The severity of stenosis has also been associated with poorer outcomes following dorsal procedures.[20,36] In their review of 47 cases, Baba et al.[4] found that patients with stenosis greater than 50% had less improvement than those with stenosis less than 50%. In this group of patients with severe stenosis, the mean improvement in JOA scores was 51.8% versus 61.6% at last follow-up ($p < 0.05$).

Laminectomy

Laminectomy is also an option for decompression, although it is used less frequently than laminoplasty, as evident by the lack of long-term clinical data.[8,22,24] Kato et al.[24] reported the largest series of patients treated with cervical laminectomy for OPLL. In their series, 52 patients underwent cervical laminectomy with a mean follow-up of 14.1 years. The neurological recovery rate of 44.2% at 1 year after laminectomy was maintained at 5 years but worsened to 32.8% at last follow-up. Late neurological deterioration was observed in 10 (23%) of 44 patients at an average of 9.5 years. The earliest deterioration occurred at 1 year and the latest was at 17 years after surgery. Postoperative expansion of the OPLL was noted in 70%, and progression of kyphotic deformity was observed in 47% of patients. This series is consistent with other reports that have demonstrated a high incidence of postlaminectomy kyphosis, although the significance of this with regard to overall outcome is still unclear.

Laminectomy With Instrumentation

The addition of instrumentation to laminectomy provides rigid fixation and prevents the development of postlaminectomy kyphosis. Although the effect of stabilization on the natural history of OPLL is unknown, it has been shown to prevent kyphosis in limited series.[7,16] Chen et al.[7] reported on 83 patients who underwent laminectomy and instrumented fusion with an average follow-up of 4.8 years. The mean JOA score significantly increased, and neurological improvement was sustained in 62.4% of patients. The degree of stenosis was not associated with a difference in outcomes in this series. Lordosis was maintained postoperatively with no revision surgeries. Progression of OPLL was not measured in this series. Postoperative nerve root palsy was seen in 10 patients and was the main complication. This was thought to be related to preserved lordosis as this was not as common in published laminoplasty series.

Strategies for Decision Making

As discussed earlier, selection of the best surgical approach depends on many factors including the radiographic assessment of cervical lordosis, severity of ventral compression, and most importantly, consideration of anticipated complications and outcomes. With a lack of prospective, randomized, controlled clinical studies with strict selection criteria to guide clinical decision making, the best available data are represented by limited retrospective institutional experiences with one particular surgical technique. In recent years, several authors have published their results comparing dorsal and ventral approaches and have attempted to identify factors that may lead to poor surgical outcomes.

Masaki et al.[27] compared their results of ventral decompression with fusion to laminoplasty for patients with cervical myelopathy due to OPLL. Nineteen patients underwent ventral surgery and 40 underwent dorsal surgery. At 1 year, the neurological improvement in the ventral group was 68.4% versus 52.5% in the dorsal group ($p < 0.05$). Elderly patients treated with laminoplasty had an especially poor surgical outcome, as did patients in the laminoplasty group who showed progressive loss of lordosis. Patients in the laminoplasty group who did poorly also showed greater evidence of segmental mobility at the operated levels on dynamic imaging.

Tani et al.[36] compared the clinical results of 14 patients who underwent ventral decompression and fusion with 12 patients who underwent laminoplasty for cervical OPLL with an occupation ratio in the spinal canal exceeding 50%. They found that the average recovery rate was significantly higher after ventral surgery than after laminoplasty. No neurological deterioration occurred after ventral surgery, whereas postoperative neurological deterioration occurred in 4 patients after laminoplasty. The authors suggested that a decrease in the lordosis of the cervical spine and tethering of nerve roots due to insufficient decompression are factors associated with poor outcomes after laminoplasty.

In the largest reported comparative series with the longest follow-up, Iwasaki et al.[20,21] compared the results of 27 patients who underwent ventral surgery with 66 who underwent laminoplasty, with a mean follow-up of 6 years. Overall, patients who underwent ventral surgery had better outcomes than those who underwent laminoplasty. This was particularly true for patients whose ossified lesions had an occupying ratio greater than 60%. Multiple regression analysis showed that the most significant predictors of poor outcome after laminoplasty were hill-shaped ossification, occupying ratios greater than 60%, lower preoperative JOA scores, postoperative changes in cervical alignment, and older age at surgery.

It is evident from these studies that each surgery has its benefits; however, it seems that laminoplasty is associated with worse outcomes, especially in patients whose ossified lesions have an occupying ratio greater than 50%.

Conclusions

There remains considerable debate regarding the surgical management of myelopathy due to cervical OPLL. Over the years, numerous innovative surgical techniques have been developed to treat these difficult lesions, from either a dorsal or ventral approach. Although there is currently little evidence to support the superiority of one technique over the other, there are data regarding the known risks, complications, and expected outcomes associated with each. Although the ventral approach offers direct decompression of the spinal cord with resection of the ossified mass, it is plagued by a high risk of CSF leakage and pseudarthrosis. Likewise, the dorsal approach provides a relatively simple and safe means to decompressing the spinal cord. However, it is subject to progressive kyphosis, expansion of the ossification, and limited neurological improvement, especially in patients with preexisting kyphosis or hill-shaped OPLL. The addition of instrumentation and fusion may help overcome some of the late complications of dorsal decompressive operations. This information, gathered from years of experience along with an understanding of the biomechanics of cervical deformity, equips the surgeon with the tools to make the best possible decision.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: Shin. Acquisition of data: Shin. Analysis and interpretation of data: Shin. Drafting the article: Shin. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: all authors. Study supervision: Shin, Krishnaney.

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Manuscript submitted November 15, 2010.
Accepted December 17, 2010.
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Laminoplasty outcomes: is there a difference between patients with degenerative stenosis and those with ossification of the posterior longitudinal ligament?

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Object. Two common causes of cervical myelopathy include degenerative stenosis and ossification of the posterior longitudinal ligament (OPLL). It has been postulated that patients with OPLL have more complications and worse outcomes than those with degenerative stenosis. The authors sought to compare the surgical results of laminoplasty in the treatment of cervical stenosis with myelopathy due to either degenerative changes or segmental OPLL.

Methods. The authors conducted a retrospective review of 40 instrumented laminoplasty cases performed at a single institution over a 4-year period to treat cervical myelopathy without kyphosis. Twelve of these patients had degenerative cervical stenotic myelopathy ([CSM]; degenerative group), and the remaining 28 had segmental OPLL (OPLL group). The 2 groups had statistically similar demographic characteristics and number of treated levels (mean 3.9 surgically treated levels; $p > 0.05$). The authors collected perioperative and follow-up data, including radiographic results.

Results. The overall clinical follow-up rate was 88%, and the mean clinical follow-up duration was 16.4 months. The mean radiographic follow-up rate was 83%, and the mean length of radiographic follow-up was 9.3 months. There were no significant differences in the estimated blood loss (EBL) or length of hospital stay (LOS) between the groups ($p > 0.05$). The mean EBL and LOS for the degenerative group were 206 ml and 3.7 days, respectively. The mean EBL and LOS for the OPLL group were 155 ml and 4 days, respectively. There was a statistically significant improvement of more than one grade in the Nurick score for both groups following surgery ($p < 0.05$). The Nurick score improvement was not statistically different between the groups ($p > 0.05$). The visual analog scale (VAS) neck pain scores were similar between groups pre- and postoperatively ($p > 0.05$). The complication rates were not statistically different between groups either ($p > 0.05$). Radiographically, both groups lost extension range of motion (ROM) following laminoplasty, but this change was not statistically significant ($p > 0.05$).

Conclusions. Patients with CSM due to either degenerative disease or segmental OPLL have similar perioperative results and neurological outcomes with laminoplasty. The VAS neck pain scores did not improve significantly with laminoplasty for either group. Laminoplasty may limit extension ROM. *(DOI: 10.3171/2011.1.FOCUS10279)*

Key Words • **ossification of the posterior longitudinal ligament** • **cervical myelopathy** • **range of motion**

The two most common causes of CSM treated at our institution are degenerative spondylosis and OPLL. The prevalence of degenerative CSM is higher in Caucasian populations, and the prevalence of OPLL-related CSM is higher in Asian populations.[12,16,17,19,27,30,32] The optimal surgical approach to treat CSM is controversial, but many prior reports suggest that laminoplasty is an acceptable surgical option in patients without cervical kyphosis.[3,4,20,22,24,28,35,37,38] It has been suggested that patients with high-grade OPLL have poor outcomes following surgery. We sought to assess if patients undergoing laminoplasty for degenerative CSM had similar outcomes to those treated for OPLL.

It has also been suggested that cervical laminoplasty could decrease the baseline cervical flexion and extension ROM.[11,15] We evaluated and compared pre- and postoperative dynamic x-rays in patients with degenerative spondylosis versus those with OPLL who underwent laminoplasty.

Methods

Patient Demographics

Between 2006 and 2010, the senior author (P.V.M.) performed 40 laminoplasty operations in patients with CSM due to either degenerative spondylosis or OPLL. All

Abbreviations used in this paper: CSM = cervical stenotic myelopathy; EBL = estimated blood loss; LOS = length of hospital stay; OPLL = ossification of the posterior longitudinal ligament; ROM = range of motion; VAS = visual analog scale.

Fig. 1. Sagittal T2-weighted MR image of the cervical spine demonstrating degenerative disc disease with multilevel compression and T2 hyperintensity within the spinal cord.

of the patients had 3 or more levels of stenosis, and none of the patients had cervical kyphosis. Patients who required bilateral foraminotomies or extension of decompression to C-2 or T-1 were treated with posterior cervical laminectomies with fusion, and were not included in this cohort.

Of the 40 patients, 12 had degenerative CSM (degenerative group; Fig. 1), and 28 had segmental OPLL (OPLL group; Fig. 2). The mean age of the patients in the degenerative group was 62 years, and the mean age of those in the OPLL group was 64 years. The degenerative group was composed of 67% men and 33% women, whereas the OPLL group was composed of 70% men and 30% women. Both the degenerative and the OPLL group had a mean of 3.9 levels treated with laminoplasty (Table 1).

Surgical Technique

All the patients underwent open-door laminoplasty with titanium miniplates, without bone graft. An air drill with a matchstick bur was used to open the hemilamina on the side with more symptoms. A shallow trough was scored on the contralateral hemilamina with the matchstick drill bit, and this side was used as a hinge to open the laminoplasty. The hinged, open-door laminoplasty was secured with a preshaped titanium miniplate, and small screws were placed through the plate apertures into the lateral mass on one side and into the opened hemilamina on the other side. Additional unilateral posterior foraminotomy on the plated side was performed if cervical radiculopathy was present. Patients underwent laminoplasty from C-3 to C-6 or C-7, depending on the extent of the stenosis.

TABLE 1: Demographic information in 40 patients with cervical myelopathy who underwent laminoplasty

Characteristic	OPLL Group	Degenerative Group	p Value
mean age in yrs	63.8	61.7	0.593
sex			
M	20	8	
F	8	4	
mean no. of levels	3.9	3.9	0.831

Patient Assessment

Perioperative Data. Perioperative data collected in all patients included the following: EBL, LOS, complications, and repeat operations.

Clinical Outcome. Patients were evaluated with pre- and postoperative Nurick grades and VAS neck pain scores.

Radiographic Data. We compared pre- and postoperative dynamic x-rays in patients with degenerative spondylosis versus those with OPLL who underwent laminoplasty (Fig. 3). To determine the ROM, we measured the pre- and postoperative Cobb angles from the inferior C-2 endplate to the superior C-7 endplate on the flexion and extension radiographs for patients in both groups.

Statistical Analysis

All of the data were calculated using the SPSS software for descriptive statistics and contingency tables (SPSS, Inc.). Student t-tests were used for mean data, the Fisher exact test was applied for categorical data, and a probability value of 0.05 was considered statistically significant.

Results

The overall clinical follow-up rate was 88%. The mean clinical follow-up was 16.4 months. Clinical follow-up in

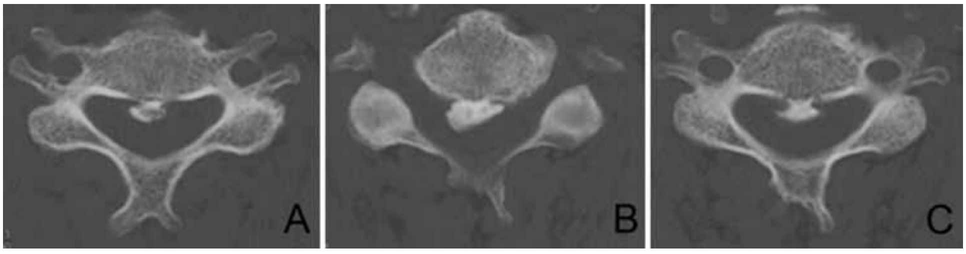

Fig. 2. Axial CT scans demonstrating OPLL. Segmental OPLL is seen in all 3 images.

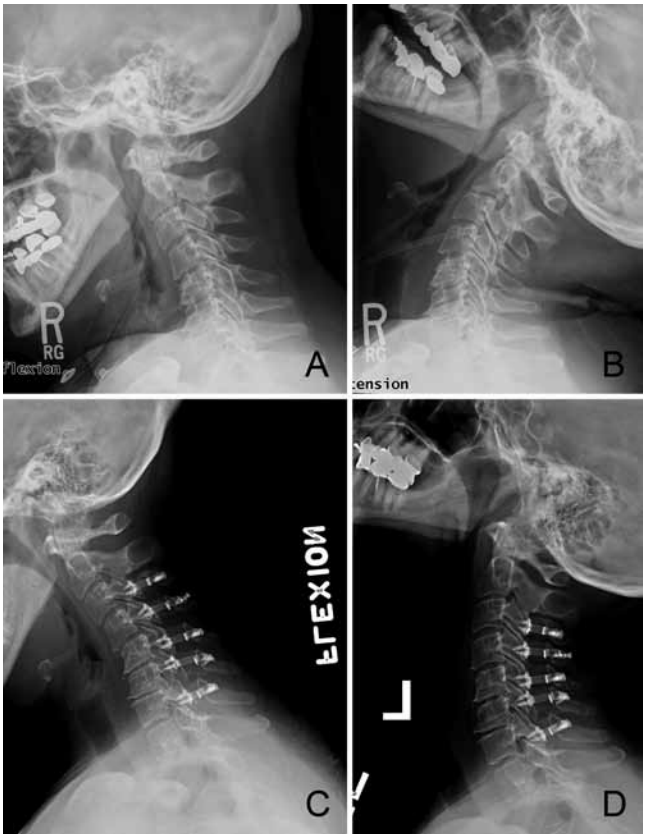

Fig. 3. Dynamic (flexion and extension) lateral radiographs of the cervical spine. **A:** Preoperative flexion. **B:** Preoperative extension. **C:** Postoperative flexion. **D:** Postoperative extension.

the degenerative group was a mean of 16.4 months, with 100% patient follow-up. Clinical follow-up in the OPLL group was also 16.4 months, with an 82% follow-up rate. The overall complication rate was 12.5%, and the reoperation rate was 5%. There were no perioperative deaths, but 1 patient died of unrelated causes (pancreatic cancer) 1 year after surgery.

Not all patients had pre- and postoperative dynamic imaging. The mean radiographic follow-up time was 9.3 months. Preoperative and postoperative dynamic x-rays were available in 83% of patients.

Perioperative Data

The mean number of levels treated for the degenerative group was 3.9, and the mean EBL was 206 ml. The mean LOS was 3.7 days. There were 2 patients with complications requiring repeat operation in the degenerative group: 1 with a wound infection and 1 with a collapsed laminoplasty segment that caused restenosis. Both of these complications led to revision surgery. The patient with the infection was treated with a wound debridement, and all hardware was left in place. This patient was given 6 weeks of intravenous antibiotics followed by 12 months of oral antibiotics. The patient with the collapsed laminoplasty segment fractured the hinge side of C-4 into the spinal canal. This was corrected by performing a laminectomy of C-4. This patient then developed a temporary C-5 nerve root palsy that resolved after 6 months.

The mean number of levels treated for the OPLL group was 3.9, and the mean EBL was 155 ml. The mean LOS was 4 days. There were 3 complications in the OPLL group (2 CSF leaks and 1 temporary deltoid palsy). There were no reoperations in the OPLL group.

There was no statistical difference between groups in EBL or LOS. There was no statistically significant difference in the rate of complications, or in complications requiring repeat operations between the groups ($p = 0.626$ and $p = 0.085$, respectively; Table 2).

Clinical Measurement

Both groups improved significantly from their baseline neurological function ($p < 0.05$). For the degenerative group, the mean preoperative Nurick grade was 2.33, and the mean postoperative grade was 0.75. For the OPLL group, the mean preoperative Nurick grade was 2.65, and the mean postoperative grade was 1.43.

The mean preoperative neck pain VAS score for the degenerative group was 6, and the mean postoperative score was 4.18. The mean preoperative neck pain VAS score was 4.16 and the mean postoperative score was 2.63 for the OPLL group. These values were not statistically different ($p > 0.05$; Table 3).

Radiographic Measurement

We found that both groups had restricted ROM on dynamic x-rays after laminoplasty. The mean preoperative flexion Cobb angle from C-2 to C-7 for the degenerative group was 12°, and the mean preoperative extension Cobb angle for these patients was 23°. The mean postoperative flexion Cobb angle for the degenerative group was 13°, and the mean postoperative extension Cobb angle for these patients was 17°. The degenerative group lost a mean of 6° in extension (26% of preoperative extension) and gained a mean of 1° in flexion (8% of preoperative flexion) following instrumented laminoplasty, but this was not statistically significant.

TABLE 2: Perioperative data and complications*

Factor	OPLL Group	Degenerative Group
no. of patients	28	12
mean LOS	4 days	3.7 days
mean EBL	155 ml	206 ml
no. of complications	3; 2 CSF leaks & 1 C-5 palsy	2; 1 wound infection & 1 revision of laminoplasty for C-5 palsy
complications requiring reop	none	2; 1 wound revision & 1 revision of laminoplasty

* The overall complication rate was 12.5%, and the overall reoperation rate was 5%.

TABLE 3: Clinical and follow-up data*

Group	No. of Patients	FU Rate	Mean Nurick Grade		Mean VAS Neck Pain Score		Mean Length of FU (mos)
			Preop	Postop	Preop	Postop	
OPLL	28	82%	2.65	1.43	4.16	2.63	16.39
degenerative	12	100%	2.33	0.75	6.00	4.18	16.41
p value			0.566	0.157	0.199	0.194	0.994

* FU = follow-up.

All of the OPLL patients had the segmental subtype of OPLL and had maintained flexion and extension motion on dynamic radiographs preoperatively. The mean preoperative flexion Cobb angle from C-2 to C-7 for the OPLL group was 14°, and the mean preoperative extension Cobb angle for these patients was 23°. The mean postoperative flexion and extension Cobb angles for the OPLL patients were 14° and 19°, respectively. The OPLL group lost a mean of 4° in extension (17% of preoperative extension) and had no change in mean flexion following instrumented laminoplasty, but this was not statistically significant (Table 4).

Discussion

The optimal treatment of OPLL-related CSM remains controversial. Patients with severe spinal stenosis caused by OPLL can be completely asymptomatic. It has been reported that prophylactic decompression in patients with OPLL who have no symptoms might not be necessary.[18,24] Due to the lack of longitudinal cohorts on a large enough scale to ascertain the disorder's natural history, the necessity, timing, and technique of choice for surgical intervention for OPLL-related CSM remains uncertain. There have been reports demonstrating successful outcomes of anterior decompression and fusion for CSM.[5,13,23,34] Although it is more intuitive to decompress the spinal cord anteriorly, at the origin of the OPLL mass effect, complications like CSF leaks are not uncommon.[1,2,7,14,36] Posterior approaches allow for expansion of the spinal canal and indirect decompression of multiple segments. Therefore, surgical treatment should be tailored according to each patient's condition and each surgeon's level of confidence with a particular technique.

The Japanese and others have reported many methods with which to perform laminoplasty.[9,21] In general, there are two major laminoplasty techniques, unilateral (open-door) and bilateral (midline opening). Submodifications of laminoplasty include the use of bone graft or instrumentation (miniplates).[6,8,10,26,33] In the current study we used the technique described by O'Brien et al.,[25] using miniplates for fixation of the hinged lamina.

Cervical laminoplasty preserves the posterior elements (unlike laminectomy), and this preservation may enhance spinal stability and prevent kyphosis.[29,31] Also, cervical laminoplasty allows preservation of some ROM (unlike laminectomy with fusion). To date, the long-term effects of laminoplasty on cervical spine ROM are still uncertain. It has been suggested that patients with OPLL treated with cervical laminoplasty have less ROM after surgery than do patients with CSM due to degenerative spondylosis.[11,15] However, it is important to note that there are several subtypes of OPLL, and the continuous type often results in reduced ROM due to bridging bone across disc space levels. The most common type of OPLL treated at our institution is segmental OPLL.

We performed a 1:2 cohort comparison of patients with CSM due to degenerative spondylosis versus those with the segmental type of OPLL. We found that laminoplasty is an effective treatment for patients with CSM due to either degenerative spondylosis or the segmental type of OPLL. Our degenerative and OPLL groups were not statistically different at baseline in age, sex, or number of treated levels. The perioperative data, including EBL, LOS, overall complications, and reoperations were not statistically different between groups. Both groups had significant improvements in their Nurick grades. The small sample size does increase the likelihood of a Type II error when comparing the groups, but it also probably overestimates the rate of complications.

Interestingly, for both groups we found there was some loss of ROM in extension, but there was no loss in flexion. In the degenerative group there was a loss of 6° of motion or 26% of preoperative extension. There was actually a mild increase of 1° of motion or 8% from preoperative flexion. The OPLL group had a loss of 4° or 17% of preoperative extension and no change in flexion. These finding suggest that the loss of ROM following laminoplasty is similar in both groups and occurs entirely in extension. However, this loss of ROM in extension did not reach statistical significance. Although our patient numbers were limited, ours is one of the first studies comparing laminoplasty for the treatment of these different types of CSM.

TABLE 4: Radiographic data and follow-up findings

Group	Mean FU (mos)	Mean Cobb Angle (°) on Flexion			Change From Baseline	Mean Cobb Angle (°) on Extension			Change From Baseline
		Preop	Postop	Change		Preop	Postop	Change	
OPLL	8.9	14	14	0	0%	23	19	−4	−17%
degenerative	10.3	12	13	1	8%	23	17	−6	−26%
p value	0.613	0.455	0.667	0.721		0.957	0.629	0.504	

Conclusions

Laminoplasty is an effective treatment for CSM due to either degenerative spondylosis or OPLL. Our patients with segmental OPLL treated with laminoplasty had similar perioperative parameters (EBL, LOS, and overall complication rate) to our patients with degenerative spondylosis. Patients with degenerative spondylosis or segmental OPLL maintained most of their baseline dynamic cervical spine motion, with only some mild reduction in extension when compared with baseline.

Disclosure

Dr. Mummaneni is a consultant for Medtronic, Inc., and DePuy Spine, Inc., and he receives royalties from DePuy Spine, Inc., and from Quality Medical Publishing, Inc. The authors report no other conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Wu, Meyer. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: Mummaneni. Statistical analysis: Wu, Meyer. Administrative/technical/material support: Mummaneni. Study supervision: Mummaneni.

Acknowledgments

The authors thank Charles Delgado, Erika Caccia, and Sharon Hoang for assistance with the data in the manuscript.

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Manuscript submitted November 16, 2010.
Accepted January 12, 2011.
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Ossification of the posterior longitudinal ligament: pathogenesis, management, and current surgical approaches

A review

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Ossification of the posterior longitudinal ligament (OPLL) is an important cause of cervical myelopathy that results from bony ossification of the cervical or thoracic posterior longitudinal ligament (PLL). It has been estimated that nearly 25% of patients with cervical myelopathy will have features of OPLL. Patients commonly present in their mid-40s or 50s with clinical evidence of myelopathy. On MR and CT imaging, this can be seen as areas of ossification that commonly coalesce behind the cervical vertebral bodies, leading to direct ventral compression of the cord. While MR imaging will commonly demonstrate associated changes in the soft tissue, CT scanning will better define areas of ossification. This can also provide the clinician with evidence of possible dural ossification. 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 well tolerated in older patients. However, there often is associated axial neck pain and less improvement in myelopathy scores. In this review, the authors discuss the epidemiology, imaging findings, and clinical presentation of OPLL. The authors additionally discuss the merits of the different surgical techniques in the management of this challenging disease. *(DOI: 10.3171/2011.1.FOCUS10256)*

Key Words • **cervical spine** • **corpectomy** • **laminoplasty** • **ossification** • **posterior longitudinal ligament** • **spinal surgery** • **spinal decompression**

Ossification of the posterior longitudinal ligament is an important cause of cervical myelopathy that results from heterotopic ossification of the cervical or thoracic PLL. It has been estimated that up to 25% of patients presenting with cervical myelopathy have features of OPLL.[12] Furthermore, OPLL has been associated with several diseases, most importantly DISH.[52] While multiple surgical approaches have been used in the treatment of myeloradiculopathy due to OPLL,[2,4,8,12–20,23,29,31,48,53,60,70] the individual merits of these techniques remain controversial. In this review, we discuss the epidemiology, natural history, and common radiographic findings associated with OPLL. The advantages and disadvantages of current treatment options, including anterior corpectomy, laminectomy, and laminoplasty are reviewed.

Epidemiology

While the overall prevalence of OPLL remains low, it has been estimated by Epstein[12] that up to 25% of the North American and Japanese populations with cervical myelopathy exhibit characteristics of OPLL. This is predominantly found in the high cervical region (C2–4)[12] and occurs nearly twice as often in males as in females.[15,18] In the Japanese literature, where the disease has been studied extensively, the general prevalence of OPLL has been documented to be between 1.9% and 4.3%.[42,58,64] In other neighboring countries, including Taiwan and

Abbreviations used in this paper: ACC = anterior cervical corpectomy; ACCF = anterior cervical corpectomy and fusion; DISH = diffuse idiopathic skeletal hyperostosis; OPLL = ossification of the posterior longitudinal ligament; PLL = posterior longitudinal ligament; ROM = range of motion.

Korea, the rate in the population is near 3%.[69] In North American populations, it appears that the disease prevalence is much lower. Resnick and Niwayama[55] calculated that the rate of classic disease in Caucasian individuals from North America was 0.12%. These rates suggest that the predominant presentation of the disease is sporadic. However, there have been cases of familial OPLL in Caucasian and European populations.[65] Furthermore, genetic loci associated with cases of OPLL in Asian populations have also been linked to non-Asian Mediterranean familials.[22] In our limited experience, several of our non-Asian patients with OPLL have family origins from in or near these Mediterranean bloodlines. Also, quite importantly, a varying percentage of patients with DISH, a very prevalent disease in Caucasian populations, have OPLL.[22]

Diffuse Idiopathic Skeletal Hyperostosis

Diffuse idiopathic skeletal hyperostosis is a syndrome that involves ossification of the soft tissue and ligaments, commonly occurring near the ventral aspect of the cervical or thoracic spine (Figs. 1 and 2).[38,45,59] This syndrome is quite common. The incidence of DISH in patients older than 65 years of age has been estimated to be between 15% and 30%.[36,54] In sharp contrast to OPLL, this syndrome is uncommon in Asian populations and more common in North American or other Caucasian populations.[34,35] Most individuals with DISH are asymptomatic. However, several cases of dysphagia have been noted. These can occur when significant bony overgrowth of the anterior longitudinal ligament leads to compression of the esophagus.[38,45] The coexistence of OPLL and DISH has been previously reported. Ehara et al.[10] found DISH to be indentified in 25% of 109 patients they studied with OPLL. Others have reported this rate of association to be as high as 50%.[44] Given this association between OPLL and DISH, an awareness of the pathogenesis and treatment of OPLL may be of particular importance in North American populations. It should additionally be noted that recent studies have shown an increased prevalence of OPLL in patients with various metabolic disorders, including hypoparathyroidism, acromegaly, and diabetes[30] as well as an association between DISH and ankylosing spondylitis.[52]

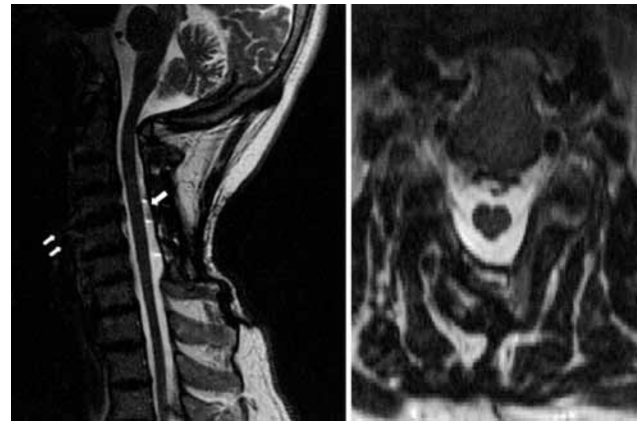

Fig. 2. Postoperative nonenhanced T2-weighted MR image showing decompression 1 year after C3–7 laminoplasty in the patient in Fig. 1. Preoperative images showed 10° of lordosis, which was enough to allow dorsal migration of the cord away from the ventral bony bar. **Left:** Magnetic resonance imaging evidence of DISH *(double arrows)* as well as extent of decompression *(single arrow)* is shown. **Right:** Axial MR image at this level following decompression.

Natural History and Clinical Presentation of OPLL

The PLL extends from the occiput to the sacrum along the posterior aspects of the vertebral bodies and the dorsal aspects of each intervertebral disc. As it becomes hypertrophied and ossifies, it results in a significant restriction of the cervical canal diameter. This compresses the spinal cord and leads to ischemia and myelopathy. In addition to this direct compression, repeated impacts of the ventral cord over the hypertrophied and ossified ligament can further lead to damage to the cord parenchyma.[66] As the most common site of ossification is in the cervical cord, cervical myelopathy is the most common presentation. However, clinically significant ossification of the ligament has also been noted to occur in the thoracic and lumbar spine.[1,19,46,50,51] Ossification of the PLL can present with pain, neurological deficit, or with acute neurological injury (even after a minor injury). However, given the prevalence of OPLL, the majority of patients with OPLL remain without significant symptoms. Another subset of patients with progressive OPLL may present

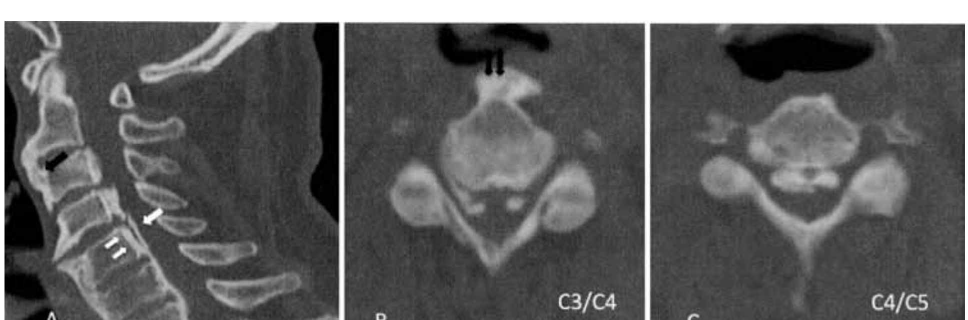

Fig. 1. Findings of DISH and OPLL can commonly be found in the same patient as seen on this preoperative CT scan. **A:** Sagittal midline CT demonstrates ossification of both the ligaments and soft-tissue ventral to the vertebral bodies *(black arrow)*; *double white arrows* indicate the first layer of ossification and the *single white arrow* indicates the second layer. **B and C:** Axial images showing the 2 layers of bone formation as well as ossification ventral to the C-3 body consistent with DISH (*arrows*, **B**).

with "clinically silent" myelopathy that is not associated with axial neck pain or radiculopathy.

A firm understanding of the natural history of OPLL is important. This is especially important for asymptomatic patients who have the potential to develop signs of myelopathy with time. In a study of 359 patients who underwent follow-up for a mean of 17.6 years, Matsunaga et al.[40] reported that 55 (17%) of 323 asymptomatic patients would eventually demonstrate examination findings of myelopathy. In 23 (64%) of the 36 patients with preexisting myelopathy, there was evidence of progression in their clinical examination. In a more recent radiographic study, Matsunaga et al.[41] studied radiographic progression in 167 patients following surgical treatment. Axial radiographic progression was seen in 70 (42%) and craniocaudal extension in 144 (86%) during follow-up.

Given this natural history of progression, it is our practice to consider patients for surgery when there is notable compression of the cervical spinal cord or T2 signal changes on MR imaging and evidence of clinical deterioration on physical examination.

These patients have often been observed using serial imaging and have been found to have progression of their disease. These patients are particularly younger and have few associated comorbid conditions. It is our belief, in common with several study groups in Japan and other Asian countries, that surgical decompression in these patients may prevent the development of progressive myelopathy and quadriparesis. However, in patients with radiographic progression without new clinical signs or symptoms, continued clinical follow-up is suggested.

Neuroimaging of OPLL

Given that the cervical dura is often involved with the ossification of the ligaments, the ability of the surgeon to anticipate the degree of dural ossification and erosion prior to going into the operating room is critical. Once the dura is ossified, it becomes intimately associated with the OPLL. This makes it difficult to cleanly separate the ossified ligament from the dura. As a result, one of the most common complications that results from an anterior approach to decompress OPLL is a CSF leak.[5] In addition, in cases in which there is significant OPLL, the risk of injury to the spinal cord or nerve roots may also be increased as the white matter and vessels of the pial layer become intimately associated with areas of ossification.[39,47] For these reasons, preoperative CT identification of either an ossified ligament or ossification of the dura is critical.

Computed tomography scanning often shows early signs of OPLL, including multiple small areas of bone contained within an enlarged ligament. In patients with progressive disease, these areas form a large, bony plaque within the ligament and ventral to the cord. Hida et al.[24] reported on 2 CT findings that were associated with dural ossification. A "single-layer sign," as described in this report, described dense ossification within the ligament that extended to the periphery. In 9 patients with this single-layer sign, only 1 patient experienced a CSF leak. A double-layer sign was also described, in which there is ossification of the ligament directly behind the vertebral body as well as the hypodense mass of the PLL (Fig. 3). Penetration of the dura (and an associated CSF leak) were significantly more common when this CT finding was present.[16,24]

On MR imaging, early OPLL appears dorsal to the interspaces and can be seen on axial and sagittal views. As the disease progresses, the dense signal behind the vertebral bodies and interbody spaces becomes hypointense on all MR imaging sequences. However, in the progressed disease, there are smaller areas of increased signal. These areas are indicative of new bone formation within the ligament. In addition, OPLL does not enhance with Gd. Thus, on enhanced MR images, it is possible to differentiate between a hypertrophied ligament and postoperative scarring. Associated changes in the spinal cord may be seen on T2-weighted imaging in association with OPLL. This includes areas of increased T2-signal associated with cord edema.

Surgical Management of OPLL

Patients with OPLL commonly present with symptoms in their 40s or 50s. This commonly begins with symptoms of numbness or axial neck pain. Without surgical decompression, symptomatic OPLL tends to progress with time. In a long-term follow-up study, Matsunaga et al.[40] demonstrated that 38% of patients presenting with baseline myelopathy had progressive worsening of their symptoms. Ossification of the PLL has been additionally found to progress following decompression[27] as well as during routine radiographic follow-up in the patient in whom decompression has not been performed.[49] For these reasons, especially for younger patients without established deficits, it is our practice to obtain strict radiographic follow-up. In patients with progressive deficits, including severe weakness or myelopathy, surgery is considered. Like other authors, we believe that older patients with significant comorbid conditions and severe, longstanding deficits may be poor surgical candidates.[14,60]

Anterior Cervical Corpectomy and Fusion

The majority of patients with OPLL present with multilevel cervical disease that often requires extensive decompression. Some controversy persists regarding the most appropriate method for treating cervical compression and myelopathy in these patients. Some authors argue that since the ossification in cases of OPLL remains ventral to the spinal cord and can continue to progress after surgery, posterior decompression fails to prevent "hill-shaped" and massive ossification in the years after a successful posterior decompression.[31] Furthermore, clinical myelopathy scores have been shown to improve most significantly with ACC. Several studies have shown better outcomes following anterior rather than posterior decompression for OPLL. Epstein[13] found superior clinical outcomes when comparing anterior versus posterior approaches in 51 patients treated for OPLL. Fessler et al.[20] found that patients treated by an anterior approach had an average improvement of 1.24 Nurick grades when compared with laminectomy patients

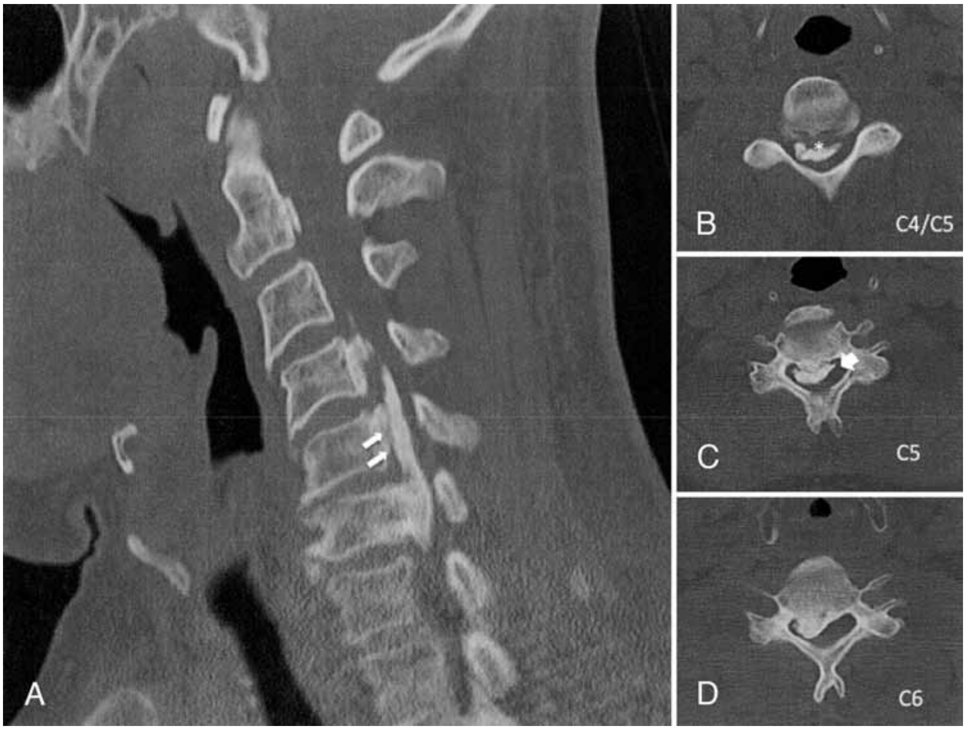

Fig. 3. A: Preoperative midline sagittal CT scan obtained in a 53-year-old man, demonstrating segmental and continuous regions of ossification starting at the C3–4 level and extending to C6–7. The patient's relative kyphosis was believed to be a contraindication to an anterior approach. **B–D:** Axial CT images obtained in the same patient showing an ossified bar *(asterisk)* with an associated pearl of calcification **(B)**, "double-layer" sign *(arrow)*, consistent with dural ossification **(C)**, and a lateral bar of ossification leading to right-sided compression **(D)**.

who only improved by 0.07. In addition, laminectomy and fusion or laminoplasty is not appropriate in patients with poorly preserved cervical lordosis.

Several authors have noted the high incidence of complication with ACC. The rate of all surgical complications (including CSF leak, graft extrusion, or incomplete fusion) was 23%.[61] Approximately half of these patients would eventually require revision surgery. Pseudarthrosis requiring revision surgery was reported to occur in up to 15% of patients following ACC for OPLL in another series.[13] Soft-tissue morbidity, including permanent dysphagia or dysphonia, need for prolonged intubation, and less commonly vertebral artery or esophageal injury may additionally occur.[4] Postoperative C-5 palsy, a known complication of anterior and posterior approaches, may also occur.[57] In our own practice, we have found these complications to be especially of concern in patients with multiple comorbidities or advanced age.

Successful attempts to remove the ossified ligament from an anterior approach have at times been limited by significant bleeding from the epidural space or dural ossification. Advanced OPLL is commonly associated with thinning of the dura, and the dural membrane's integrity is commonly compromised as it merges with the ossified PLL. As a result, dural injuries causing a postoperative CSF leak as well as injury to the neural tissue become more likely.[24] In cases of severe dural ossification, we use an "anterior floating" method. With this method, central areas of densely ossified ligament and dura are detached laterally and superomedially from the surrounding PLL. This results in a "floating," ossified island of bone that will move freely and does not compress the cord (Fig. 4). This method has been previously advocated for patients in whom the ossified mass involves more than 60% of the cervical canal.[70] This method has made anterior decompression for cervical myelopathy associated with severe OPLL more efficient and safer.

Posterior Cervical Approaches

While anterior cervical discectomy or anterior corpectomy are excellent options for younger patients and those with inadequate cervical lordotic curve, dorsal procedures can often be used in patients with a well-maintained cervical lordotic curve. This can include patients with multilevel cervical spondylosis as well as those with OPLL. Cervical laminectomy and decompression can often be augmented by lateral mass fusion to correct instability or to prevent loss of future sagittal alignment. Laminoplasty is also offered as an alternative to lateral mass fusion. In patients undergoing posterior decompression surgery, there should be evidence of preoperative cervical lordosis of at least 10° and less than 7 mm of anterior-posterior OPLL for indirect decompression to be successful.[71] The most significant advantage of a posterior approach is that it avoids the potential soft-tissue complications of the anterior approach. Furthermore, there is no risk of graft extrusion, but there is a decreased incidence of postoperative pseudarthrosis. It has additionally been proposed that OPLL is associated with a "dynamic myelopathy" in which the cervical spinal

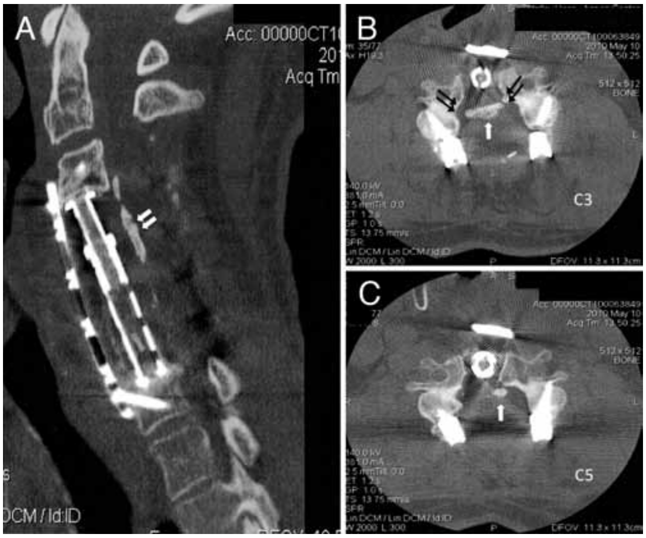

Fig. 4. Postoperative CT scans demonstrating ventral decompression supplemented with anterior fusion with a plated cage and posterior laminectomy and fusion in the patient in Fig. 3. A central ossified bar was left in place following extensive lateral decompression. **A:** This "floating" bar can be seen on the sagittal midline CT *(arrows)*. **B and C:** Axial image obtained at the C-3 level **(B)** demonstrating the extent of lateral decompression *(black arrows)* and remaining midline bar (*white arrows* in **B and C**). At C-5, a single pearl of ossified bone remains **(C)**.

cord is progressively injured by repeated movement of the cord parenchyma over the ossified ventral mass.[21] Arthrodesis and simple collar immobilization in these patients may serve to "stiffen" the cervical spine and decrease deleterious motion.

Laminectomy With or Without Fusion

Laminectomy is done through a midline posterior cervical incision. A subperiosteal dissection of the underlying ligaments and paracervical muscles will expose the spinous processes as well as laminae of the subaxial cervical spine. In cases in which posterolateral fusion is planned, the dorsal surface of the bony lateral masses and the facet joints are exposed. In most circumstances, the laminectomy is planned to allow for decompression rostral and caudal to the most severe area of cervical canal narrowing. In doing so, the cord will have the ability to migrate dorsally away from any areas of compression caused by degenerative osteophytes or ossified ligament.

The laminectomy can be undertaken by developing 2 bony troughs through the lateral lamina at the junction of the lamina and bony lateral mass. Under microscopic or loupe magnification, a high-speed drill can be used to cut through the anterior and posterior cortex of the lamina. This exposes the underlying ligamentum flavum overlying the cord. In cases of severe compression or an atretic ligament, we also advocate the use of a lower-speed diamond drill following initial removal of the outer cortex. After the bony troughs are developed, residual bone may be removed using either a 1- or 2-mm Kerrison rongeur. Following this step, the dorsal lamina should be unattached, constituting a mobile, "floating" segment relative to native cervical spine. Removal of any residual ligamentous attachments using a small-caliber Kerrison punch allows the entire segment of bony lamina to be removed together.

Following removal of the lamina, careful medial facetectomy and multilevel foraminotomy are completed. We are careful to avoid removing more than 25% of the medial facet joint at any level to prevent postoperative instability. However, we have found that in cases of severe lateral recess stenosis, partial facetectomy is required for adequate decompression. Furthermore, unroofing of the foramen using an undercutting technique with a small-caliber (2 mm or less) Kerrison punch allows for cervical nerve root decompression and mobilization of the cord. The cord can be covered (and protected) by placement of a collagen matrix on the dura and an epidural drain is placed prior to closure.

Laminectomy alone is chosen by some surgeons to decompress the cervical spine in OPLL. In general, when a posterior decompression is chosen, it is our practice to undertake either laminectomy with fusion or laminoplasty. This is in line with the philosophy of decreasing the "dynamic" component of myelopathy. However, if a laminectomy is chosen, the extent of medial facet resection should be kept to 25% or less to avoid postoperative instability. Long-term results from laminectomy are, however, generally positive. Kato et al.[33] noted a 44% rate of neurological recovery at 1 year in 44 patients with OPLL. Despite a high rate of kyphosis (47%), there was no associated decline in the patients' clinical state. We believe that this approach may be appropriate in select, older patients with maintained cervical lordosis and little evidence of instability or motion. However, posterior decompression should be avoided in patients with a kyphotic alignment, spondylolisthesis, suggested instability, or high disc spaces.

Laminectomy With Fusion

In patients with at least 10° of lordosis, a multilevel laminectomy will allow a release of the cord and promotes subsequent dorsal migration in cases of OPLL.[17] It will also decrease cervical ROM across an anterior ossified bar. There are multiple fusion techniques that can be used, including facet wiring, lateral mass screws, and pedicle screws. Epstein[19] demonstrated that posterior decompression with facet wiring can be successful in geriatric patients with OPLL and an appropriately lordotic cervical spine. Houten and Cooper[29] demonstrated that laminectomy and posterior lateral mass fusion can result in high rates of fusion, preserved lordosis, and clinical results comparable or superior to those seen with ACC. While many series show fusion rates near 100%, there is a defined morbidity for lateral mass screw placement. In a single study of lateral mass screw complications, nerve root injury was 0.6%, cord injury 2.6%, and screw loosening or avulsion was 1.3%.[23] It is also important to note that a stable pseudarthrosis will often yield the same clinical result as a solid fusion.

Cervical Laminoplasty

Cervical laminoplasty was described in the 1970s as an alternative to laminectomy in patients with myelopathy.[26] It is the opinion of many surgeons that laminoplasty is optimally designed to treat patients with multilevel OPLL. It offers dorsal decompression of the cervical spine without decreasing stability. However, it obviates the need to achieve a formal fusion and there is a placement of segmental spinal hardware. This segmental hardware helps to decrease range of motion. Biomechanically, when compared with laminectomy without fusion, laminoplasty has been shown to have an equivalent or even superior ability to maintain cervical alignment without the development of delayed postoperative kyphosis.[2] However, despite this increase in stability, in certain cases, kyphosis may still occur. Another theoretical advantage of the technique is that laminoplasty avoids the development of the postlaminectomy membrane and delayed restenosis.[25]

Multiple different approaches have been developed for cervical laminoplasty. These include the open-door or "hinge," midline "French window," and the Z-plasty techniques.[26,53] Each technique is aimed to allow expansion of the cervical canal with simultaneous preservation of a dorsal laminar cover. With these separate techniques, multiple reports have been able to clearly demonstrate that each technique of laminoplasty increases the functional diameter of the cervical canal.[37,48] In a recent review of the existing clinical literature, it was found that an approximately 55%–60% recovery rate was found for Japanese Orthopaedic Association scores following laminoplasty in patients with myelopathy in the setting of myelopathy or OPLL.[43] However, the predominance of the clinical data are retrospective in nature and any recommendations in favor of this technique are based on Class III evidence.[43]

The typical cervical laminoplasty performed in our practice is similar to the technique first described by Hirabayashi and Satomi.[26] This involves a standard dorsal exposure that includes the lamina and extends out to the facets bilaterally. A high-speed drill is used to make a unilateral bony trough on one side in a fashion similar to our standard laminectomy technique. This is the "open door" side of our laminoplasty. On the contralateral side, the drill is used to create a "greenstick" fracture and the "hinge" side of the trough is only developed to partial depth (Figs. 5 and 6). Gentle tension is then applied with a Kocher or other instrument and allows the spinous process and laminar complex to be hinged dorsally, away from the thecal sac. This effectively increases the volume of the cervical canal (Fig. 7). The decompression is then maintained with the application of titanium miniplates. Selective cervical foraminotomies can be performed as needed to relieve cervical radicular compression in an effort to prevent postoperative C-5 deltoid palsy.

A description of our view of the advantages and disadvantages of anterior versus posterior surgical approaches is shown in Fig. 8.

Complications, Monitoring, and Precautions

Approach-Related Injuries

Anterior approach–related complications related to injury to the soft-tissue structures of the neck are well known. These include temporary or permanent dysphagia, recurrent laryngeal or superior laryngeal nerve injury, vertebral artery injury, esophageal perforation, and soft-tissue swelling that constricts the airway and necessitates prolonged intubation or tracheostomy.[4] Timing of extubation is particularly difficult in patients with previous operations, lengthy operations, obesity, or significant comorbid conditions. Elective tracheostomies, although rare, should be entertained in patients who cannot be safely extubated. While a posterior approach avoids many of these potential complications, commonly there is significant postoperative muscular spasm and pain related to the approach. Significant early and long-term axial neck pain may also occur after cervical laminoplasty.[7] The cause of this axial neck pain remains poorly understood; however, many authors have attempted to better preserve the paravertebral muscles in an attempt to reduce this type of pain.[28]

Dural Injury and CSF

In cases of OPLL, the anterior approach presents a significant risk of dural injury and subsequent CSF leak. Epstein et al.[19] reported that this can occur in up to 35% of patients treated by anterior corpectomy for advanced OPLL. Yamaura et al.[70] described the operative "anterior floating method" for focal decompression and fusion in

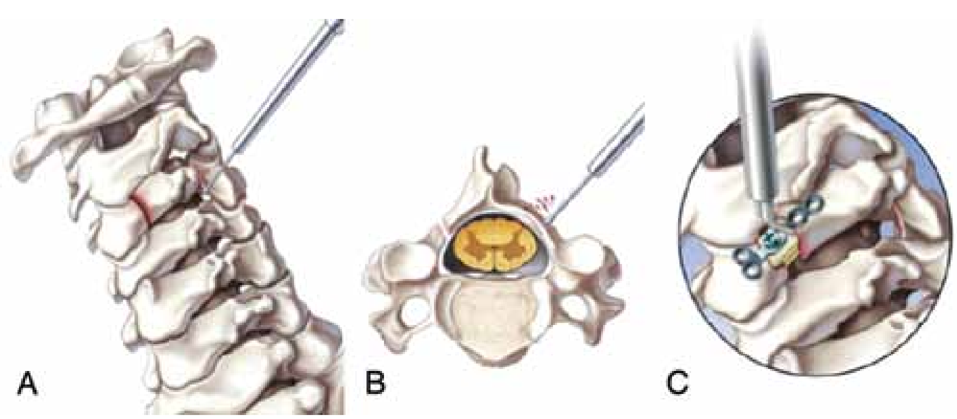

Fig. 5. Illustrations showing the surgical steps in cervical laminoplasty using a modification of the open-door method first described by Hirabayashi and Satomi. **A and B:** A full-thickness trough is developed on one side while a "greenstick" fracture is prepared on the other side. **C:** A small bone graft is placed following angled "hinging" of the lamina and this is held in place with segmental hardware. Reprinted with permission from Aesculap, Inc.

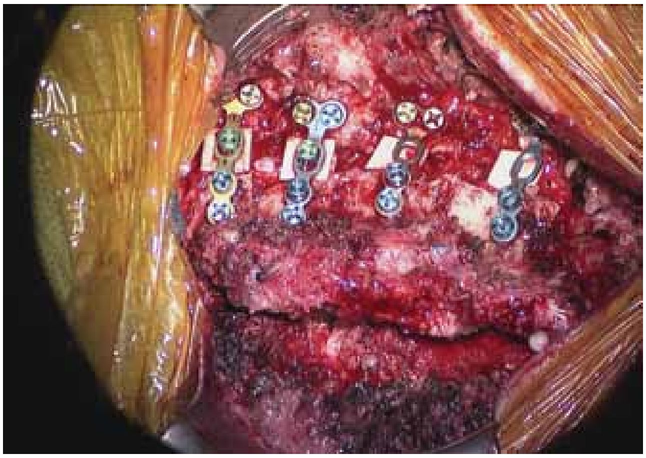

Fig. 6. Intraoperative photograph showing a standard final construct following placement of segmental bone grafts and titanium miniplates (Aesculap, Inc.) for a C3–7 laminoplasty. The lateral mass of C-7 and lamina and spinous process at this same level can be seen clearly. Rostral exposure begins to the left side of the image.

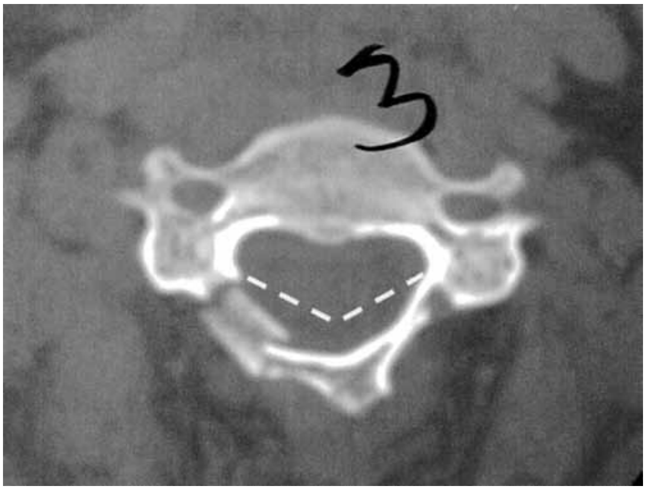

Fig. 7. Postoperative axial CT showing positioned bone graft. Increased axial dimension at this level is shown with the dotted line corresponding to the initial dimensions of the cervical canal.

OPLL. Any specific area that has suspected dural erosion is separated from the surrounding tissue and allowed to float free. This allows for adequate decompression while minimizing the risk of dural trauma associated with direct decompression. Dural ossification can be identified prior to the operation by using CT scanning,[24] and the surgeon should always have a high index of suspicion. In our experience, areas suspicious for dural ossification may be avoided during decompression. We do not believe that this jeopardizes the degree of cervical decompression. However, it may require a more extensive lateral exposure and potentially increases the risk of neurovascular injury. If a CSF leak is encountered, a lumbar drain is placed. In our experience, maintaining drainage for 5–7 days will ensure that the dura is sealed. Use of a small intraoperative ultrasongraphy device is often beneficial in confirming the adequacy of the decompression and restoration of the subarachnoid dural CSF pulsations.

C-5 Palsy Following Cervical Decompressive Surgery

Postoperative upper-extremity paresis is a well-known and troubling complication following cervical decompression surgery. It appears primarily to be associated with the C-5 nerve and can result in temporary, or less commonly permanent, deltoid weakness. While paresis of the other cervical nerves (C6–8) can occur in isolation or combination, these have been reported with a significantly lower incidence.[6,67] In patients with postoperative C-5 palsy, half of the affected patients will have primarily sensory deficits and/or severe pain in the C-5 dermatome (shoulder region) with motor weakness and the other half will have primarily weakness of the deltoid and biceps brachii muscles.[72] Sakaura et al.,[57] in an analysis of multiple reports, found the average incidence of postoperative C-5 palsy to be 4.6% (range 0%–30%). The frequency of this complication did not appear to correlate with the direction (anterior vs posterior) or exact type of approach. The average incidence was 4.3% for anterior decompressive techniques and there was a similar rate, 4.7%, for laminoplasty.[57] A recent review of more than 700 cases of instrumented cervical decompression also showed similar rates between ventral as opposed to dorsal decompressions (J Eck, presentation to the American Academy of Orthopaedic Surgeons, 2009).

Various mechanisms for the development of C-5 radiculopathy have been postulated; however, the precise mechanism remains controversial. The development of C-5 palsy immediately following surgery is presumed to be the result of direct nerve injury. However, this fails to explain the many cases of C-5 palsy that occur several days following an operation. Other reports have hypothesized either a traction or vascular phenomenon that contributes to nerve root injury. A traction hypothesis is supported by the unique anatomy of the C4–5 joint. The zygapophysial joint at C4–5 protrudes more anteriorly than the other joints, and the C-5 nerve root is shorter than adjacent segments. In addition, with a multilevel laminectomy, the C-5 root is the center of decompression. As a result, the greatest degree of posterior shift is believed to occur at this level.[62] Others have proposed either the development of local ischemia or reperfusion injury as a pathological mechanism. Chiba et al.[6] found that increased postoperative T2 signals occur more frequently in patients with upper-extremity palsy. This led to the proposal that reperfusion injury could contribute to damage to the proximal nerve root.

Patients with postoperative C-5 palsy generally have a good prognosis for functional recovery. Specific protocols for preventing these injuries have not yet been established. However, postoperative physical therapy, muscle strengthening exercises, and ROM exercises have been advocated to prevent the development of contractures and adhesive capsulitis (a clinical syndrome more commonly known as a “frozen shoulder”). In our own experience, these patients often show significant improvement in strength and ROM with time and physical therapy.

Graft-Related Complications

Complications related to graft placement include the extrusion of the graft as well as the development of pseud-

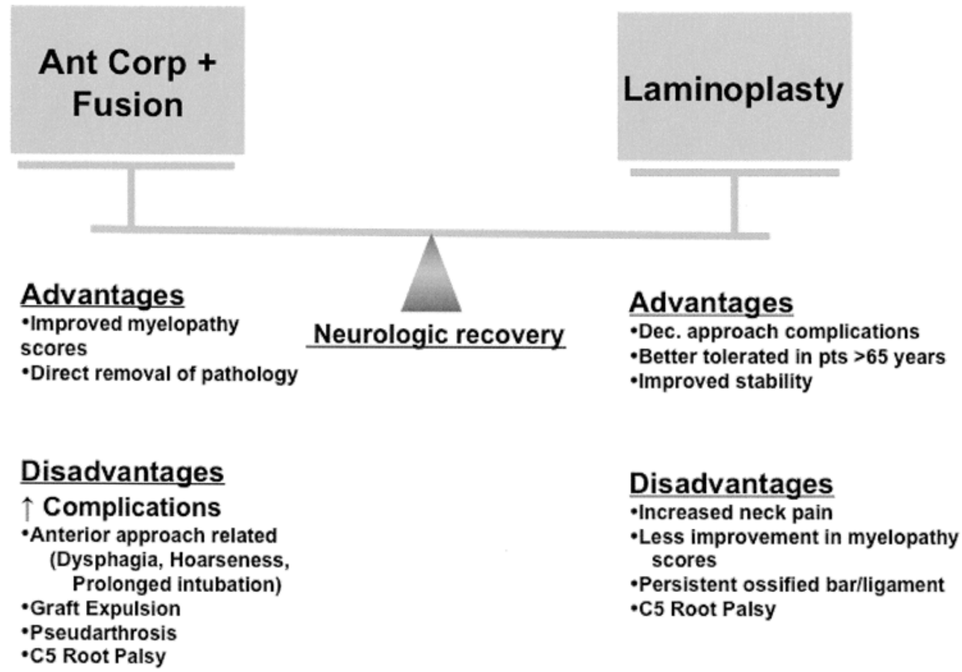

Fig. 8. Chart showing our perceived advantages and disadvantages of anterior versus posterior techniques for decompression in OPLL. The merits of each approach should be weighed for each unique case. Dec. = decreased.

arthrosis. Complications have been reported following multilevel ACC with and without the use of anterior plates. Saunders et al.[60] reported on 3 (9.7%) of 36 patients with acute graft extrusion following 4-level ACC. Vaccaro et al.[68] noted a 9% rate of graft extrusion with 2-level ACC and a significantly higher rate with 3-level anterior surgery. In these circumstances, immediate revision surgery is invariably required to replace the graft. However, when there is only partial extrusion, serial radiographic follow-up may be appropriate. These patients often will still develop a solid fusion without further complication.[3,9] However, with any radiographic signs of progression of graft displacement, further follow-up should likely include revision surgery. Reported rates of pseudarthrosis following ACCF for the treatment of OPLL are quite variable. In 76 patients with nonplated ACCF or multilevel nonplated ACC, Epstein[14] reported a 13% incidence of pseudarthrosis during the first 6 months. Swank et al.[63] noted a 31% rate of pseudarthrosis in 26 patients undergoing ACC. This rate was increased to 44% in patients with multilevel corpectomy constructs. Significantly better fusion rates were reported by Eleraky et al.,[11] who reported a 98.8% fusion rate in 87 patients with 1-level ACC and 98 patients with multilevel fixation. In the authors' experience, patients with asymptomatic nonunion can be clinically observed for evidence of graft extrusion. When pain is present in association with the nonunion, posterior cervical fusion may be chosen to relieve pain and to provide stability for fusion.

Postlaminectomy Kyphosis

The incidence of kyphotic change after multilevel laminectomy has been reported to be between 21% and 47% in larger retrospective series.[32,33] Although progressive kyphosis was seen in 47% of patients as reported by Kato et al.,[33] there appeared to be no effect on clinical outcomes. In a recent report by Cho et al.[8] in 14 patients treated by total laminectomy for OPLL, kyphosis was observed in all but 1 patient. However, similar to the series of Kato et al., progressive kyphosis did not lead to neurological deterioration. Facet injury is the most important contributor to postoperative kyphosis. An extension of the facetectomy to include greater than 50% is thought to result in significant kyphosis and resultant instability.[73]

Monitoring and Precautions During Cervical Spine Operations

It is our opinion that the patient with significant cervical compression due to advanced OPLL requires unique attention from the entire surgical team. Particularly difficult in these patients are the challenges of airway management following extensive anterior or combined anterior-posterior decompressive surgery. At our hospital, we recommend that all patients undergo awake, fiberoptic intubation to avoid injury due to hyperextension of the neck. We additionally have elected to extubate all patients on postoperative Day 1 or later when the patient has undergone multilevel corpectomy or combined anterior-posterior surgery. All patients are also evaluated for the ability to ventilate around a deflated endotracheal cuff.[3] Perioperative steroids are routinely administered. Intraoperative blood pressure is closely monitored throughout all cases to avoid any hypotension. We have found that fiberoptic evaluation of the vocal cords has been beneficial in high-risk patients (prior anterior surgery, obesity, chronic obstructive pulmonary disease, or significant blood loss). If significant airway edema is encountered, extubation is commonly delayed into the 1st postoperative week. The use of continuous intraoperative electrophysiological monitoring during either anterior or posterior cervical approaches for OPLL is used during all cases at our institution. The use of this monitoring, specifically motor evoked potentials, may serve as a sensitive means to diagnosis potential neurological injury during decompression.[56] In our opinion, the use of motor evoked potentials represents the current best clinical practice and is a sensitive real-time mechanism for detecting injury. This is especially important for anterior compression of the ventral horns.

Disclosure

Drs. Smith and Khoo are consultants for Aesculap USA, Inc. and have received financial support in the form of clinical research grants and lecture fees. Dr. Buchanan has no significant disclosures to report.

Author contributions to the study and manuscript preparation include the following. Conception and design: Khoo, Smith. Acquisition of data: Smith, Buchanan. Analysis and interpretation of data: Khoo, Smith. Drafting the article: Smith. Critically revising the article: Khoo, Smith. Reviewed final version of the manuscript and approved it for submission: Khoo, Smith. Statistical analysis: Smith. Administrative/technical/material support: Khoo, Smith. Study supervision: Khoo, Smith.

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Manuscript submitted November 9, 2010.
Accepted January 19, 2011.
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Neurosurg Focus 30 (3):E11, 2011

Analysis of demographics, risk factors, clinical presentation, and surgical treatment modalities for the ossified posterior longitudinal ligament

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Object. Ossification of the posterior longitudinal ligament (OPLL) is a rare disease that results in progressive myeloradiculopathy related to pathological ossification of the ligament from unknown causes. Although it has long been considered a disease of Asian origin, this disorder is increasingly being recognized in European and North American populations. Herein the authors present demographic, radiographic, and comorbidity data from white patients with diagnosed OPLL as well as the outcomes of surgically treated patients.

Methods. Between 1999 and 2010, OPLL was diagnosed in 36 white patients at Barrow Neurological Institute. Patients were divided into 2 groups: a group of 33 patients with cervical OPLL and a group of 3 patients with thoracic or lumbar OPLL. Fifteen of these patients who had received operative treatment were analyzed separately. Imaging analysis focused on signal changes in the spinal cord, mass occupying ratio, signs of dural penetration, spinal levels involved, and subtype of OPLL. Surgical techniques included anterior cervical decompression and fusion with corpectomy, posterior laminectomy with fusion, posterior open-door laminoplasty, and anterior corpectomy combined with posterior laminectomy and fusion. Comorbidities, cigarette smoking, and previous spine surgeries were considered. Neurological function was assessed using a modified Japanese Orthopaedic Association Scale (mJOAS).

Results. A high-intensity signal on T2-weighted MR imaging and a history of cervical spine surgery correlated with worse mJOAS scores. Furthermore, mJOAS scores decreased as the occupying rate of the OPLL mass in the spinal canal increased. On radiographic analysis, the proportion of signs of dural penetration correlated with the OPLL subtype. A high mass occupying ratio of the OPLL was directly associated with the presence of dural penetration and high-intensity signal. In the surgical group, the rate of neurological improvement associated with an anterior approach was 58% compared with 31% for a posterior laminectomy. No complications were associated with any of the 4 types of surgical procedures. In 3 cases, symptoms had worsened at the last follow-up, with only a single case of disease progression. Laminoplasty was the only technique associated with a worse clinical outcome. There were no statistical differences ($p > 0.05$) between the type of surgical procedure or radiographic presentation and postoperative outcome. There was also no difference between the choice of surgical procedure performed and the number of spinal levels involved with OPLL.

Conclusions. Ossification of the posterior longitudinal ligament can no longer be viewed as a disease of the Asian population exclusively. Since OPLL among white populations is being diagnosed more frequently, surgeons must be aware of the most appropriate surgical option. The outcomes of the various surgical treatments among the different populations with OPLL appear similar. Compared with other procedures, however, anterior decompression led to the best neurological outcomes. *(DOI: 10.3171/2010.12.FOCUS10265)*

Key Words • ossification of the posterior longitudinal ligament • laminoplasty • laminectomy • anterior cervical decompression • modified Japanese Orthopaedic Association Scale

Ossification of the posterior longitudinal ligament is a pathological ectopic ossification of this ligament that usually occurs in the cervical or thoracic spine and, less frequently, in the lumbar spine.[37] It has long been considered a disease of Asian origin, and more specifically of the Japanese population. Increasingly, however, this disorder is being recognized in European and North American populations. The prevalence of OPLL in Japanese and East Asian countries has ranged from 1.9% to 4.3%,[17,21,34,42,43] while in white populations it has ranged from 0.01% to 1.7%.[14,21]

The typical age at onset is 50 years, with a male/female ratio of 2:1.

The Japanese Investigation Committee on the Ossification of the Spinal Ligaments[42,43] defined 4 subtypes of OPLL based on the extent of the condition: 1) focal, local-

Abbreviations used in this paper: ACD = anterior cervical decompression; DISH = diffuse idiopathic skeletal hyperostosis; mJOAS = modified Japanese Orthopaedic Association Scale; OLF = ossification of the ligamentum flavum; OPLL = ossification of the posterior longitudinal ligament.

ized to the disc space; 2) segmental, located behind each vertebral body and not extending beyond the adjacent disc level; 3) continuous, between several levels overpassing the disc; and 4) mixed, combination of segmental and continuous types. The segmental type occurs in most cases (39%) followed by the mixed (29%), continuous (27%), and focal types (5%).[3]

Clinical presentations correspond to the level and magnitude of spinal cord compression. Cervical and thoracic OPLL typically manifests with signs and symptoms of myelopathy, while the lumbar disease usually manifests with signs and symptoms of stenosis.[17,27,29] Predictors and risk factors for the development or progression of myelopathy include > 60% OPLL-induced spinal stenosis, increased range of motion of the cervical spine, progression of OPLL, type of OPLL (that is, the segmental type is associated with the greatest risk), and lateral-deviated OPLL.[25–27,30] After 30 years, however, myelopathy-free rates as high as 71% have been reported among patients who had no myelopathy when the OPLL was first diagnosed.[27]

Surgical procedures for the treatment of cervical OPLL can be separated into anterior or posterior approaches. The anterior approach involves direct removal of the ossified mass, while the posterior approach involves laminoplasty, laminectomy, or laminectomy with posterior fusion for decompression and stabilization. Rates of neurological improvement after anterior surgery have been as high as 92% and have been associated with fewer complications than the posterior procedures.[27,29,40]

Both laminectomy and laminoplasty are safe and effective treatments for high-risk patients with multilevel OPLL. The rates of neurological improvement associated with laminoplasty and laminectomy have been reported to be 67% and 42%, respectively.[12,15] However, significant neurological deterioration immediately after surgery, cervical kyphosis, and progression of ossification are concerns when a using these techniques.[12,16,24,40]

Several factors have been associated with negative surgical outcomes, including age, misalignment of the cervical spine, preoperative neurological score, intramedullary high-intensity signal on sagittal T2-weighted MR imaging, OPLL subtype, and a mass occupying ratio ≥ 60%.[12,22,24,36,40,45]

As OPLL is recognized and its incidence increases accordingly, it is worthwhile to understand trends related to this disease. We therefore analyzed the demographics, clinical and imaging features, and potential risk factors associated with OPLL in a population of white patients. Note that the surgical experience in white patients with OPLL is limited as compared with that in the Asian population; consequently, we evaluated our institutional experience in these patients.

Methods

This study was approved by the Institutional Review Board of St. Joseph's Hospital and Medical Center in Phoenix, Arizona.

Between September 1999 and September 2010, symptomatic OPLL was diagnosed in 41 white patients at the Barrow Neurological Institute, and data were retrospectively reviewed in 36 of them for this study. Data for the remaining 5 patients were not sufficient for analysis. Sixteen patients (44.5%) were males, and 20 (55.5%) were females, with a mean age of 56 years (range 32–85 years). Patients were divided into 2 groups based on the anatomical location of their OPLL: a group of 33 patients (16 males [48.5%] and 17 females [51.5%], with a mean age 56 years) with cervical OPLL and a group of 3 female patients (mean age 49 years) with thoracic (2 patients) or lumbar (1 patient) OPLL.

Analyzed comorbid conditions included diabetes mellitus, systemic hypertension, dyslipidemia, hypothyroidism, meningioma, DISH, cigarette smoking, and previous lumbar surgeries (Table 1). Each patient's family history for disease as well as any history of trauma was documented. Analyzed imaging data included high-intensity signal of the spinal cord on T2-weighted MR imaging, mass occupying ratio (percentage of spinal canal diameter occupied by the OPLL) on CT scanning, type of OPLL, signs of dural penetration as described by Hida et al.,[8] and involved spinal levels.

Of the patients identified, 15 were surgically treated (Table 2). Ten (66.7%) were males and 5 (33.3%) were females, with a mean age of 56 years (range 32–75 years). The mean duration of follow-up among this group was 22.5 months (range 1–150 months). Cervical OPLL was present in 14 cases. Thoracic OPLL was present in 1 case, which was separately evaluated because of the difference in its clinical presentation and management. Inclusion into this small surgical series required a patient to have undergone OPLL surgery performed by a senior neurosurgeon at the Barrow Neurological Institute. Surgically treated patients with OPLL were excluded if their clinical presentation or indication for spine surgery was unrelated to OPLL; if there were no data on the patient's demographics, comorbid conditions, and follow-up; or if no appropriate diagnostic imaging studies were available after a thorough review of the patient's medical records, computerized data, films, and charts.

Patients underwent the following surgical approaches (Table 3): ACD and fusion with corpectomy, posterior laminectomy with fusion, posterior open-door laminoplasty, and combined anterior corpectomy with posterior laminectomy and fusion (360° approach). The clinical pre-

TABLE 1: Comorbid conditions in 36 white patients with OPLL

Condition	No. (%) Cervical OPLL	Thoracic-Lumbar OPLL
diabetes mellitus	11 (33.3)	1 (33.3)
systemic hypertension	19 (57.6)	2 (66.7)
dyslipidemia	4 (12.1)	
DISH	1 (3.0)	
hypothyroidism	3 (9.1)	
meningioma	3 (9.1)	1 (33.3)
cigarette smoking	5 (15.2)	
history of trauma	9 (27.3)	
history of spine op	3 (9.1)	

TABLE 2: Summary of clinical characteristics in 15 patients who underwent surgical treatment for OPLL*

Case No.	Age (yrs), Sex	Comorbidity/Surgical or Medical History	Level of Disease	Type of Disease†	Level of Op	Type of Op
1	65, F	systemic hypertension, dyslipidemia, cervical spine op	C2–6	continuous	C2–7	laminectomy & fusion
2	51, M	diabetes mellitus, systemic hypertension, DISH	C2–T1	continuous	C4–7	360°
3	32, F	none	C3–5	segmental	C3–6	ACD & fusion w/ corpectomy
4	49, F	systemic hypertension, meningioma	C3–6	continuous	C3–6	laminectomy & fusion
5	75, M	systemic hypertension, dyslipidemia, diabetes mellitus	C5–7	segmental	C5–T1	360°
6	56, M	systemic hypertension	C4–5	segmental	C3–6	laminoplasty
7	47, M	systemic hypertension	C3–7	mixed	C3–7	laminectomy & fusion
8	73, M	systemic hypertension	C3–6	segmental	C3–7	ACD & fusion w/ corpectomy
9	45, M	none	C4–7	Segmental	C4–7	ACD & fusion w/ corpectomy
10	73, M	none	C2–4	mixed	C2–5	laminectomy & fusion
11	63, M	none	C2–4	mixed	C2–5	laminectomy & fusion
12	53, F	systemic hypertension, dyslipidemia, diabetes mellitus, hypothyroidism	C1–5, C7–T1	mixed	C1–4	laminectomy & fusion
13	53, M	systemic hypertension, smoking	C3–T1	mixed	C3–6	laminectomy & fusion
14	58, M	none	C4–6	mixed	C3–6	laminectomy & fusion
15	32, F	systemic hypertension	T3–10, T-12	mixed	T6–10	laminectomy & fusion

* 360° = ACD and corpectomy with posterior laminectomy and fusion.
† Type of OPLL as classified by the Japanese Investigation Committee on the Ossification of the Spinal Ligaments. See Tsuyama, 1984.

sentation associated with OPLL and treatment outcomes were assessed using the mJOAS as described by Benzel et al.,[1] in which motor, sensitivity, and sphincter functions were scored. The maximum mJOAS score, corresponding to normal, for patients with cervical OPLL was 18, and the maximum score for patients with thoracic or lumbar OPLL, which excludes upper limb function, was 13. Subsequently, the recovery rate was calculated using the Hirabayashi et al.[9] method (recovery rate = [postoperative mJOAS score − preoperative mJOAS score] × 100/(maximum score − preoperative mJOAS score) and was defined as excellent (100%–75%), good (74%–50%), fair (49%–25%), unchanged (24%–0%), or deteriorated (score < 0%). Intraoperative and postoperative (follow-up) complications were also analyzed.

Statistical analysis was performed with a personal computer operating SPSS, version 18. Independent t-tests were used to analyze demographic and comorbid conditions by radiographic presentation. A post hoc test (Fisher least significant difference) was applied to determine differences in radiographic features at presentation (that is, mass occupying ratio and dural penetration) by type of OPLL. Analysis of variance was utilized to compare mean scores by OPLL type and surgery type as well as to analyze outcome variables by the type of surgery performed. A p value ≤ 0.05 was considered significant.

Results

Cervical OPLL

Patients with cervical OPLL (Table 4) had the following OPLL types: localized, 9 patients (27.3%); continuous, 5 patients (15.2%); segmental, 12 patients (36.4%); and mixed, 7 patients (21.2%). One-level disease was present in 4 cases (12.1%), 2-level disease in 9 (27.3%), 3-level disease in 9 (27.3%), 4-level disease in 3 (9.1%), 5-level disease in 5 (15.2%), and 6-level disease in 3 (9.1%). Signs of dural penetration were evident in 16 patients (48.5%), whereas high-intensity T2-weighted MR imaging signals were present on the spinal cord in 17 cases (51.5%). On axial CT scans, the mean mass occupying ratio was 38.7%

TABLE 3: Preoperative and postoperative neurological status of 15 patients based on the mJOAS as a function of surgical approach

Op Type	No. of Cases	Mean Preop mJOAS Score	Mean Postop mJOAS Score	Mean Recovery Rate (%)*	Recovery Rate Result*
laminectomy	9	11.2	14.1	36.5	fair
laminoplasty	1	14.0	12.0	−50.0	deteriorated
ACD & corpectomy	3	15.3	17.0	58.3	good
360°	2	12.0	13.5	31.2	fair

* According to Hirabayashi method: recovery rate = (postoperative mJOAS score − preoperative mJOAS score) × 100/(maximum score − preoperative mJOAS score).

TABLE 4: Cases of OPLL by cervical level

Level	No. (%)
C-1	1 (3.0)
C-2	9 (27.3)
C-3	14 (42.4)
C-4	22 (66.7)
C-5	23 (69.7)
C-6	23 (69.7)
C-7	10 (30.3)

(range 16%–74.5%). The mean score on the mJOAS, as a reflection of clinical status, was 14.3 (range 8–18). Figure 1 shows the average mJOAS score for each comorbid and radiographic condition.

The mJOAS scores were significantly worse for patients whose T2-weighted MR imaging studies showed a high-intensity signal from the spinal cord ($p = 0.001$, 12.8 vs 16 in those without T2-weighted signal from the spinal cord) and for patients with a history of cervical spine surgery unrelated to OPLL ($p = 0.003$, 14.3 vs 16 in those without previous spine surgery). Furthermore, mJOAS scores correlated negatively with the mass occupying rate of the OPLL mass in the spinal canal ($p = 0.001$). Patients with an occupying rate > 50% had a mean mJOAS score of 11.6, as compared with a score of 14.9 in patients with a rate < 50% (no patients had a 50% mass occupying rate).

There was a significant difference in the likelihood of signs of dural penetration based on OPLL type ($p = 0.007$); that is, the mixed type of OPLL had less dural involvement than the localized ($p = 0.005$) and segmental types ($p = 0.001$). Furthermore, there were significant differences in the mean occupying ratio in the spinal canal by OPLL type ($p = 0.028$). Post hoc analysis showed that the mixed type of OPLL had a significantly higher occupying ratio than the localized ($p = 0.011$) or segmental types ($p = 0.008$).

Signs of dural penetration on CT or of high-intensity signal on T2-weighted MR images of the spinal cord were directly associated with the mass occupying ratio ($p = 0.005$ and $p = 0.001$, respectively); that is, a higher occupying ratio (mean 45% ± 13%) was directly correlated with the presence of either radiographic sign.

Thoracic and Lumbar OPLL

Radiographic evaluation showed the following involvement of the OPLL in 3 patients: a single level at T-9, 9 levels at T3–10 and T-12, and 4 levels at L1–4. Of the thoracic cases, 1 was localized and 1 was mixed, whereas the single lumbar case was a segmental type. One of the thoracic cases (whose mass occupying ratio was 73.3% on axial CT) had signs of dural penetration on CT and a high-intensity signal on T2-weighted MR images of the spinal cord. The patient in this case had an mJOAS score of 8 of 13 (after adjusting the scale without considering upper limb function), as compared with a score of 11 in the second case of thoracic OPLL, which lacked signs of both dural penetration and high-intensity signal on T2-weighted MR imaging. The sole lumbar case showed radiographic signs of dural penetration, had a mass occupying ratio of 40.5%, and an mJOAS score of 13.

Surgically Treated Group

No surgical complications occurred. At the last follow-up, however, symptoms had worsened in 3 patients. One patient had undergone a combined anterior corpectomy and posterior laminectomy and fusion (360°), and yet disease had progressed. A second patient had undergone posterior laminectomy and fusion and presented with a newly diagnosed cervical syrinx. A third patient had undergone laminoplasty, and his status had worsened for unknown reasons. Based on radiographic evaluation, the subtypes of cervical OPLL were as follows: none were localized, 3 (20%) were continuous, 5 (33.3%) were segmental, and 7 (46.7%) were mixed. Signs of dural penetration were evident in 9 cases (60%). Sagittal T2-weighted MR images showed high-intensity signal

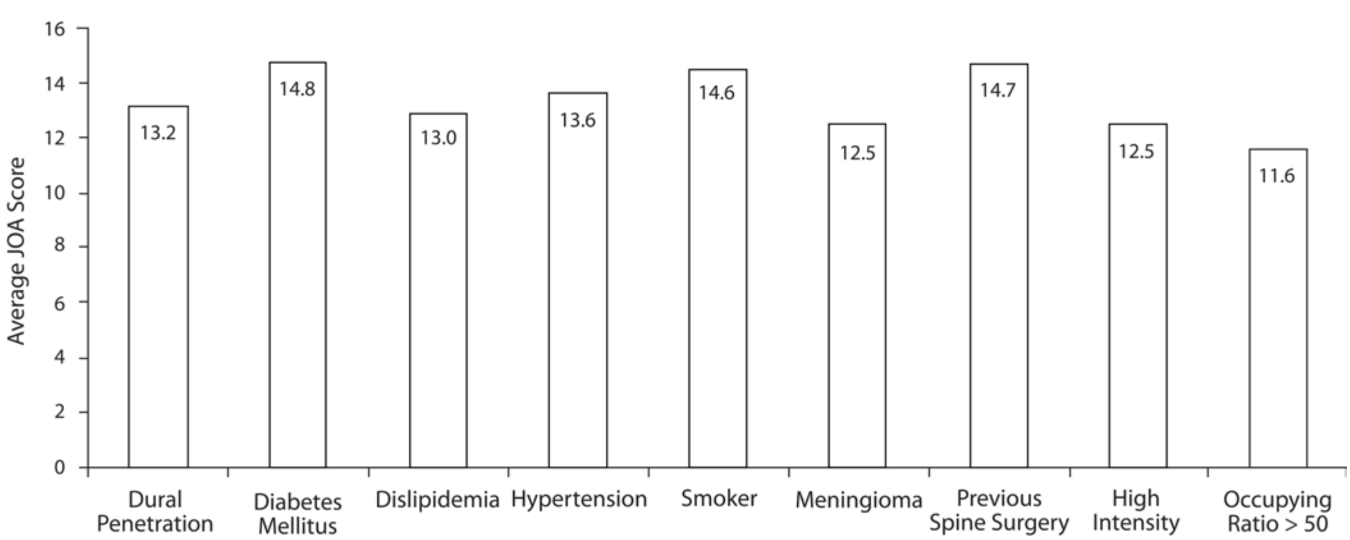

Fig. 1. Bar graph depicting mJOAS scores, measures of neurological function, as a function of demographic features and radiographic presentation.

in 11 cases (73.3%). The mean occupying ratio was 46.6% (range 24%–74.5%).

Overall, the mean improvement in mJOAS scores after all surgical procedures was 1.85. Individual mJOAS scores according to the type of surgery are shown in Figs. 2 and 3. At the last follow-up, laminoplasty was the only surgical technique associated with a worsening clinical outcome (Table 3). Comparisons of the type of surgical procedure or radiographic presentation with postoperative outcome (mJOAS score improvement and recovery rate) failed to reach significance ($p > 0.05$). Furthermore, no difference was found between the choice of surgical procedure and the number of levels involved by the OPLL (mean number of levels 4.29)

The only patient with thoracic OPLL who underwent surgical treatment was a 32-year-old woman with a mixed type OPLL involving T3–10 and T-12. She underwent laminectomy and fusion from T-6 to T-10 without intraoperative or follow-up complications. Her preoperative radiographic evaluation demonstrated an occupying ratio of 73.3% of the spinal canal space with signs of dural penetration and high-intensity signal on sagittal T2-weighted MR imaging. Her preoperative mJOAS score of 8 improved to 12 (after adjusting the scale without considering upper limb function), an 80% recovery rate.

Discussion

With an estimated rate of 0.12% in North America, the prevalence of OPLL is much lower in the white population than in the Asian population.[35] However, its prevalence is likely to increase as awareness of the disease grows among spine surgeons. Most cases in North America are reported as sporadic; however, in vitro characteristics of cell lines from American patients with OPLL are similar to those from East Asian patients,[5] which can account for the similarity of our results with findings in previously published studies in Asian-based patients with OPLL in which specific comorbidities and radiographic markers correlated with the clinical neurological presentation of disease.

It has been estimated that 70% of OPLL cases involve the cervical spine, 15% the thoracic spine, and 15% the upper lumbar spine (L1–3). The disease appears to have a multifactorial etiology in which genetic and environmental components interact. Recent studies indicate that single nucleotide polymorphism in the collagen 11A2 gene (*COL11A*) located within the Class II histocompatibility complex region on chromosome 6, which encodes the α2 chain of the Type XI collagen, could be responsible.[20,21] Two single nucleotide polymorphisms at intron 6 and exon 6 of *COL11A* could be helpful markers of this disease, and the latter could explain the sex difference in the prevalence of OPLL, which has a male/female ratio of 2:1.[23,36]

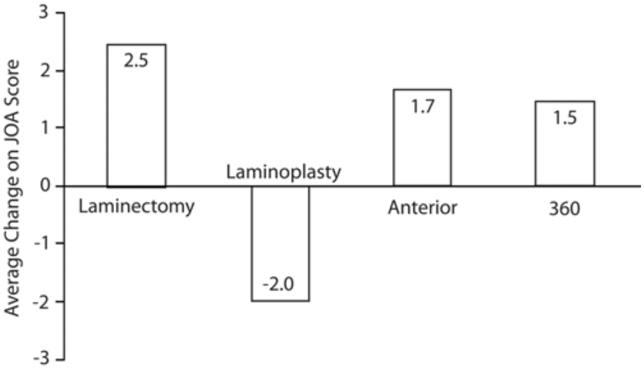

Fig. 2. Bar graph demonstrating changes in neurological status as measured by the mJOAS, as a function of surgical treatment.

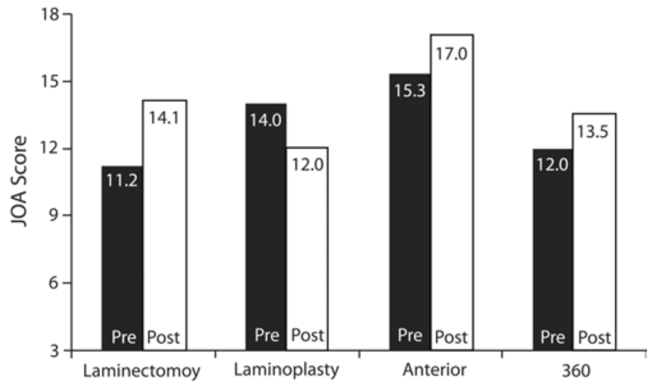

Fig. 3. Bar graph showing a comparison of preoperative and postoperative neurological status as measured by the mJOAS, as a function of surgical technique. 360 = 360° procedure.

The prevalence of polymorphisms at the collagen 6A1 gene (*COL6A1*), located on chromosome 21q, which encodes the α1 chain of Type VI collagen, is significantly greater in patients with OPLL than in healthy controls.[39] Several authors have suggested that the overproduction of both Type VI and XI collagen, as a result of the genetic alteration on their encoding genes, provides a framework for osteoblasts and/or chondrocytes to generate ectopic endochondral ossification.[20,23,39] However, the qualitative abnormality of these collagen molecules in patients with OPLL has not been demonstrated.[10]

Imaging of the spine continues to be the most appropriate diagnostic tool (Fig. 4). Lateral plain radiographs are used to measure the percentage of spinal canal occupied by the OPLL. Transaxial CT scans are the best means of visualizing the diseased ligament by showing sclerotic bone extending from the posterior side of the vertebral body into the spinal canal.[28] A sagittal overview CT is best for assessing the actual extent and subtype of OPLL and is the image of choice for evaluating dural penetrance according to the single- or double-layer sign. And T2-weighted MR imaging is essential for evaluating spinal cord swelling, myelomalacia, or gliosis within the spinal cord.[3] As diagnostic tools, additional complementary tests, including those measuring bone mineral density and bone formation markers, have been associated with promising results.[10,38]

Numerous medical factors, such as hypoparathyroidism, hypophosphatemic rickets, spondyloepiphyseal dysplasia, myotonic muscular dystrophy, obesity, DISH, ankylosing spondylitis, OLF, and a high salt/low animal protein diet, have already been identified as potential risk or associated factors for OPLL.[3,7,10,19,31,36,44] Kobashi et al.[19] reported a higher frequency of diabetes mellitus among

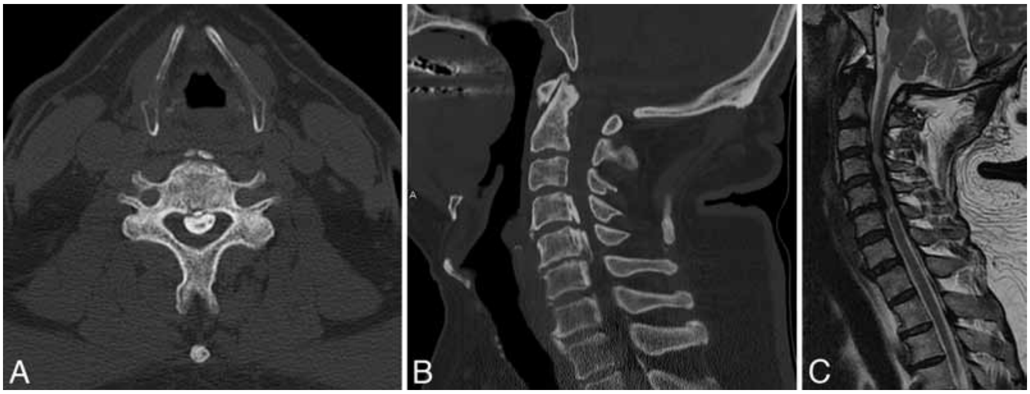

Fig. 4. Representative images obtained in a 58-year-old man with cervical OPLL from C-4 to C-6. Axial CT scan **(A)** and sagittal CT reconstruction **(B)** demonstrating an OPLL mass. Sagittal T2-weighted MR image **(C)** showing high signal intensity in the medullary region from C-4 to C-6.

Japanese men and women with OPLL as compared with controls (20% vs 5% in men, 27.6% vs 1.7% in women). In a Japanese study conducted by Ehara et al.,[2] the rate of concurrent DISH and OPLL reached 25%. In that same study the rate of concurrent OPLL and OLF was 16.7%. In a North American population, McAfee et al.[28] found that the rate of concurrent DISH and OPLL was 50%, concurrent ankylosing spondylitis and OPLL was 2%, and concurrent OLF and OPLL was 6.8%. Similarly, Epstein[4] found that OLF was present in 20% of the OPLL cases she analyzed.

In the present study, we found comorbid conditions previously reported as potential risk factors in both Asian and non-Asian populations. The prevalence of diabetes mellitus was 34.4% in those with cervical OPLL and 33.3% in those with thoracic or lumbar OPLL. One patient also had DISH. Note, however, that the prevalence of systemic hypertension was extremely high among both groups (cervical 57.5%, thoracic-lumbar 66.7%). Hypothyroidism (9.4%), dyslipidemia (12.1%), and a history of meningioma (11.1%) were also notable.

Because our population was entirely white, we used the mJOAS to measure neurological function instead of the original scale. In our attempt to identify risk factors correlating with a neurological manifestation of OPLL, we found that patients with high-intensity signal on T2-weighted MR imaging studies of the spinal cord had significantly worse mJOAS scores. These results are consistent with those of Yagi et al.,[45] who found that preoperative JOAS scores were lower in patients whose MR images showed changes in signal intensity than in those whose did not (8.8 ± 1.1 compared with 10.2 ± 1.3, respectively). Furthermore, mJOAS scores decreased as the occupying rate of the OPLL mass in the spinal canal increased. This phenomenon was also reported by Matsunaga et al.,[26] who found that patients with ≥ 60% canal stenosis also had myelopathy.

Dural penetration in diagnosed OPLL cases represents a challenge when surgical treatment is considered because of the risk of creating a dural defect and a subsequent CSF leak when the mass is removed. Consequently, CT films must be carefully evaluated to identify dural involvement indicated by single- or double-layer signs.[8] Furthermore, according to our results and those of Hida et al.,[8] a high mass occupying ratio is likely to be associated with dural penetration.

To determine the most appropriate treatment, several conditions must be regarded. Conservative management should be considered when neurological signs or symptoms (mainly neck or arm pain) are minimal and there is no evidence of myelopathy. Immobilization using cervical orthoses and skull traction combined with steroidal or nonsteroidal pharmacological agents is the available option for conservative treatment.[3,13]

Because long-lasting spinal cord compression can cause irreversible damage, surgical decompression is indicated for cervical OPLL when myelopathy is noticeable. However, the optimal surgical approach is controversial.[27] Anterior corpectomy with resection of the ossified mass followed by fusion is a radical surgical procedure best indicated for a local or segmental type of OPLL that extends fewer than 3 vertebral levels below C-2 and above T-1 in a patient with no congenital stenosis. The ossified mass should be hill-shaped, the occupying ratio should be ≥ 60%, and local kyphosis of the spinal cord should be present.[13,27,29] In contrast, the posterior surgical approach, mainly laminoplasty, is widely used to treat high-risk patients older than 65 years with multilevel disease and a nonkyphotic deformity.[3]

Even though the anterior approach for cervical OPLL is more technically demanding than a posterior approach, the best rates of improvement and functional neurological outcomes have been associated with the former. Tani et al.[40] reported a 58% rate of improvement in patients undergoing anterior decompression as compared with a 13% improvement rate in those undergoing posterior laminoplasty. In this same study, significant neurological deterioration occurred in 5 patients who had undergone laminoplasty, immediately after surgery in 4 and during late follow-up in 1. Similarly, Iwasaki et al.[11] reported a 5% rate of immediate and a 16% rate of late neurological deterioration after laminoplasty. Late-onset neurological decline is compatible with reports of postoperative progression of OPLL in patients who undergo laminoplasty. Although the frequency of OPLL progression after laminoplasty has been reported to be as high as 70%,[11,15] rates of its symptomatic progression are low.[15,32] Additional surgical complications, primarily associated with the anterior approach, include CSF leakage and bone graft extrusions or pseudarthrosis.

In our study, patients who underwent ACD and corpectomy with fusion had the best outcomes and no surgical complications. The improvement rate following the anterior approach was 58% compared with 28.2% following the posterior approach. These results are consistent with those in previous reports.[12,40] Furthermore, as previously shown,[14,23] laminoplasty is associated with the worst outcomes, although we performed this procedure in only 1 case. Disease progression was evident in a single case—a patient who underwent combined anterior and posterior surgery. This patient had the longest follow-up (150 months). Due to the gradual nature of the disease, it is possible that in other cases progression would be apparent on longer follow-up.

In contrast to previous indications for choosing the surgical approach, the number of involved levels was not a criterion in the choice of surgery. The mean number of spinal levels involved with OPLL was approximately 4, and the outcomes of all techniques were promising. Furthermore, if laminoplasty is excluded (1 case with a negative outcome), there was no significant difference between the procedure performed and neurological outcome ($p = 0.206$) or improvement score ($p = 0.372$). Hence, neurological function improved after all procedures.

In our series, the primary indication for surgical treatment was the presence of deteriorating myelopathic symptoms with or without its associated radiographic presentation. Most of the cases showed spinal changes in the spinal cord on MR imaging and a high mass occupying ratio. Excluding laminoplasty, all patients' overall neurological function improved at least a fair amount as measured according to the Hirabayashi et al.[9] method. Therefore, we strongly support surgical treatment for patients with cervical OPLL who have symptomatic myelopathy, even in those with no radiological evidence of severe disease.

It is well known that surgical outcomes for thoracic myelopathy related to OPLL are worse than those for cervical OPLL.[33,49] Authors of many studies have reviewed the indications and results of the different approaches without establishing a definitive standard of treatment.[6] Several factors increase the difficulty and operative risks for patients with thoracic OPLL. First, the natural kyphosis at this spinal level decreases the effectiveness of decompressive laminectomy because posterior shifting of the spinal cord is restricted. Second, the spinal cord is vulnerable at the site of compression because of poor vascularity. Third, the anterior approach is limited by the presence of the rib cage.[47]

Removal of the posterior longitudinal ligament may be the most effective method of relieving pressure on the spinal cord in patients with thoracic myelopathy related to OPLL. Treatment via a posterior approach with extensive decompression could induce postoperative kyphosis, eliminating the effectiveness of the procedure.[48] To avoid inducing kyphosis, surgeons began using laminoplasty or fusion with a bone graft in combination with instrumentation. However, the outcomes associated with this technique are not ideal, because of the limiting posterior shift of the spinal cord.[46,47]

In 1990, Tomita et al.[41] described a new technique for circumspinal decompression that included the safe removal of OPLL plaque. In 2001, this technique was improved by the introduction of the concept of dekyphosis stabilization.[18] It is now widely accepted that the ossified mass must be completely removed to achieve a full recovery from OPLL-derived myelopathy and that the posterolateral approach is an effective and safe procedure for achieving an optimal outcome.[48] In our single case experience, laminectomy and fusion from T-6 to T-10 was performed without complications. Although the mass was not removed, the patient's postoperative improvement was excellent at his last follow-up visit at 57 months, with no evidence of disease progression. Unfortunately, 1 case precludes a comparative analysis among surgical procedures and clinical outcomes. However, this patient did recover almost fully from the disease, an outcome that supports other reports of promising results following the surgical treatment of thoracic OPLL.

Conclusions

Our findings provide further evidence of the prevalence of a pathology that was once called "the Japanese disease" among whites. As the results of our study show, the demographic and radiographic factors of OPLL are similar in both Asian and white populations, and as in the Asian population, the etiology and potential risk factors in the white population remain unknown. The most appropriate surgical treatment for OPLL remains elusive. We could identify no specific indications for selecting a particular treatment option. All techniques were associated with promising outcomes regardless of the number of involved diseased levels or the radiographic or pathological presentation. The clinical improvement rate was significant, and no surgical complications occurred; therefore, surgery appears to be a safe and effective treatment for OPLL at any spinal level.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Acquisition of data: Kalb, Martirosyan, Kalani. Analysis and interpretation of data: Perez-Orribo. Drafting the article: Kalb. Reviewed final version of the manuscript and approved it for submission: Theodore. Statistical analysis: Kalb. Administrative/technical/material support: Kalb, Martirosyan. Study supervision: Theodore, Kalani.

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Manuscript submitted November 12, 2010.
Accepted December 20, 2010.
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Approach-related complications after decompression for cervical ossification of the posterior longitudinal ligament

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The surgical management of compressive cervical ossification of the posterior longitudinal ligament (OPLL) can be challenging. Traditionally, approach indications for decompression of cervical spondylotic myelopathy have been used. However, the postoperative complication profile after cervical OPLL decompression is unique and may require an alternative approach paradigm. The authors review the literature on approach-related OPLL complications and suggest a management strategy for patients with single- or multiple-segment OPLL with or without greater than 50% canal stenosis. *(DOI: 10.3171/2011.1.FOCUS10278)*

Key Words • ossification of the posterior longitudinal ligament • decompression • cervical myelopathy • complication

Ossification of the posterior longitudinal ligament can be a problematic cause of compressive cervical myelopathy. Although more commonly diagnosed in Japan, OPLL is a source of compressive cervical myelopathy within the US and may have an incidence as high as 25%.[13,16]

When determining a cervical approach for this condition, several important questions are asked, such as: 1) what is the cervical alignment, 2) is the deformity fixed or flexible, 3) is the pathology segmental or extensive (> 3 levels), 4) is there instability or subluxation, and 5) what is the patient's medical status? These questions aid in determining the optimal surgical approach and minimizing postoperative complications. However, decompression of the spinal cord in the setting of OPLL has a different complication profile and the preferred approach and/or technique remains controversial. This complication profile that includes CSF fistula, neurological injury, and myelopathic progression may need to be given greater thought during the decision process. In the following paper, we review the surgical OPLL literature and evaluate the complications associated with the different approaches and techniques, to better formulate a surgical strategy for the operative management of OPLL compressive cervical myelopathy.

Abbreviation used in this paper: OPLL = ossification of the posterior longitudinal ligament.

CSF Leaks and Fistulas

Anterior Approach

Traditionally, cervical corpectomy and resection of the OPLL has been the method of choice within the US. The incidence of dural tears and CSF fistulas after cervical corpectomy for all pathologies has been reported to be between 0% and 8%.[10,12,26,28] However, the incidence of a CSF leak after anterior cervical OPLL resection is much higher (between 6.7% and 31.8%).[1,15,16,38] Dural tears after OPLL resection tend to be problematic. Repair techniques employed include gelatin sponges, patch grafts, fibrin glue, primary suture closure, and CSF diversion. Despite these techniques, the incidence of fistula and pseudomeningocele formation remains high (4.6%–22.7%).[12,38] In all reported cases, these fistulas ultimately require some form of temporary or permanent CSF diversion.

Mizuno and Nakagawa[31] reported a 20% incidence of CSF leak (21 of 107 patients) after anterior cervical decompression for OPLL. All 21 cases were repaired using a muscle graft, Oxycel, and fibrin glue. Nevertheless, more than 33% of these patients required CSF diversion via a lumbar drain for 1 week.

Several surgical techniques have been used to prevent dural tears. One such technique is the cervical "floating method" of OPLL decompression. The technique involves thinning the OPLL and isolating it from the remainder of the involved cervical vertebrae. In a retrospective review, Matsuoka et al.[27] reported the long-term outcomes in 63 patients after anterior cervical decompression using the floating method. These investigators reported the incidence of a CSF leak or fistula to be 5.1%. Similarly, Joseph et al.[21] in a larger retrospective study of 144 patients reported a low incidence of CSF leak (6.3%) after anterior cervical OPLL decompression using the same floating method. In this study, the incidence of CSF leak increased from 5.6% and 5.3% for a 1- and 2-level corpectomy, respectively, to 16.7% for a 3-level corpectomy.

Indirect decompression and fusion has also been described as an alternative strategy for surgically managing OPLL-induced cervical myelopathy while avoiding the potential risk for a CSF leak. Onari et al.[34] reported long-term results in 30 patients treated with an anterior cervical interbody fusion without resection of the OPLL. The majority of the patients were classified as having an excellent or good outcome and there were no CSF leaks.

Posterior Approach

Posterior cervical decompressions, laminoplasty, and laminectomy, in patients with or without OPLL, have a low incidence of durotomy. Even in the presence of an ossified ligamentum flavum, the decompression can often be performed without risk of a CSF leak. Alternatively, the resection of postlaminectomy compressive pseudomembrane can be problematic and often is associated with a CSF leak.

Both radiographic and clinical studies have demonstrated a low incidence of CSF leak/fistula after posterior cervical decompression. In a retrospective review of 400 cervical CT scans in postlaminectomy patients, Teplick et al.[42] noted only 8 patients (2%) with a pseudomeningocele. Miyazaki and Kirita[30] noted no CSF leaks in a retrospective review of 155 patients who underwent a laminectomy for OPLL. Similarly, Chiba et al.[9] noted a very low incidence of dural tears after performing an expansive laminoplasty for OPLL.

Neurological Injuries and C-5 Nerve Palsy

Anterior Approach

Postoperative C-5 nerve palsy after surgery for compressive cervical myelopathy is a well-known complication that is poorly understood. The incidence of C-5 nerve palsy after anterior cervical decompression has been reported to occur in 1.6%–12.1% of patients, with an average incidence of 4.3%.[35] Half of these patients develop sensory deficits and/or intractable C-5 dermatome pain. The majority of C-5 nerve palsies are unilateral. In a review of the literature, Sakaura et al.[35] cited an incidence of 8% for bilateral C-5 palsies. In the majority of patients, the palsy appears within the 1st week but may appear as late as 4 weeks after surgery.

As previously mentioned, the origin of C-5 palsy is unclear, but direct injury with dural resection of OPLL has been reported. Mizuno and Nakagawa[31] reported 3 C-5 palsies that occurred immediately postoperatively. All 3 C-5 palsies were associated with a dural tear while removing extensive lateral recess OPLL. Two of the palsies were transient and the other was permanent. The authors believed that the palsies were the result of a direct nerve root injury during OPLL dissection. Belanger et al.[6] also noted immediate postoperative deltoid weakness in 2 patients in whom the dura was violated in proximity to the C-5 nerve root. Although no obvious compression of the nerve root could be demonstrated, the mechanical decompression may have resulted in a neurapraxia of the C-5 nerve root. Both patients eventually recovered full function.

Preserving the OPLL while decompressing the spinal canal does not appear to eliminate the risk of C-5 palsy. Matsuoka et al.[27] reported an incidence of 9.5% after using the "floating method" for decompressing the anterior cervical spine. None of the deficits were the result of direct injury. Nonetheless, C-5 palsy was detected in patients immediately or shortly after surgery.

Interestingly, patients who undergo anterior indirect decompression and fusion are not at risk for C-5 palsy. Onari et al.[34] reported long-term results for 30 patients with OPLL-induced cervical myelopathy. All of the patients were treated using an anterior cervical fusion without OPLL decompression, and none of the patients developed C-5 nerve palsy. However, 80% of the patients had good to excellent long-term results.

Posterior Approach

The incidence of C-5 nerve palsy after posterior cervical decompression for OPLL is similar to that of spondylotic cervical myelopathy. The incidence ranges from 0% to 30%, with an average of 4.7%.[27] Complications associated with iatrogenic spinal cord injury and postoperative spinal cord compression from epidural hematoma are also technique dependent and not related to the cause of compression.

Although neurological recovery after laminoplasty and laminectomy with and without fusion can be achieved, there is concern that there is a critical point of central canal compression with OPLL in which anterior decompression may be preferred.[6,39,41,45] Iwasaki et al.[20] reviewed data for 66 patients after laminoplasty for OPLL with a mean follow-up period of 10 years. They noted a poor recovery rate in patients with 60% or higher occupying ratio of the central canal. These patients accounted for nearly 30% of the patients with poor outcomes due to their cervical OPLL. The remainder of the poor outcomes were attributed to change in cervical alignment, hill-shaped OPLL, and postoperative progression of OPLL.

Tani et al.[41] compared the relative safety of anterior corpectomy versus laminoplasty for decompression of massive OPLL (> 50% canal compression). As compared with laminoplasty, patients treated with a corpectomy were noted to have significantly better functional results and no postoperative neurological complications. Patients treated with a laminoplasty were noted to have significant neurological deterioration. One-third of the neurological deteriorations occurred immediately after surgery. Similarly, Baba et al.[3] noted poor long-term neurological results after laminoplasty in patients with OPLL and greater than 50% stenosis.

Long-Term Neurological Outcome and Deterioration

The primary goal of cervical decompression is clinical stabilization. However, clinical improvement or decline may occur. Patients with severe clinical symptoms are more likely to benefit from surgery,[5,25,36] whereas patients with mild symptoms will tend to have their symptoms stabilize. Despite surgical intervention, patients may still develop progression of their disease.

Both anterior and posterior surgical approaches can achieve good to excellent clinical results over a 2- to 4-year follow-up period.[6–8] However, benefits may not be sustained due to comorbidities in the elderly and to OPLL progression. Anterior decompression has been shown to maintain adequate long-term outcomes more than 10 years postoperatively.[11,27] Similarly, posterior decompression with open-door laminoplasty has demonstrated satisfactory long-term outcomes for more than 10 years.[9] Regardless of technique, patients tend to initially improve and sustain these results for 3–5 years and subsequently show some clinical decline over the following 5–10 years.

Although OPLL progression does occur, it may only account for a small percentage of the clinical decline appreciated in patients. Matsuoka et al.[27] reported the long-term outcomes in 63 patients after the "floating method" of anterior cervical decompression; after 10 years, 36 patients (57%) demonstrated progression of their OPLL beyond the operative field. However, only 3 of these patients demonstrated clinical deterioration. Onari et al.[34] reported progression of OPLL in 26 of 30 patients. Interestingly, the neurological status of these patients did not correlate with the progression of OPLL. Twenty-one patients did not demonstrate any change in neurological status, and 5 patients improved over the course of the study. Of the 4 patients who demonstrated a neurological decline, none were the result of cervical progression of OPLL.

Cervical Kyphosis

Performing a posterior cervical laminectomy does not immediately destabilize the cervical spine. The posterior cervical exposure results in denervation and atrophy of the posterior cervical musculature, consequently increasing the anterior vertebral body compressive load, promoting kyphosis. The kyphotic alignment drapes the spinal cord over the posterior aspect of the vertebral bodies and may contribute to neurological decline.

The incidence of postoperative kyphosis after multilevel cervical laminectomy has been reported to be 20%.[23] However, postoperative kyphosis does not appear to correlate with clinical progression. Miyazaki and Kirita[30] followed 155 patients after a laminectomy for OPLL compressive myelopathy, with an average follow-up duration of 4 years. These authors noted an increase in lordosis in 7% of patients, a decrease in lordosis in 16%, and an increase in kyphosis in 17%. No correlation with clinical outcome was found.

Laminectomy and instrumented fusion is believed to prevent postlaminectomy kyphosis and potentially improve cervical lordosis. Chen et al.,[8] in a retrospective radiographic review of 83 patients with OPLL compressive myelopathy, reported improved postoperative lordosis after cervical laminectomy and instrumented fusion. In addition, there was a correlation between cervical lordosis and a better prognosis. However, there was also a correlation between improved lordosis and the incidence of C-5 nerve root palsy.

It is believed that a better decompression can be obtained in patients with a lordotic cervical spine than in a straight or kyphotic spine. An advantage of subaxial laminoplasty is that it prevents postoperative kyphosis.[18,19,24,37] Seichi et al.[37] reported 10-year follow-up data in 35 patients after double-door laminoplasty for OPLL compressive cervical myelopathy. None of the patients developed a postoperative kyphotic deformity, but the authors did note a decrease in range of motion from 36° to 8° in flexion/extension. No neurological deterioration was attributed to the decompression or cervical alignment.

The preservation of the semispinalis attachment at C-2 is considered essential in the prevention of postlaminoplasty kyphosis. Takeshita et al.[40] demonstrated that if C-2 was incorporated into the laminoplasty, there was an increase in postoperative kyphosis. However, there was no significant difference in neurological outcome at 4-years' follow-up.

Discussion

Determining the optimal approach for decompression of OPLL-induced cervical myelopathy can be problematic. Traditionally we consider cervical alignment, flexibility, instability, and patient medical status to determine the optimal approach for this condition. However, cervical OPLL compression has a unique complication profile as compared with typical spondylotic myelopathy.

Durotomy is a well-known complication of spinal canal decompression that is often easily managed with primary repair. However, anterior cervical repair of a durotomy can be challenging. In the setting of OPLL, this often requires a dural substitute to be sutured to the tenuous surrounding dura followed by temporary CSF diversion.[1,15,16,38] To minimize the risk of durotomy, various surgical techniques have been adopted that do not involve OPLL resection.[21,27,34] Irrespective of technique, there is a direct correlation between the number of OPLL segments decompressed and the risk of durotomy.[21,27] One- and 2-segment decompression represents a modest risk that is similar to that of multilevel posterior decompression. Given that both laminectomy and laminoplasty are better suited for multilevel (> 3 levels) decompression, the durotomy risk associated with anterior 1- and 2-segment decompression is reasonable. Patients requiring greater than a 2-level decompression should be considered for a laminectomy with or without fusion or a laminoplasty.

Iatrogenic neurological injury is a constant concern for a spine surgeon. Preoperative planning and proper surgical technique help to minimize potential injury. Nevertheless, postoperative C-5 nerve root palsies occur and most often without direct insult. Approach does not appear to play a role in the incidence or recovery of a C-5 palsy.[31,35] Direct decompression appears to have a mechanical effect on the nerve tension, resulting in palsy. Interestingly, patients who undergo indirect decompression do not appear to be at risk.[34]

Approach-specific complications irrespective of OPLL also need to be considered. Anterior approaches can be complicated by dysphasia, recurrent laryngeal nerve injury, and increased risk of pseudarthrosis with multilevel fusions.[4,22,29,43,44] Conversely, posterior approaches tend to have an increased risk for infection, increased postoperative neck pain, and postlaminectomy kyphosis.[2,17,32,33] The incidence of epidural hematoma resulting in spinal cord compression is similar for both approaches.[8,9] The reported overall incidence of epidural hematoma is 1%, slightly less than that reported for posterior cervical decompression.[14] In general, cervical spine complications are not well tolerated by the elderly. However, the risks associated with a posterior approach may be better endured.

Certainly, approach-related complications should be taken into account when considering the surgical management of cervical OPLL. In addition, the OPLL morphology and extent of canal compromise should be evaluated carefully. While clinical outcomes appear to be similar for both anterior and posterior approaches, patients with greater than 50% OPLL canal compromise or "hill-shaped" OPLL compression have improved outcomes after anterior decompression.[5,23,24]

When determining a surgical approach for OPLL decompression, the following considerations are made: 1) number of decompression segments; 2) OPLL morphology and extent of spinal canal compromise; and 3) patient age and comorbidities. Whether an anterior or posterior approach is chosen, patients should be made aware of the short- and long-term complications associated with this difficult disease to make the best decision with their surgeon.

Conclusions

Anterior cervical decompression is associated with a higher incidence of CSF leaks and fistulas. However, using the floating method of anterior decompression decreases the incidence of CSF leaks for 1- and 2-segment OPLL. Posterior decompression through laminoplasty or laminectomy with or without fusion should be considered in patients with less than 50% OPLL stenosis and without hill-shaped OPLL compression.

Disclosure

Dr. Liu serves as a consultant to Medtronic and DePuy.

Author contributions to the study and manuscript preparation include the following. Conception and design: Koski, Ganju, Liu. Acquisition of data: Cardoso. Analysis and interpretation of data: all authors. Drafting the article: Cardoso. Critically revising the article: Cardoso, Liu. Reviewed final version of the manuscript and approved it for submission: all authors. Administrative/technical/material support: all authors. Study supervision: Koski, Liu.

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Manuscript submitted November 15, 2010.
Accepted January 10, 2011.
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Neurosurg Focus 30 (3):E13, 2011

Management of cerebrospinal fluid leaks after anterior decompression for ossification of the posterior longitudinal ligament: a review of the literature

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Object. Anterior decompression is an effective way to treat cervical myelopathy associated with ossification of the posterior longitudinal ligament (OPLL); however, this approach is associated with an increased risk of a dural tear and resultant CSF leak because fusion of the dura with the ossified PLL is common in these cases. The authors review the literature and present an algorithm for treatment of CSF leaks in these patients.

Methods. A MEDLINE review was performed to identify papers related to CSF leak after anterior decompression for OPLL, and data were summarized to identify treatment options for various situations. A treatment algorithm was identified based on these findings and the experience of the authors.

Results. Eleven studies were identified that presented data on intra- and postoperative management of a CSF leak during ventral surgery for OPLL. The incidence of cervical dural tears and CSF leaks after anterior decompression procedures for OPLL ranged from 4.3% to 32%. Techniques including preventative measures, intraoperative dural repair with various materials, and postoperative drainage or shunt placement have all been used.

Conclusions. Although direct dural repair is the preferred treatment for CSF leak, this technique is not always technically possible. In these cases, intraoperative adjuncts in combination with postoperative measures can be used to decrease the pressure gradient across the dural tear. *(DOI: 10.3171/2010.12.FOCUS10255)*

Key Words • **ossification of the posterior longitudinal ligament** • **cerebrospinal fluid leak** • **anterior cervical decompression**

Ossification of the posterior longitudinal ligament (OPLL) is a known cause of cervical stenosis resulting in myelopathy and/or radiculopathy. Various operative procedures, including anterior, posterior, and combined approaches, have been used for treating this disease.[49] Although posterior approaches such as multilevel laminoplasty or laminectomy with or without fusion provide a straightforward albeit indirect approach to treat OPLL, anterior decompression with direct resection of the OPLL is often necessary because the anchoring effect of the dentate ligaments, nerve roots, and anteriorly attached root sleeves may preclude sufficient decompression of the spinal cord with a posterior approach. In cases of OPLL, however, the dura mater often becomes ossified or calcified and fuses with the PLL, thereby increasing the chance for CSF leak and spinal cord or nerve root injury during surgical manipulation for removal of the ossified mass. The possibility for traumatic manipulation increases the risk of a CSF leak during an anterior decompression in comparison with a posterior approach,[31,54] because laminoplasty or laminectomy obviates direct manipulation of OPLL. Hence, although anterior decompression of the spinal cord by resection of the ossified ligament combined with anterior fusion can achieve more satisfactory results than a posterior approach,[43,45,54,56] the surgeon must take into account the risk of a CSF leak. Additionally, when choosing an anterior approach, the surgeon must be aware of intra- and postoperative management strategies to treat a CSF leak and minimize manipulation of the thecal sac to avoid any spinal cord damage.[20,36,52] In this article, we review the literature on intra- and postoperative management of cervical dural tears during surgery for OPLL and suggest a treatment algorithm.

Abbreviations used in this paper: LP = lumboperitoneal; OPLL = ossification of the PLL; PLL = posterior longitudinal ligament; WP = wound–peritoneal cavity.

Methods

To identify the relevant publications on this subject, we searched the PubMed database (http://www.ncbi.nlm.nih.gov/PubMed/) for the keywords "ossification of the posterior longitudinal ligament," "cerebrospinal fluid leak," and "dural tear." We also performed a search using the MeSH terms "ossification of the posterior longitudinal ligament" and "decompression, surgical" and "cervical vertebrae." The "Related Articles" feature in PubMed was also used to search for relevant citations, and the reference lists of other articles were checked for further publications. The online archives of key publications, including *Journal of Neurosurgery*, *Neurosurgery*, and *Spine,* were searched using the same terms. All articles were initially screened for relevance by title and abstract. Articles in languages other than English and articles without an abstract were excluded. All suitable reports and important cross-references were obtained as full-text copies for review. Publications were scrutinized for the following information: incidence of CSF leaks after anterior surgical decompression of the cervical spine for OPLL; primary intraoperative strategies and success rates; postoperative management modalities and success rates; and dural repair techniques. Inclusion criteria were publication date between January 1, 1970, and July 31, 2010; English language; and either 1) documentation of the incidence of CSF leak after anterior decompression to treat OPLL, 2) description of the management of CSF leaks encountered during spine surgery, or 3) laboratory investigations, technical reports, or retrospective case series focused on the repair of dural tears. Using these findings and the experience of the senior author, a treatment algorithm was developed to guide management of a dural tear with CSF leak after anterior decompression and resection of OPLL.

Results

Literature Review

The current evidence on intra- and postoperative management of a CSF leak during surgery for OPLL consists of retrospective case series, experimental investigations of dural repair, and technical case reports. To our knowledge, there are no randomized trials available. The details of the literature search are outlined in Fig. 1. Eighty-four full-text articles were identified for further analysis. Six were excluded because the full-text version could not be located. Eight were published in a non-English language. Thirteen did not address the topic of CSF leaks or dural tears. Fifty-seven papers were reviewed, including 39 articles describing management strategies for CSF leaks, 11 of which were case series reporting data on the use of intra- and postoperative adjuncts for treatment of a CSF leak after anterior decompression for OPLL (Table 1). In 26 articles, dating from 1981 to 2009, surgical management of OPLL was the major topic.

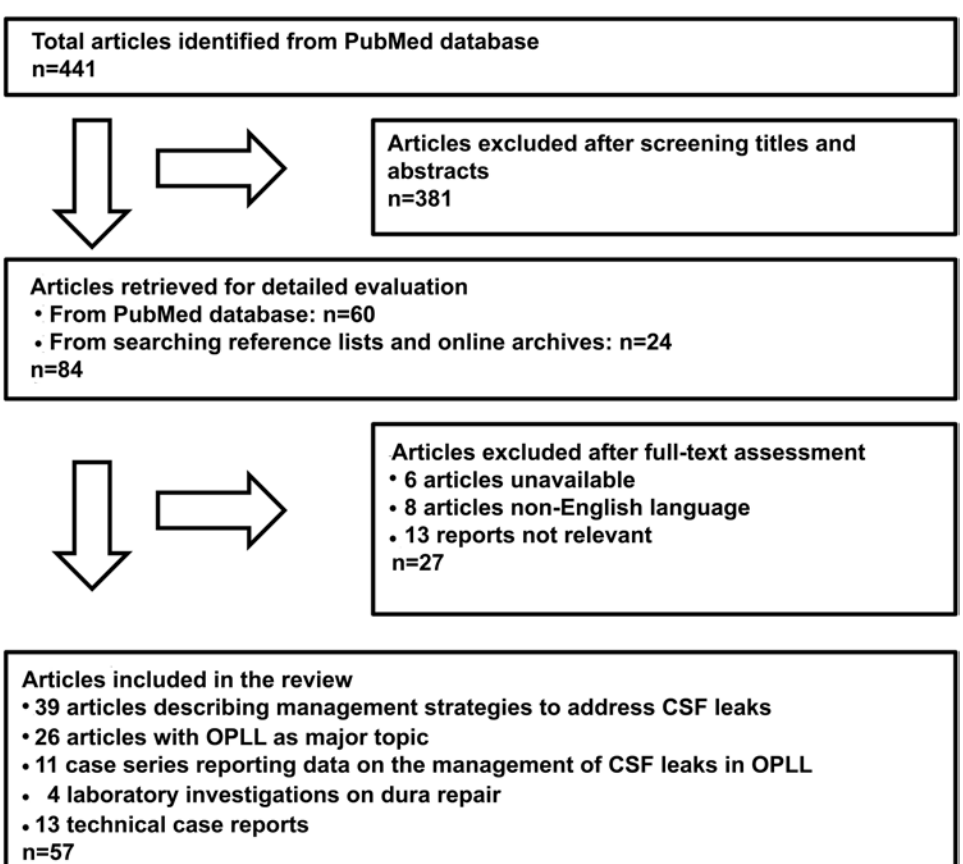

Fig. 1. Selection of articles for review.

Incidence

The incidence of cervical dural tears and CSF leaks after anterior decompression procedures has ranged from 0.5% to 3%.[4,9,16,21,22,25,26,28,36,55] For OPLL, the incidence is much higher, ranging from 4.3% to 32%.[1,3,11,12,17,27,33,42,43,52] In a review of 1994 cases, Hannallah et al.[26] reported that the presence of OPLL was the greatest risk factor for the development of a CSF leak after anterior decompression surgery and that patients with OPLL were 13.7 times more likely to have a leak than were patients without this condition.

Secondary Complications

Technical reports have described various secondary complications associated with a CSF leak after cervical operations, including meningitis,[41] delayed wound healing, airway obstruction,[2,10] cutaneous CSF fistula,[52] and pseudomeningocele.[2,15,34] Life-threatening CSF leaks in the immediate postoperative period are uncommon but require early identification and prompt intervention. Evidence on the long-term sequelae of CSF leaks that are managed adequately, however, is optimistic. Whereas Saxler et al.[48] found that patients with incidental dural tears had poorer outcomes (they underwent more reoperations and experienced more pain and pain-related functional limitations), other authors have reported that the long-term deleterious effects of CSF leaks may be limited. Hannallah et al.[26] reported no long-term sequelae, such as wound infection, pseudomeningocele, sinus tract formation, or meningitis, in 20 patients with CSF leaks with an average follow-up of 5.4 years. Cammisa et al.[9] reported that when CSF leaks were recognized and treated appropriately, patients experienced no complications such as persistent recurrent headaches, meningitis, pseudomeningocele, cutaneous fistula, or neurological deficit after an average follow-up of 22.4 months. Similarly, Wang et al.[57] found that a dural tear did not increase the risk of postoperative infection, neural damage, or arachnoiditis.

Treatment of CSF Leaks

Various techniques, reviewed below in further detail, have been described to manage dural tears and CSF leaks. These include repair with gelatin foam,[1] fibrin glue,[7,44,50] collagen matrix,[20,46] fat and fascia graft,[5,47] biological graft,[19] synthetic materials,[14,61] or blood patch;[37] insertion of a lumbar drain[26,35] or LP[16] and WP (wound-peritoneal cavity) shunts;[2,19] ventriculostomy;[34,41] laser techniques;[23] and microdural stapling.[17]

Intraoperative Strategies

Primary Dural Repair. Although direct repair is optimal management in most cases of dural tear with a resultant CSF leak in all spinal regions, when this situation is encountered during anterior cervical surgery for OPLL, exposure is often inadequate to facilitate direct repair. Hannallah et al.[26] reported that only 5 of 20 intraoperative ventral CSF leaks in their series were accessible for direct repair. Primary repair techniques aim to provide a watertight seal of the dural tear. If it is technically possible, direct repair with suturing is preferable. Still, the reported failure rate is 5%–10% with this technique.[5,6,9,15,32,50,57] Dural tears are likely to occur when the dura becomes ossified and adheres to the PLL and cannot be dissected off.[11] Such dural tears create tissue gaps that are not amenable to primary repair. Ossified dura may be diagnosed on preoperative CT as either a single homogeneous ossified mass of dura adhered to the PLL or a double-layer sign in which anterior and posterior ossified rims are separated by a hypodense area of hypertrophied PLL.[43] Another reason primary repair may fail may be the pinhole-sized tears from suture needles that allow CSF to leak through the dura.[8,29,46] The potential risk of using primary suture closure for small incidental dural tears is conversion of a low-pressure defect to high-pressure pinholes from suture needles.[46]

Chemical Sealants and Dural Grafting. The addition of a chemical seal has been proposed as a mechanism to overcome the problem of CSF leak from the suture holes.[46] Fibrin glue has been shown to be a useful adjunct to prevent leaks in conjunction with direct repair.[50] Laboratory data demonstrate that dural defects repaired by suture alone leak at physiological pressures, whereas repairs supplemented by sealants, such as fibrin glue, withstood higher pressures in the postoperative period.[7,8,50] Nakajima et al.[44] demonstrated the importance of fibrin glue for sealing the suture holes at the repair site to prevent CSF leaks. Smith et al.[52] reported a series in which 7 patients with dural defects received a patch without fibrin glue, using either an autogenous fascia graft or synthetic materials such as gelatin foam. Five of these patients developed durocutaneous fistulas and 3 required reoperation to repair the dura. Because fibrin sealant remains in situ for only 5–7 days before being resorbed, it should be supplemented with dural grafting to form a watertight closure in the immediate postoperative period.

Narotam et al.[46] reported the successful use of a collagen matrix onlay sutureless graft during primary repair of dural tears. The onlay graft is placed over the defect and attaches via surface tension to the dura, where it provides a low-pressure absorptive surface to diffuse any CSF and acts as a site for biological dural repair. The hemostatic properties of collagen initiate clot formation, resulting in an immediate chemical seal. The collagen matrix is a chemoattractant and provides a scaffold for fibroblasts to infiltrate and deposit new collagen, thereby reconstituting new dura. In this series of 110 patients with intraoperative anterior/posterior spinal dural fistulas, including 10 anterior cervical dural lacerations, the application of microfibrillar collagen matrix (in 100% of cases), combined with subfascial drains (in 82%), fibrin glue (in 7.3%), lumbar drains (in 2.7%), or other adjunct including suture (in 8%), resolved the dural fistulas 95% of the time.

Epstein[17,19] described a technique of suturing or using microdural staples to secure a pericardial graft over the dural defect. This is followed by application of fibrin sealant and dural graft matrix and a WP or LP shunt. In many cases of OPLL, however, direct repair is not possible because of location or size of the dural defect. Furthermore, not all dural tears can be recognized and repaired primarily, and the need for postoperative treatment strategies persists.

TABLE 1: Summary of 11 studies on intra- and postoperative adjuncts for treatment of a CSF leak after anterior decompression for OPLL*

Authors & Year	No. of Cases	No. of CSF Leaks & Dural Tears (%)	No. of Cases w/ Primary Repair (%)	Intraop Adjuncts Used	Success Rate (%)	Incidence of Postop CSF Fistula or Pseudomeningocele (%)	Postop CSF Leak Management	No. of Patients Requiring Revision Op (%)	Revision Repair
Abe et al., 1981	12	3 (25)	3/3 (100)	Gelfoam	3/3 (100)	NM	NA	0	
Belanger et al., 2005	65	8 (12)	1/8 (13)	Gelfoam, fascia graft, fibrin glue	3/8 (38)	5/8 (62)	bed rest, lumbar drain	3/8 (38)	reop
Chen et al., 2009	138	18 (13)	0	none	NA	18/18 (100)	continuous pressure to wound for 3–5 days	3/18 (17)	multiple percutaneous aspirations over 2–3 mos
Choi et al., 2005	47	2 (4)	2/2 (100)	fibrin glue, fat or fascia graft, lumbar drain	2/2 (100)	0/2 (0)		0	
Epstein, 2001	65	3 (5)	3/3 (100)	bovine pericardial graft, fibrin glue, WP shunt, LP shunt	3/3 (100)	0/3 (0)	WP shunt, LP shunt	0	
Epstein, 2009	82	5 (6)	5/5 (100)	bovine pericardial graft, fibrin glue, collagen matrix, WP shunt, LP shunt	5/5 (100)	0/5 (0)	WP shunt, LP shunt	0	
Harsh et al., 1987	19	3 (16)	3/3 (100)	patch graft, Gelfoam	3/3 (100)	NM	NA	0	
Joseph et al., 2009	144	9 (6)	9/9 (100)	Gelfoam, fascia graft, lumbar drain	9/9 (100)	0/9 (0)	lumbar drain for 5 days	0	
Min et al., 2008	19	6 (32)	NM	lumbar drain	6/6 (100)	NM	lumbar drain	0	
Mizuno et al., 2001	107	21 (20)	21/21 (100)	fascia graft, fibrin glue, oxidized cellulose, lumbar drain in >33% of patients	NM	NM	lumbar drain for 7 days	0	
Smith et al., 1992	22	7 (32)	7/7 (100)	Gelfoam, fascia graft, lumbar drain in 1 patient	2/7 (29)	5/7 (71)	lumbar drain for 4–7 days	3/7 (43)	reop

* NA = not available; NM = not mentioned.

Wound Drains. The use of subfascial drains for management of intraoperative CSF leaks is controversial. Such drains are placed to evacuate any accumulation of serous fluid, blood, or CSF and to obliterate the dead space in the immediate postoperative period. When patients are mobilized after surgery, a hydrostatic pressure gradient develops that facilitates transient CSF effusion into the subfascial space. When porous grafts, such as collagen matrix, are used, the risk of CSF egress may increase, especially in the first few postoperative days before the chemical seal forms and the graft becomes established.[46] Although some authors have argued against the use of drains,[15] most studies have found no associated increase in the rate of durocutaneous fistulas with their use.[26,57]

Postoperative Strategies

Lumbar Drains. The use of CSF diversion for the treatment of CSF leaks is well documented. Reported success rates have ranged from 83% to 100%.[26,35,38,39,42,51,53] Tables 2 and 3 compare studies of patients undergoing repair of CSF leaks after anterior decompression for OPLL with and without intraoperative placement of a lumbar drain or shunt. None of the patients who received a lumbar drain or shunt developed a CSF fistula or pseudomeningocele or required reoperation. Treatment of a dural tear by CSF diversion may be explained by the decreased fluid pressure through the leak with preferential egress through the catheter or by decreased distension of the dural sac with approximation of the dural edges to facilitate healing.[6,35,41]

Kitchel et al.[35] retrospectively reviewed 19 cases involving patients treated with postoperative lumbar drainage after a CSF leak and found that 14 of the 17 patients treated with CSF diversion for a full 4 days had resolution of the leak. Smith et al.[52] reported on a series of 22 patients who underwent anterior decompression of the spinal canal for OPLL and cervical myelopathy, 7 of whom had absent dura adjacent to the ossified part of the ligament. Two patients had transient CSF leak at the time of the decompression that ceased during the operation; in 1 of these 2 cases, the patient underwent immediate placement of an LP shunt. Five of the 7 developed a postoperative CSF fistula, and 3 of these 5 underwent a second operation to repair the defect in the dura. The CSF fistula was identified on the first postoperative day in 3 patients who had large amounts of obvious CSF drainage from the wound; the other 2 had smaller amounts of drainage but unexpected swelling of the neck that was noted later on postoperative Day 2 in 1 case and Day 16 in the other. Because of the delayed diagnosis of a CSF leak in these patients, the authors recommended patching the dural defect with a graft of muscle and fascia, prophylactic placement of a lumbar drain, limited mechanical pulmonary ventilation as safely feasible, and administering antiemetic and antitussive medications in the postoperative period to minimize extreme positive thecal pressure and thereby protect the autogenous fascial graft.

In a series involving 36 patients undergoing 2- to 4-level anterior corpectomy and fusion operations, 9 of whom had OPLL, 3 patients developed postoperative CSF leaks that were successfully treated by lumbar drainage.[38] Choi et al.[12] reported on a series of 47 patients who underwent corpectomy for OPLL, 2 of whom developed a CSF leak intraoperatively; both of these patients underwent primary repair with either a fat or a fascial graft augmented with fibrin sealant followed by immediate placement of a lumbar drain in the recovery room. Similarly, Min et al.[42] reported successful resolution using lumbar drainage and bed rest of 6 intraoperative CSF leaks among 19 patients who underwent ventral surgery for OPLL, and Joseph et al.[33] described successful resolution of 9 intraoperative CSF leaks in 144 patients. All 9 in the latter series were treated with a fascia graft, Gelfoam, and immediate placement of a lumbar drain that remained in place for 5 days.

In one of the largest series evaluating CSF leak after elective anterior cervical spine surgery, Hannallah et al.[26] reported the overall incidence of a CSF leak to be 1%, but in patients with OPLL, the incidence was 12.5%. Of the 20 patients who developed CSF leaks, 15 had dural tears that were not accessible to direct repair, 4 of which were treated successfully by placement of a lumbar CSF shunt either at the time of the index procedure (in 3 cases) or on postoperative Day 7 (in 1 case).

For CSF leaks diagnosed in the postoperative setting only (for example, in patients with CSF in the drainage container or cutaneous CSF fistulas), bed rest alone does not lead to a favorable outcome in most patients.[15] Although direct surgical repair with suture is an accepted treatment, it requires a second operative procedure. Many authors have advocated the use of lumbar drains without reoperation for primary closure of the dural tear.[35] Other measures, shown to be less effective, include application of continuous direct pressure.[11] Although effective in treating CSF leaks, the use of lumbar drains is not without complications, being associated with an approximately 5% reported infection rate.[13,51] In addition, lumbar drains are gravity-dependent systems in which a pressure gradient is necessary for CSF drainage; any change in the position of the drain cham-

TABLE 2: Studies reporting outcomes of repair of CSF leak after anterior decompression for OPLL without intraoperative placement of lumbar drain or shunt

Authors & Year	No. of Cases	No. of CSF Leaks & Dural Tears (%)	Intraop Adjuncts Used	Incidence of Postop CSF Fistula or Pseudomeningocele (%)	No. of Patients Requiring Revision Op (%)
Belanger et al., 2005	65	8 (12)	Gelfoam, fascia graft, fibrin glue	5/8 (63)	3/8 (38)
Smith et al., 1992	22	7 (32)	Gelfoam, fascia graft	5/7 (71)	3/7 (43)
Harsh et al., 1987	19	3 (16)	patch graft, Gelfoam	NM	0
Abe et al., 1981	12	3 (25)	Gelfoam	NM	0
Chen et al., 2009	138	18 (13)	none	18 (100)	3/18 (17)

TABLE 3: Studies reporting outcomes of repair of CSF leak after anterior decompression for OPLL with intraoperative placement of lumbar drain or shunt

Authors & Year	No. of Cases	No. of CSF Leaks & Dural Tears (%)	Intraop Adjuncts Used	Incidence of Postop CSF Fistula or Pseudomeningocele (%)	No. of Patients Requiring Revision Op (%)
Epstein, 2009	82	5 (6)	bovine pericardial graft, fibrin glue, collagen matrix, WP shunt, LP shunt	0/5 (0)	0
Choi et al., 2005	47	2 (4)	fibrin glue, fat or fascia graft, lumbar drain	0/2 (0)	0
Joseph et al., 2009	144	9 (6)	Gelfoam, fascia graft, lumbar drain	0/9 (0)	0
Min et al., 2008	19	6 (32)	lumbar drain	NM	0

ber with respect to the patient can result in rapid egress of CSF.[30] Pneumocephalus with brainstem compression after overdrainage has been reported.[24] Other side effects associated with overdrainage include headaches, nausea, and vomiting. Moreover, the standard practice of keeping patients with lumbar drains on bed rest to prevent rapid CSF drainage due to positional change may increase the risk of postoperative morbidity due to the development of deep venous thrombosis and pulmonary embolism after prolonged immobilization.[59] The use of flow-regulated CSF draining systems using a volumetric pump set to withdraw CSF at a controlled rate,[22,30] a low-pressure control valve,[20] or a combined volume- and pressure-controlled system (LiquoGuard; Möller Medical) may overcome most of these potential problems associated with lumbar drains.

Shunts. More complex intraoperative CSF leaks may require the addition of closed-system WP or LP shunts.[20] Such complex dural tears include those that are not accessible without performing additional bone resection to gain access for a direct repair. Epstein[19] described performing a complex primary dural repair combined with placement of both WP and LP shunts in patients undergoing multilevel anterior cervical corpectomies and fusion to resect OPLL. Dural repair consisted of bovine pericardial grafts sewn in place with sutures and microdural staples in 1 patient and used as onlay grafts in 4 patients, in addition to 2 layers each of microfibrillar collagen and fibrin sealant. The WP catheter was placed with the proximal catheter positioned superficial to the bone graft and to the left of the cervical plate. Finally, an LP shunt was placed in case of WP shunt failure or obstruction.

Although shunting CSF into the abdominal cavity may provide short-term advantages such as decreased risk of infection and postoperative subdural hematomas with immediate postoperative mobilization compared with multiple percutaneous aspirations or temporary lumbar external drainage, major drawbacks must be considered. It is an invasive therapy that may expose the patient to many additional problems such as over- or underdrainage, migration or obstruction of the proximal or peritoneal tip, infection, or shunt breakdown, which may require revision surgeries over time.[58] Therefore, placement of a permanent shunt represents a last resort after failure of all other measures.

Prevention of CSF Leakage

Anterior Floating Technique. Various surgical techniques have been proposed to minimize the chance of intraoperative dural tears during anterior decompression in patients with OPLL. The "anterior floating method" and variations thereof have been well described.[40,60] In general, these techniques leave behind the thinned down medial posterior wall of the vertebral body and the ossified PLL but decompress laterally around it, so that the ossified PLL becomes a "free-floating" mass on the dura. Epstein[18] described that during the drilling process, the ossified PLL mass should be left attached to the margins of the corpectomy defect to keep it stabilized until the midportion of the PLL has been thinned sufficiently. After the PLL mass is freed from the bony margins, further thinning of the ossified PLL must be done with great care. A few isolated islands of ossified PLL tightly adherent to the dura can be left in place, thereby reducing the chance of CSF leak.[54] One group reported that incidence of postoperative CSF fistulas with the anterior floating method for OPLL was 5.1%[40] compared with a reported 16–25% incidence associated with the standard anterior extirpation method.[18]

Discussion

Because anterior decompressive surgery for OPLL of the cervical spine involves up to a 32% risk of dural tear, the surgeon must have a strategy to manage CSF leaks both during and after surgery. Given the many problems that stem from an unresolved CSF leak, such as delayed wound healing with cutaneous CSF fistula, risk of meningitis, or pseudomeningocele, repair should involve appropriate measures to promote healing of the dural tear. If a violation of the dura is recognized during the surgery, a primary closure with microsurgical suture may be attempted, although it is frequently technically not feasible. In most cases of OPLL, lack of dural elasticity or gaps due to resection of adherent or ossified dura[43] or even absent dura[52] preclude a watertight closure with sutures. It therefore appears to be more important to use intraoperative adjuncts in combination with postoperative measures to decrease the pressure gradient across the dural tear. Onlay adjuncts such as collagen matrix (Duragen; Integra LifeSciences Corporation) or autogenous fascia have been successfully used in patients with dural tears.[15,46,52] Alternatives may include equine or bovine pericardium or Gelfoam (Pharmacia & Upjohn). Collagen matrix can

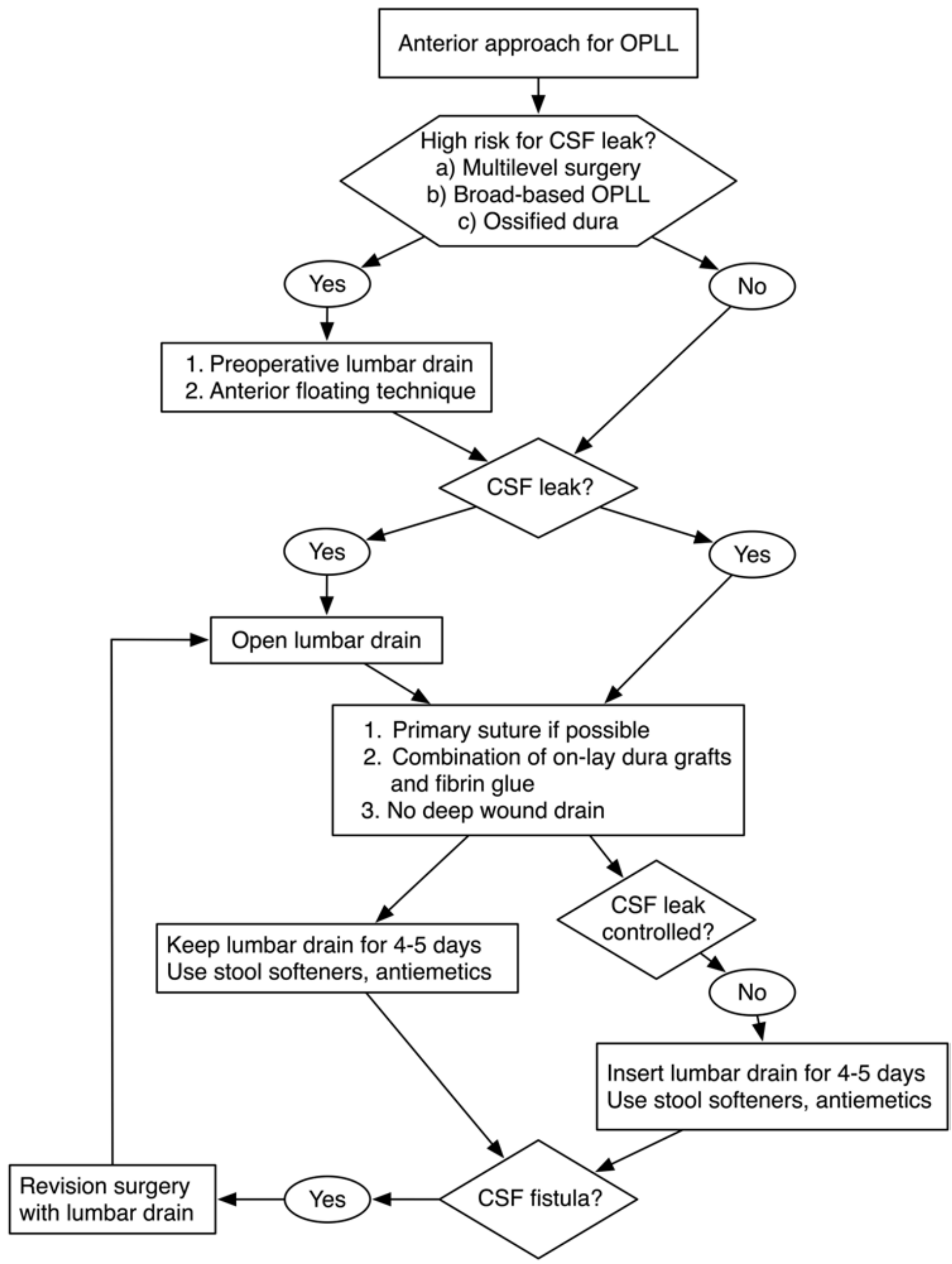

Fig. 2. Treatment algorithm for avoidance and management of CSF leaks in anterior approaches for OPLL. The left side of the diagram shows the strategy for high-risk situations, and the right side shows intra- and postoperative management of unanticipated CSF leaks.

be used as onlay graft without the necessity of a primary watertight closure,[46] which is particularly helpful for large dural tears after resection of an ossified PLL. It can also be combined with fibrin glue. In vitro, fibrin glue increased the strength of the repair of the sutured dura 7-fold and was also found to be effective as a stand-alone sealant.[7,8] Experimental data on fibrin glue is corroborated by clinical experience.[50] Moreover, a combination of adjuncts may enhance the overall sealing effect.

The simplest device to decrease intrathecal CSF pressure is the lumbar drain, which is left in situ for the first 4–5 days after surgery, with drainage at a rate of 5–15 ml/hour. This time frame is based on histological evidence for dura sealing, which takes approximately 4 days to complete.[7,8] The collection system attached (automatic pressure/volume-regulated pump versus gravity-assisted collection bag) guides whether a patient must be managed in the intermediate care unit with close observation or on the general floor and how much mobilization is possible. Mobilization is generally restricted because of concerns about overdrainage and the risk of tonsillar herniation and a rise of the gradient across the dural tear. With pressure/volume-regulated CSF drainage devices, mobilization may be possible without the risk of overdrainage or substantial increases of the intrathecal pressure because the dural tear is in the cervical spine. Stool softeners are prescribed to avoid intrathecal pressure peaks during Valsalva maneuvers.

Patients with multilevel or broad-based OPLL are at the greatest risk of intraoperative CSF leaks. In these cases, the surgeon may choose to place a lumbar drain as part of the anesthesia setup and have it opened if CSF leakage is noticed during surgery. This will immediately diminish the egress of CSF and help the adjuncts to adhere to the dura. A lumbar drain is also a therapeutic choice for a CSF leak that is suspected postoperatively on the basis of CSF in the wound drain or the development of a cutaneous CSF fistula.[41]

The use of wound drains with CSF fistulas is controversial. At our institution, we tend not to use deep wound drains in the case of a CSF leak. Placement of an LP or WP shunt is considered a last-resort therapy, to be undertaken after failure of all previously mentioned modalities. The potential complication rate for infection, obstruction, disconnection, dislocation, or over- or underdrainage is substantial; therefore, we choose to perform a second revision surgery with the mentioned adjuncts and a lumbar drain before considering placement of a permanent shunt.

Figure 2 demonstrates the treatment algorithm that we use in most cases at our institution. The presence of multilevel and broad-based OPLL increases the likelihood that there is dural ossification, which increases the risk for a dural tear.[11,43] In these situations, we insert a lumbar drain preoperatively and use the anterior floating technique unless the ossified PLL can be separated from the underlying dura. When a dural tear arises, we attempt a primary repair using a combination of adjuncts such as a nonautologous onlay graft augmented by fibrin glue. Primary suture is reserved for cases in which the dural defect is minimal and exposure of the site is sufficient. If the CSF leak cannot be controlled using intraoperative adjuncts, we insert a lumbar drain at the end of the operation. The patient is kept on bedrest, and CSF is drained at a rate of 10–15 ml/hour for 4–5 days, which is the time needed for adequate dural sealing. Postoperative drainage of CSF may cause nausea and emesis, which are treated with antiemetics or slight reduction of the drainage rate. This treatment, together with the use of stool softeners, aims to prevent sudden peaks of intrathecal pressure.

Anterior decompression to resect an ossified PLL is associated with an increased risk of CSF leak, which may not be amenable to direct repair. Studies have shown that postoperative lumbar drainage decreases the likelihood of the patient developing a persistent CSF fistula or pseudomeningocele and minimizes the likelihood of reoperation. Therefore, we favor the placement of a lumbar drain as a first-line intervention when an intraoperative CSF leak is difficult to control. We also recommend the use of a lumbar drain as an adjunct to surgical exploration if a CSF fistula is diagnosed in the postoperative setting.

Conclusions

Currently, the management of CSF leakage after resection of an ossified PLL has been described primarily in case series and technical notes. No large-scale studies have been reported. Most dural tears associated with surgery for OPLL can successfully be managed by a combination of intraoperative adjuncts (sealants, grafts) and postoperative lumbar CSF drainage for 4–5 days.

Disclosure

The authors do not report any conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Bisson, Schmidt. Acquisition of data: Mazur. Analysis and interpretation of data: Mazur, Jost. Drafting the article: Mazur, Jost. Critically revising the article: Bisson, Schmidt. Reviewed final version of the manuscript and approved it for submission: Bisson, Schmidt. Study supervision: Bisson, Schmidt.

Acknowledgment

The authors thank Kristin Kraus, M.Sc., for kind review and editing of the paper.

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Manuscript submitted November 5, 2010.
Accepted December 17, 2010.
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Diffusion tensor imaging in the assessment of ossification of the posterior longitudinal ligament: a report on preliminary results in 3 cases and review of the literature

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Cervical spondylotic myelopathy due to ossification of the posterior longitudinal ligament (OPLL) is a common neurosurgical disease that carries high morbidity. OPLL and other degenerative processes cause narrowing of the central canal, with subsequent spinal cord injury. Repeated minor trauma and vascular aberrations have been purported to underlie cervical spondylotic myelopathy, although the exact pathophysiological mechanism is unclear. Regardless, detection of early axonal damage may allow more timely surgical intervention and prediction of functional outcome. Diffusion tensor (DT) imaging of the cervical spine is a novel technique with improved sensitivity compared with conventional anatomical MR imaging that is currently available on most clinical scanners. This review describes the theoretical basis, application, and analysis of DT imaging as it pertains to neurosurgery. Particular emphasis is placed on OPLL. *(DOI: 10.3171/2011.1.FOCUS10262)*

Key Words • **ossification of the posterior longitudinal ligament** • **cervical myelopathy** • **diffusion tensor imaging** • **magnetic resonance imaging**

Ossification of the posterior longitudinal ligament occurs in 25% of patients with CSM,[9] which is the most common form of acquired spinal cord dysfunction[11] and is present in more than 60% of the population older than 40 years of age.[4] Thickening and calcification of the posterior longitudinal ligament play a role in CSM through narrowing of the spinal canal, leading to cord compression. Resultant spinal cord ischemia and trauma are purported mechanisms of injury underlying CSM.[2] The MR imaging findings indicative of CSM, such as increased signal (hyperintensity) of the spinal cord on T2-weighted imaging, typically occur late in the disease process and predict poor neurological outcome despite decompression.[12,25] Diffusion tensor imaging is a relatively new technique in spinal imaging, with the sensitivity potentially to detect minor SCI prior to irreversible CSM. We describe its application in the preoperative evaluation of patients with cervical spinal stenosis due to OPLL, where signal artifact from calcification further complicates image acquisition.

Abbreviations used in this paper: CSM = cervical spondylotic myelopathy; CSS = cervical spinal stenosis; DT = diffusion tensor; FA = fractional anisotropy; mJOA = modified Japanese Orthopaedic Association; OPLL = ossification of the posterior longitudinal ligament; SCI = spinal cord injury; VB = vertebral body.

Pathophysiological Features of CSM in OPLL

Narrowing of the anteroposterior diameter of the cervical spinal canal is correlated with the degree of CSM in OPLL.[8,19] As the spinal cord becomes compressed by ossified or hypertrophied ligament and bone spurs, the cushioning effect of CSF is lost. In a series of 200 patients seeking treatment for CSS, 63 (31.5%) reported an episode of minor trauma in the preceding 2 weeks.[29] Physiological neck motion, as well as abnormal motion due to cervical instability, which is often associated with spondylosis,[22] predisposes the spine to repeated microtrauma.[23] Tension applied by dentate ligaments preferentially stretches the lateral aspect of the spinal cord on neck flexion,[17] which corresponds to lateral column atrophy noted in autopsy studies. Segmental OPLL has been shown to permit abnormal mobility between adjacent VB segments, with a range of motion > 35° at C1–7 associated with progressive myelopathy.[20]

Other investigators have postulated an ischemic origin. Ito et al.[16] studied the spines of 7 patients with CSM at autopsy and found a characteristic pattern of lesion progression, beginning with atrophy and neuronal degeneration of the anterior horn and intermediate zones, followed by atrophy of the lateral and posterior funiculi. End-stage disease was marked by cell death throughout the gray matter and severe degeneration of the lateral funiculi. Although vascular occlusion or compression was not identified, the pattern of degeneration appeared consistent with generalized hypoperfusion. The authors postulated that increased intraspinal pressure may have reduced spinal perfusion to the stenotic region. Spinal hypoperfusion has been demonstrated in animal models, in which posterior compression resulted in reduced blood flow to the central gray matter through intramedullary branches.[7] Turnbull[27] examined histological sections through the human spinal cord and noted that the small arteries and veins of the lateral columns and gray matter became stenotic on cord compression in the anteroposterior plane. Vessels supplying the anterior and posterior columns, on the other hand, remained patent. This correlates with the pattern of degeneration in CSM. Nevertheless, the relative contributions of trauma and ischemia have yet to be fully elucidated in live human subjects. Noninvasive MR perfusion and vascular permeability techniques being developed in step with spinal DT imaging protocols may provide more definitive evidence.[18,26] Regardless of the mechanism, reproducible patterns of neural degeneration are found on imaging modalities such as DT studies.

Diffusion Tensor Imaging

Water molecules in a solution move freely and randomly in a process termed Brownian motion. Such isotropic diffusion lacks preference in any particular direction. The gray matter of the brain approximates this situation, because normal cell membranes allow for isotropic diffusion of water in this region.[21] Myelin and axonal membranes of white matter, in contrast, present barriers to water diffusion in directions perpendicular to their long axis. Water moves anisotropically; that is, much more freely within the axonal plane than across it.[1,3] Application of a directional diffusion gradient to heavily T2-weighted echo planar MR imaging sequences measures the spin of protons in water and can be used to track their movement over time. This principle forms the basis of DT imaging, in which diffusion of protons is tracked in 3 perpendicular orientations (x, y, and z) or eigenvectors. The principal eigenvector denotes the orientation of greatest diffusion and is subtracted from the 2 orthogonal middle and minor eigenvectors to calculate FA.[28] The mean diffusivity value is an average of the 3 eigenvectors, analogous to apparent diffusion coefficient values in conventional diffusion-weighted images.

Acquisition of DT Imaging for the Cervical Spine

Diffusion-weighted imaging has proven utility in brain MR imaging for the assessment of acute ischemia and to identify fiber tracts preoperatively. However, spinal applications have lagged behind, in large part due to technical difficulties involving image acquisition. The spinal cord is a small structure relative to the brain and has a limited signal-to-noise ratio. Pulsations of CSF, breathing, and patient movement contribute to motion artifacts. Surrounding bone and calcified ligament, especially in the context of OPLL, produce susceptibility artifacts that further degrade image quality. However, the prevalence of 3-T magnets, with an increased signal-to-noise ratio compared with 1.5-T units, has accelerated acquisition time and reduced artifacts through parallel imaging and periodically rotated overlapping parallel lines with enhanced reconstruction (also known as PROPELLER) techniques. This has enabled performance of DT imaging protocols on most clinical MR imagers. Software bundled with MR imagers and available free over the internet, such as DTI Studio (http://lbam.med.jhmi.edu/DTIuser/DTIuser.asp), can process raw data into useful representations for evaluation by the neurosurgeon.

Clinical Application of DT Imaging

Fractional anisotropy values have demonstrated superior sensitivity in detecting SCI compared with increased T2 signal intensity in studies of patients with CSM.[6] This raises the possibility of using DT imaging to distinguish patients with permanent myelopathic injury, reversible myelopathic injury, and absence of myelopathic change. Budzik et al.[5] correlated mJOA scores with DT imaging results in 20 patients with CSM and found lower FA values in those with worse clinical function. The mean upper- and lower-extremity mJOA scores of 76.1 and 63.4, respectively, in this mildly affected population underscore the high sensitivity of DT imaging in detecting white matter damage. Measurements of T2 signal hyperintensity, on the other hand, did not show a relationship with regard to function. Correlation coefficients between FA values and mJOA score were not reported, however, and follow-up clinical data after surgery are also missing from this study. Facon et al.[10] conducted a similar study of 6 patients with CSM and reported confirmatory results. Statistically significant reductions in FA between patients and healthy controls ($p = 0.012$) were noted with a sensitivity of 73.3% compared with a sensitivity of 46.7% with T2 signal hyperintensity. Myelopathy was qualitatively assessed by simply noting "motor deficit" or "sensory deficit."

Sensitivity may be improved further by parsing eigenvectors and analyzing major, middle, and minor vectors separately.[14] Axonal edema and protein degradation associated with compressive demyelination have been shown to increase middle and minor eigenvectors while sparing the major vector in animal models.[24] Preliminary studies by Hesseltine et al.[13] have shown this dissociation in 11 patients with CSM. Biomarkers specific for myelin breakdown may have prognostic value, because remyelination plays a role in functional improvement following decompression.[15] A larger study of 84 patients found similar discrepancies between eigenvectors in mild CSS[28] with effacement of the subarachnoid space alone, whereas cord compression resulted in reduced FA values. Unfortunately, a clinical correlation was not performed.

The practice of comparing DT imaging to T2 hyperintensity, a measure with poor sensitivity and weak prognostic value, underscores the lack of a clinical or imaging gold standard when assessing CSS. Currently, it is not known whether DT imaging can distinguish patients with permanent myelopathic injury, reversible myelopathic injury, and absence of myelopathic change. A prospective trial addressing this issue is currently under way at our institution.

Illustrative Cases

Case 1

This 57-year-old woman was evaluated at our institution for neck and bilateral upper-extremity pain. Neurological examination revealed grip strength of 4/5 bilaterally, with numbness in her hands and feet. The Babinski sign was positive bilaterally. Her mJOA, Nurick, and Oswestry scores prior to surgery were 8, 3, and 62, respectively. An admission CT scan of the cervical spine revealed continuous OPLL between the C-3 and C-4 VBs and posterior to C-5, with mild to moderate central canal stenosis at C3–4 and C4–5 (Fig. 1). Standard anatomical MR imaging of the cervical spine showed multilevel disc disease, with severe central canal stenosis at C4–5 accompanied by signal abnormality within the spinal cord (Fig. 2A). Diffusion tensor images were highly suggestive of axonal injury, with greater than 50% loss of FA in the left corticospinal tract (Fig. 2C). At 3 months after C4–6 anterior cervical discectomy and fusion and C3–T2 posterior spinal fusion, the patient's mJOA and Oswestry scores improved to 12 and 49, respectively. Her Nurick score remained the same.

Case 2

This 52-year-old man presented with complaints of neck pain and left upper-extremity pain and numbness. Neurological examination revealed hyperreflexia of the bilateral upper extremities, positive Hoffman sign of the left upper extremity, and bilateral Babinski signs. Preoperatively, his mJOA, Nurick, and Oswestry scores

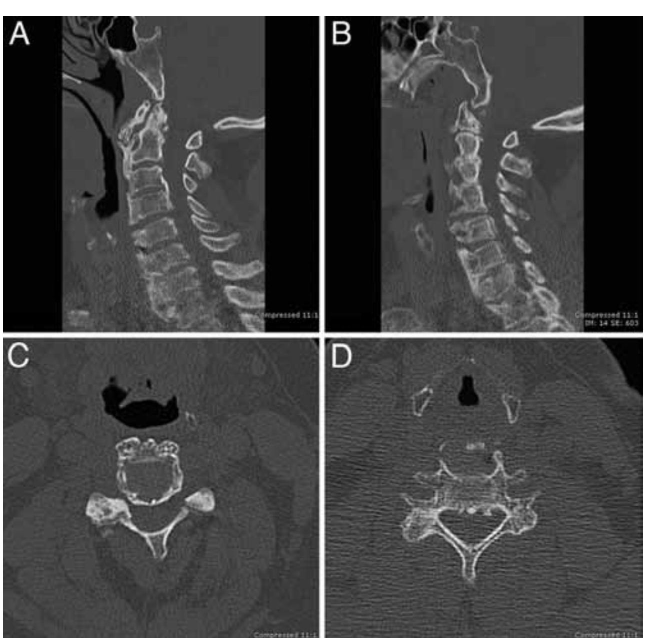

Fig. 1. Admission CT scans of the cervical spine in sagittal **(A and B)** and axial **(C and D)** projections demonstrate OPLL bridging the C3–5 disc space and posterior to the C-5 VB.

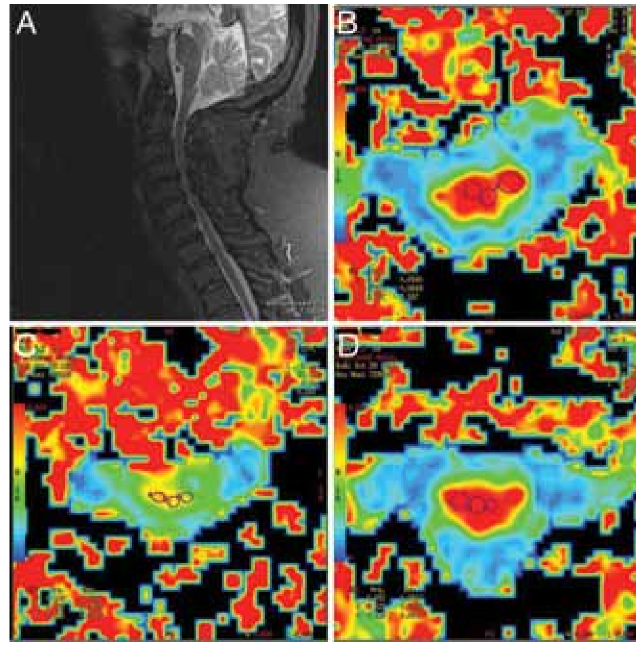

Fig. 2. Sagittal MR imaging study of the cervical spine in the same patient reveal signal change within the spinal cord on the STIR sequence **(A)** due to severe CSS. The DT imaging studies demonstrate marked reduction of FA values within the stenotic region **(C)** compared with C2–3 **(B)** and C7–T1 **(D)**, which is suggestive of axonal injury.

were 7, 4, and 78, respectively. Standard MR imaging of the cervical spine (Fig. 3A) demonstrated multilevel spondylosis, worst at C6–7, where a disc-osteophyte complex resulted in moderate CSS. No signal abnormality within the spinal cord was noted. The DT imaging findings (Fig. 3B–E) included a marked reduction in FA at C6–7, below even the threshold of fiber tracking. The patient subsequently underwent a C4–7 anterior cervical discectomy and fusion, based primarily on clinical deterioration consistent with progressive CSM. His follow-up mJOA, Nurick, and Oswestry scores at 4 months improved to 10, 3, and 72, respectively.

Case 3

This 82-year-old man presented with neck pain radiating to his left upper extremity. Neurological examination demonstrated diffuse 3+/4 hyperreflexia and broad-based ataxic gait. His mJOA, Nurick, and Oswestry scores were 14, 1, and 34, respectively. An admission CT scan of the cervical spine revealed extensive continuous OPLL from C-3 to C-7, with moderate to severe spinal canal narrowing (Fig. 4). Standard MR imaging showed compression of the spinal cord and questionably associated signal abnormality within the cord at the level of the C-6 VB (Fig. 5A). The FA values at the level of worst stenosis, however, were suggestive of preserved white matter tracts (Fig. 5B). Despite the finding of severe stenosis on conventional MR imaging, the patient was only mildly symptomatic from CSM. Given his age and medical comorbidities, the patient is currently being monitored conservatively with serial neurological examination for his OPLL with cervical stenosis.

These illustrative cases describe how DT imaging

Fig. 3. A T2-weighted MR imaging study **(A)** of the cervical spine shows loss of lordosis and moderate CSS that is worst at C6–7 without signal change within the spinal cord. The DT imaging studies demonstrate a 35% decrease in FA values between the C2–3 and C6–7 levels **(B–D)**. The FA values were below the threshold for fiber tracking, leading to a gap on the composite image **(E)**.

might quantify the degree of SCI, yet a clinical trial with rigorous statistical analysis is necessary to confirm such anecdotal reports.

Discussion

Based on several experimental and early clinical studies, DT imaging of the cervical spine appears to manifest improved sensitivity in the detection of myelopathy compared with conventional anatomical MR imaging.[28] By examining changes in FA levels, DT imaging can detect abnormal values seen early in the course of myelopathy that may be otherwise clinically asymptomatic or undetectable by standard MR imaging protocol. The increase in sensitivity to detect myelopathic changes by DT imaging can potentially improve clinicians' ability to determine the most optimal treatment for patients with OPLL and other forms of cervical myelopathy. Patients who are mildly symptomatic or who harbor only mild to moderate stenosis on conventional MR imaging but who demonstrate FA values suggestive of axonal injury, may benefit from early surgical decompression. On the other hand, patients with severe stenosis who present with mild or no clinical myelopathy symptoms or signs and normal FA values on DT imaging can perhaps be monitored with serial neurological examination and imaging.

Fig. 4. Sagittal CT scan of the cervical spine showing continuous OPLL with severe central spinal canal stenosis.

The ability to detect physiological changes accurately using noninvasive imaging modalities such as DT imaging can be particularly valuable in the management of OPLL. Although the incidence of OPLL is low compared with spondylotic myelopathy, complications from surgical treatment of OPLL are significantly higher. The ability to determine with accuracy the subgroup of patients who have incurred axonal injury from OPLL prior to major clinical manifestations may allow clinicians to select those who will benefit from prophylactic decompression prior to the onset of irreversible CSM. Conversely, undesired perioperative risks associated with OPLL may be avoided in patients without findings of axonal injury on DT imaging, despite the appearance of stenosis on conventional MR imaging.

At this time, DT imaging remains an experimental modality in the evaluation of cervical myelopathy. The advantage of this modality over conventional MR imaging is its ability to quantify minor axonal injury that is other-

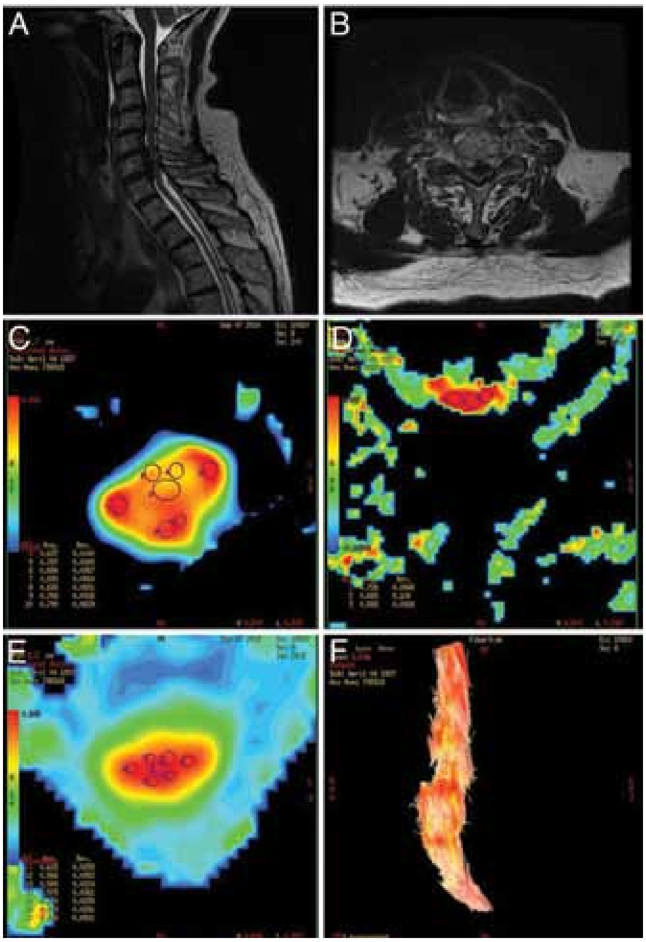

Fig. 5. The T2-weighted MR imaging studies of the cervical spine demonstrate a mass-like OPLL posterior to the C-6 and C-7 VBs **(A)**, and deformation of the spinal cord **(B)**. The FA values from the region of stenosis **(D)** are relatively preserved in comparison with C2–3 **(C)** and C7–T1 **(E)** levels. The fiber tracking is also robust **(F)**.

wise undetectable.[10] Whereas signal changes in the spinal cord on T2-weighted imaging are generally late findings indicative of SCI and often associated with poorer clinical prognosis, early detection of axonal injury on DT imaging may identify at-risk patients who will benefit from surgical decompression. Although there are published data demonstrating that decreased FA values on DT imaging are correlated with diminished neurological function, it is not known what threshold level will constitute permanent versus reversible neurological injury. The results of early experimental and small clinical studies suggest that DT imaging may allow for prognostication of patient outcomes prior to intervention. Future studies to correlate DT imaging findings with the various stages of CSM in a large prospective cohort will be important to determine the utility of this advanced imaging modality in the evaluation of OPLL and other causes of cervical myelopathy.

Conclusions

At this time, current studies on the use of DT imaging to evaluate myelopathy are still limited to small series of patients and lack long-term follow-up. Our preliminary results in 3 patients demonstrate that DT imaging is feasible in OPLL despite central canal narrowing and susceptibility artifact from the ossified ligament. Further studies are needed to better interpret FA and fiber tracking metrics by correlating the findings on DT imaging to the clinical symptoms. Clinical studies with larger patient cohorts designed to evaluate the sensitivity and specificity of DT imaging are needed to determine the utility of this modality to identify patients at risk for progressive myelopathy or possibly to predict treatment outcome. In conjunction with clinical findings, advanced MR techniques such as DT imaging may provide clinicians with the pertinent information needed to predict treatment outcome and determine optimal timing of surgical decompression.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: Hsieh. Acquisition of data: Jones, Kim. Analysis and interpretation of data: all authors. Drafting the article: Jones, Lerner, Hsieh. Critically revising the article: Lerner, Law, Hsieh. Reviewed final version of the manuscript and approved it for submission: Hsieh. Administrative/technical/material support: Jones. Study supervision: Lerner, Law, Hsieh.

Acknowledgments

The authors thank medical students Thomas Chong and Amy Cummings for their diligent assistance with manuscript preparation.

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Manuscript submitted November 13, 2010.
Accepted January 14, 2011.
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Ossification of the ligamentum flavum: a unique report of a Hispanic woman

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Ossification of the ligamentum flavum (OLF) is a disease of ectopic bone formation within the ligamentum flavum, which may result in mass effect and neurological compromise. The low thoracic region is the most common region of occurrence, and this is followed by the cervical, then lumbar, spine. The prevalence of OLF is significantly higher in the Japanese population compared with other nationalities and has a male preponderance. Ossification of the ligamentum flavum has been reported in association with the more common ligamentous pathological entities—ossification of the posterior longitudinal ligament and diffuse idiopathic skeletal hyperostosis. These latter two conditions have been linked to several metabolic processes, and a possible genetic basis has been hypothesized. Here, the authors present a unique case of OLF of the cervical spine in a patient with idiopathic hypercalcemia.
(DOI: 10.3171/2011.1.FOCUS10266)

Key Words • **ossified ligamentum flavum** • **ossified yellow ligament** • **hypercalcemia** • **cervical stenosis**

The ligamentum flava are broad paired spinal ligaments that connect the adjacent laminae of the vertebral column extending from C-2 to S-1.[9,27,52] These ligaments can undergo uni- or bilateral hypertrophy, calcification, or ossification.[30] Ossification of the ligamentum flavum is an acquired degenerative disease that was first described by Polgar[36] in 1920 on lateral radiograms. It occurs through endochondral ossification of hypertrophied fibrous tissue within the ligaments.

Ossification of the ligamentum flavum is a relatively rare disease, and there are insufficient controlled epidemiological data in the literature. Ossification of the ligamentum flavum is reported to affect 20% of Asians older than 65 years of age.[10] Although OLF has been reported as endemic to Japan, reports from outside of this endemic area—North Africa,[2,5,13] the Middle East,[3] India,[14,15,42] Caribbean,[34] Europe,[4,7,10,32,33,35,43] and North America[20,27,31,41,48,49]—have been increasingly reported in the literature. However, the Japanese population remains the largest population affected, with 88.8% of the reports of OLF in the literature based on Japanese patients, and Caucasians are the second-most common, comprising 8.2% of the reports.[27]

The low thoracic spine is the most common location of OLF, T9–12 being the most affected region.[10,29,34,38,49,52] The predominance of OLF in the low thoracic spine is thought to be associated with the transitional segment between the end of the rib cage and the thoracolumbar junction resulting in increased motion, degeneration, and microtrauma to the ligamentum flava.[10] In a study by Guo et al.,[10] 1736 Chinese patients underwent MR imaging of the spinal axis to screen for OLF. In patients with OLF, the lesions were located in the cervical region in 4.3%, the thoracic region in 95.6% (52.2% had disease T9–12), and the lumbar region in 0.1%.[10] The authors also found that 15% of patients had noncontiguous OLF lesions and recommended thorough screening prior to treatment.

Case Report

History. This 45-year-old Hispanic woman had a 5-year history of idiopathic hypercalcemia, chronic kidney disease, and nephrolithiasis after left urethral stenting. She presented with a progressive 1.5-year history of neck pain and left arm weakness and numbness. She also complained of gait instability and apraxia of the hands. She had no history of trauma. On presentation to the emergency department, her serum creatinine (3.2 mg/dl) and calcium (15.2 mg/dl) levels were elevated above baseline (1.9–2.2 mg/dl and 11–12 mg/dl, respectively), and her serum glomerular filtration rate (15 ml/minute) was lower than her baseline (28 ml/minute).

Abbreviations used in this paper: CLF = calcification of the ligamentum flavum; DISH = diffuse idiopathic skeletal hyperostosis; OLF = ossification of the ligamentum flavum; OPLL = ossification of the posterior longitudinal ligament; PTH = parathyroid hormone.

Examination. On examination we observed a well-nourished Hispanic woman with no apparent distress. Her neck was supple with mild tenderness along the cervical spine and cervicothoracic junction of the column. Neurologically, she exhibited muscle weakness (Grade 4-/5) and sensory deficit of the left upper and lower extremities with long tract findings on the left as well. The right upper and lower extremities were normal.

Admission CT scanning (Fig. 1) and MR imaging (Fig. 2) revealed hypertrophy and ossification of the ligamentum flavum, bilaterally, from C-2 to T-3, resulting in severe C3–7 canal stenosis with severe cord compression. The anteroposterior diameter of the canal at C-5 measured approximately 4.2 mm. The dura mater was also calcified at the same levels mentioned above. There was no subluxation, neural foraminal narrowing, or vertebral joint hypertrophy. We found no evidence of DISH, OPLL, and other ligamentous pathologies or ectopic bone formations.

Operation. The patient was diagnosed with idiopathic hypercalcemia, likely due to increased gastrointestinal tract absorption of calcium. Her renal function improved with aggressive hydration and cinacalcet (Sensipar, Amgen Inc). Once her medication levels were optimized, she was brought to the operating room. Anesthesia was induced following fiberoptic intubation, the patient was placed in the Mayfield head holder, and somatosensory and motor evoked potentials were established at baseline, intraoperatively, and postoperatively. Instrumentation was applied from C-2 to C-7. A C2–7 laminectomy was then performed using a high-speed drill, a forward-angled curette, and a Kerrison rongeur. A markedly hypertrophic, partly ossified ligamentum flavum was then encountered. Resection was performed in piecemeal fashion at C7–T1 with rongeurs until the dura could be appreciated. Blunt dissection was conducted (Fig. 3 and Video 1).

Video 1. Intraoperative video recorded using the operative microscope. Cranial is the left lower portion of the screen and caudal in right upper portion of the screen. The ossified part of the ligamentum flavum is removed with a combination of blunt and sharp dissection. A curette is used to identify the plane laterally. Metzenbaum scissors are then used to sharply amputate the ossified ligamentum flavum, which is then reflected cranially and dissected away from the dura with blunt dissection using a No. 4 Penfield instrument. Click here to view with Windows Media Player. Click here to view with Quicktime.

We observed several areas of OLF that were indistinguishable from underlying calcified dura (Fig. 4). A small durotomy was repaired in primary fashion with muscle patch and fibrin glue after we failed to reapproximate the calcified dura with suture. Once a generous decompression was achieved from C-2 through T-1 and confirmed at each level by direct palpation with a Woodson device, the instrumentation was extended to T-2 caudally and the construct was then completed with titanium rods and cross-link connectors. Finally, we applied graft material that included local and iliac crest nonstructural autograft, nonstructural allograft, and an internal bone growth stimulator. Both somatosensory and motor evoked potentials were stable throughout the surgery. The patient was transferred to the neurosurgical intensive care unit in stable condition.

Postoperative Course. The patient experienced complete resolution of her neck pain, weakness, and numbness of the left upper extremity. Cervical CT scanning revealed a wide and adequate decompression of the spinal cord, especially at C5–6. On her discharge on postoperative Day 7, motor examination revealed no weakness; Grade 5/5 strength in all muscle groups; and no upper motor signs. At the 1-month follow-up visit, the patient reported significant improvement in her mobility, gait, and left-hand clumsiness.

Pathological review of the tissue submitted was inconclusive. Calcification and crystalline deposits were identified, but the composition of the crystals could not be elucidated as the specimen was placed in formalin. Nodules of giant cells and granulomatous reaction were also seen.

Discussion

Ossification of the Ligamentum Flavum

The ligamentum flava are broad paired spinal liga-

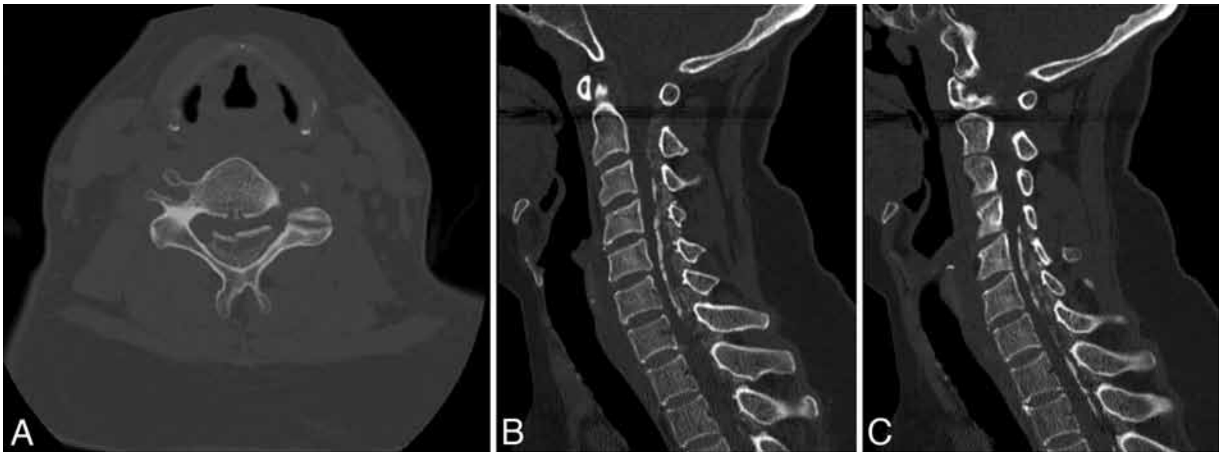

Fig. 1. A: Axial CT scan at the level of the C-6 neural foramen demonstrating significant posteromedial compression, extending toward the left nerve root. **B and C:** Sagittal CT scans demonstrating the contiguous nature of the ossified ligamentum flava extending from C2–T3.

Fig. 2. Upper: Axial CT scan of the cervical spine demonstrating significant cord compression. **Lower:** Sagittal MR image again demonstrating the extent of spinal cord compression. Despite the extent of compression, there is no intramedullary hyperintense signal.

ments that connect the adjacent laminae of the vertebral column extending from C-2 to S-1.[9,27,52] Each pair attaches to the anteroinferior surface of the superior lamina and the posterosuperior surface of the inferior lamina.[9,49] The ligamentum flavum originates bilaterally at the articular processes on either side of the nerve roots and extends posteriorly along the lamina to midline.[9] At the midline, the ligamentum flavum is partially fused with the contralateral side.[9] It is composed of longitudinal elastic connective tissue.[27] The ligamentum flavum functions as an elastic band aiding the spinal column in resuming neutral position after flexion and extension motion.[9,49]

Ossification of the ligamentum flavum is characterized by replacement of the structure by ectopic bone formation through endochondral ossification.[34,49,52] It is an enthesopathy in which the normal fibrous structure of the ligamentum flavum is lost and replaced by hypertrophied fibrous tissue, rich in fibrocartilaginous cells, that has an increased affinity for calcium deposition and serves as promoter for chondrometaplasia.[22] Ossification results from progressive replacement of the hypertrophied ligamentum flavum by lamellar bone through endochondral ossification of the vascularized fibrocartilaginous tissue starting at the densely adherent ligamentous-osseous junction (enthesis) then extending along the ventral aspect of the ligament.[22] Histological studies have found ossification along the yellow ligaments, fewer elastic fibers, and more fibrocartilaginous cells, premature osteons, and osteoblasts.[47] Heterotopic ossification occurs by fibroblast proliferation, followed by chondroblast formation in which the chondroblasts transform into osteoblasts.[44] In a study by Zhong et al.,[52] cultured OLF cells were shown to express osteocalcin (a maker of osteoblasts) and collagen Type II (a marker for chondrocytes), confirming that OLF cells have osteoblast and chondrocyte phenotypes.[52]

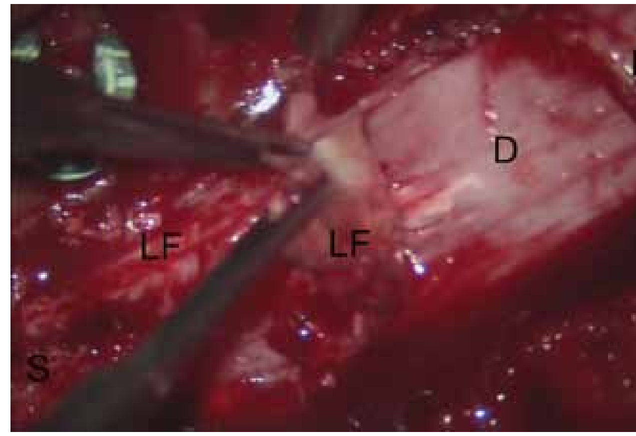

Fig. 3. Intraoperative photograph of the removal of ossified ligamentum flavum (LF) bilaterally. The laminectomy has already been performed and the ossified ligamentum flava are being removed from inferior to superior in a stripping manor using blunt and sharp dissection techniques. D = dura; I = inferior; S = superior.

Ossification of the ligamentum flavum has been di-

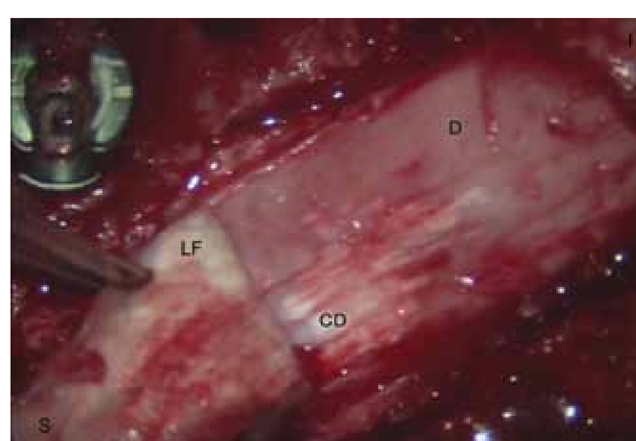

Fig. 4. Intraoperative photograph of the removal of ossified ligamentum flavum. In some places the ossified ligamentum flavum was adherent to the dura, and a dissection plane could not be identified. CD = calcified dura.

vided into 5 types based on extent/location of the ossification.[29] The lateral type, Type I, is located only laterally at the origin of the ligamentum flavum at the articular processes.[29] The extended type, Type II, extends from the lateral origin of the ligamentum flavum to the interlaminar portion of the ligamentum flavum.[29] The enlarged type, Type III, protrudes into the canal posterolaterally but is not fused in the midline.[29] The fused type, Type IV, consists of bilateral ossified ligaments that are fused at the midline with a groove at the fusion in midline.[29] Type V, the tuberous type, occurs when the fused ossified ligamentum flavum forms a "tuberous" mass posteriorly in the midline, which protrudes into the spinal canal.[29]

Computed tomography and MR imaging are the imaging modalities of choice. Radiography generally lacks the sensitivity to identify OLF. Computed tomography, with the use of bone windows, produces the most accurate information regarding location, size, and extent of the disease. Ossification of the ligamentum flavum begins laterally at the facet capsule and grows medially, as previously discussed. This process results in the V-shaped appearance of calcification on axial CT scans.[34] This is also the reason that the calcification is best identified on sagittal CT scans. Additionally, CT is useful in determining whether the dura is involved in OLF. Muthukumar[29] defined two reliable signs on CT scans that demarcate dural involvement in OLF: the tram track sign and the comma sign. The tram track sign is a hyperdense bony excrescence with a hypodense center.[29] The comma sign is ossification of one-half of the circumference of the dura.[29] This is important to identify preoperatively because this may change the approach/manner of the laminectomy and decompression. Magnetic resonance imaging is useful in demonstrating the extent of spinal cord compression and identifying underlying spinal cord injury (the high signal intensity on T2-weighted images) and the compressive lesion.[43]

Calcification of the ligamentum flavum is often confused with OLF. Histologically, CLF is composed of degenerated ligamentum flavum and with calcified granules consisting of calcium pyrophosphate dihydrate and hydroxyapatite, whereas OLF contains ectopic bone produced through endochondral ossification.[18,50] An additional difference is that CLF often affects women in the cervical spine, whereas OLF is more predominant in men in the thoracic and lumbar distributions.[18] Radiographically, CLF reportedly involves only one interlaminar segment and is not contiguous with or only partially in contact with the laminae, which is most readily distinguished on sagittal CT scanning.[49] Ultimately, the distinction between OLF and CLF is based on the pathological specimen.

Management

Ossification of the ligamentum flavum presents most often as a myeloradiculopathy. Patients usually present first with sensory deficits, followed by limb weakness, and later gait disturbance.[34,45] Lateral OLF lesions have been associated, although rarely, with radiculopathy due to nerve root compression.[34] As previously mentioned, OLF often can occur in a noncontiguous manner. We advise, prior to surgical intervention, a thorough screening of the spinal axis and confirmation that the clinical symptoms match the location of disease.

To date there are no pharmacological therapies for OLF. At best, management of the underlying cause may slow progression of the disease. The majority of these patients, however, do not come to medical attention until they are symptomatic. Once myelopathy develops, the only treatment option is surgical decompression.

The literature has described laminoplasty, laminectomy, and laminectomy with fusion as surgical options. Li et al.[22] performed decompressive surgery in 40 patients for thoracic OLF. They compared laminoplasty to laminectomy with fusion. They did not undertake laminectomy as a stand-alone procedure due to the reports of late-onset kyphosis.[22] They performed 4 laminoplasty procedures: symptoms in 1 patient improved (25%) and symptoms in 3 patients (75%) were unchanged or worse (and 2 of these 3 patients developed late-onset kyphosis). In the laminectomy and fusion group, 83% of the patients had a "good or fair" outcome and symptoms in 17% were unchanged or worse. The authors concluded that laminoplasty yielded an insufficient decompression, and hence the poor result, was associated with kyphotic deformity, and was technically difficult given the adherence of the OLF to the dura.[22] They found decompressive laminectomy and fusion to be the superior surgical management.[22] This procedure allows aggressive, wide decompression and limits motion and thus microtrauma, which some postulate may be the source of the OLF.[22]

Of note, an ossified ligamentum flavum can be very adherent to the dura, with rates in the literature ranging from 11% to 62%.[29] Specifically, the enlarged, fused, and tuberous types are associated with a high incidence of dural ossification.[29] The benefit of complete resection of the ossified ligamentum flavum and involved dura, compared with decompression leaving a portion of ossified dura, has not been described in the literature. While complete resection in OLF, including the involved dura, is ideal, wound healing and CSF leakage can pose a substantial problem even with a dural graft, tissue glue, and possible lumbar drainage.[29]

Different laminectomy techniques have been posed to address the adherent dura: an en bloc approach, a "separating" laminectomy, and microsurgical drilling. The en bloc laminectomy is performed in a standard fashion by drilling through the lamina bilaterally and then removing the bone in a lobster-tail manner.[22] The separating laminectomy involves removing the spinous process, drilling the midline down to the dura, and bilateral drilling of the mid-facet joint in an attempt to remove the ossified mass, medial to lateral.[22] Finally, complete resection of the lamina and ossified ligamentum flavum through microsurgical drilling has also been advocated.[8]

The only factor associated with poor neurological outcome is the presence preoperatively of an intramedullary hyperintense signal on MR imaging.[49] Dural ossification has been associated with a complicated hospital course including higher rates of CSF leakage and meningitis, but no effect on long-term neurological function has been reported.[25] Factors associated with good outcomes included a short duration of mild clinical symptoms,[1,38] single-level disease,[21] and unilateral lesions.[21] Complications noted in the literature include paralysis, likely due to spinal cord manipulation in adherent, stenotic cases; epidural hematoma; CSF leakage; and delayed kyphosis.[25,49,51]

Metabolic Associations

The cause of OLF remains unclear, despite its identification 90 years ago. It has been described in association with hyperostotic syndromes including OPLL, DISH, and ankylosing spondylosis.[26,27,43] It has been thought to be linked to metabolic derangements including diabetes mellitus, hyperinsulinism, impaired glucose tolerance, obesity, Paget disease, hemochromatosis, fluorosis, X-linked hypophosphatemia, and hypoparathyroidism.[12,24,27,43,47] Additionally, mechanical stress, trauma, and genetics have been suggested as contributing factors associated with OLF.[29]

A number of factors in our case are unique: the patient is a young, Hispanic female with idiopathic hypercalcemia and OLF in nearly the entire cervical spine, extending from C3–T2. Wang et al.[47] studied the calcium level in ligamentum flavum in normal patients, those with degenerative disease, and those with ossified disease. They found statistically significant higher levels of calcium in the ligamentum flavum in patients with OLF and degenerative disease compared with normal patients. Interestingly, they also evaluated the serum levels of calcium in the same 3 patient groups and found no difference.[47] Vitamin D–resistant rickets has also been associated with OLF. Patients with this disorder, however, have low serum phosphate and slightly lower serum calcium levels.[46]

Our patient suffered from chronic kidney disease secondary to idiopathic hypercalcemia; the cause of chronic kidney disease in this case was 2-fold. She had previously suffered from kidney stones requiring placement of ureteral stents. Additionally, she had intrinsic renal failure demonstrated by elevated serum creatinine and decreased glomerular filtration rate. Renal insufficiency secondary to hypercalcemia can be to the result of different mechanisms including arteriolar vasoconstriction, alterations in glomerular permeability, nephrocalcinosis, and nephrolithiasis.[28] Parathyroid hormone has an interesting effect on bone formation. It regulates the serum calcium levels indirectly by stimulating osteoclasts. When given in continuous manner, PTH causes bone resorption and an increase in serum calcium, but when administered in an intermittent fashion, it causes bone formation and a decrease in serum calcium.[19] Additionally, PTH-related protein modulates proliferation and differentiation of chondrocytes and subsequently endochondral bone formation.[40] Both PTH and PTH-related protein have been suggested as possible links to ossification of spinal ligaments.

Hyperinsulinemia is another metabolic abnormality associated with ectopic bone formation within the spinal ligaments, specifically in OPLL.[39] Specifically, noninsulin-dependent diabetes mellitus has a higher incidence of OPLL and DISH compared with insulin-dependent diabetes. This difference is thought to be secondary to the higher levels of circulating insulin in patients with NIDDM.[39] The suggested roles insulin plays in hyperostosis include stimulating intestinal calcium absorption[39] and stimulating the proliferation of bone morphogenic protein–2-induced osteogenic differentiation.[23] Insulin-like growth factor–I is upregulated in NIDDM as well as acromegaly and has been linked to increased bone mineral density.[16,37]

As previously noted, OLF is seen in association with other hyperostotic syndromes such as OPLL. In a review by Guo et al.[11] 13 studies of tandem OPLL and OLF were reviewed. They found that 53% of the patients had thoracic OPLL and thoracic OLF, 23% of which were at the same level. Despite OPLL commonly occurring in the cervical spine, tandem cervical OPLL and cervical OLF only occurred in 1.4% of the patients. The remaining 45.6% had noncontiguous lesions—OPLL and OLF in different spinal regions.

Kawaguchi et al.[17] demonstrated that growth factors play a significant role in hyperostosis of the spinal ligaments. They performed immunohistochemical analysis on surgically obtained posterior longitudinal ligament during decompression surgery for OPLL. They found bone morphogenic protein–2 and transforming growth factor-β at the site of ligamentous ossification, but not in normal ligament obtained in the same patient,[17] indicating these growth factors play an essential role in ossification of the spinal ligaments. The upregulation of these elements within the OLF (as well as in OPLL)[6] suggests a role of inflammation in the development of this condition and may serve as a target for future medical therapies in halting its progression.

Conclusions

Ossification of the ligamentum flavum is a well-established disease entity, but there is much to be learned about the underlying mechanism. We present a case of a young, Hispanic female with idiopathic hypercalcemia and OLF from C2–T3.

Disclosure

Dr. Goldstein is a consultant for Zimmer Spine and Alphatec Spine.

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: Christiano, Assina. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: all authors. Administrative/technical/material support: Christiano, Goldstein. Study supervision: Goldstein.

Acknowledgment

We would like to acknowledge Dr. Ada Baisre De Leon, in neuropathology, who assisted in the pathological diagnosis of this patient.

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Manuscript submitted November 12, 2010.
Accepted January 12, 2011.

Supplemental online information:
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Neurosurg Focus 30 (3):E16, 2011

Management of ossification of the posterior longitudinal ligament of the thoracic spine

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The management of thoracic ossification of the posterior longitudinal ligament has been studied by many spinal surgeons. Indications for operative intervention include progressive radiculopathy, myelopathy, and neurological deterioration. The ideal surgery for decompression remains highly debatable as various methods of surgical treatment of ossification of the posterior longitudinal ligament have been devised. Although numerous modifications to the 3 main approaches have been identified (anterior, posterior, or lateral), the indication for each depends on the nature of compression, the morphology of the lesion, the level of the compression, the structural alignment of the spine, and the neurological status of the patient. The authors discuss treatment techniques for thoracic ossification of the posterior longitudinal ligament, cite case examples from a single institution, and review the literature.
(DOI: 10.3171/2010.12.FOCUS10282)

Key Words • **ossification of the posterior longitudinal ligament** • **thoracic myelopathy** • **thoracic spine**

Ossification of the posterior longitudinal ligament is an epidemiological event that often affects the cervical spine. Tsukimoto[32] was the first to describe OPLL of the cervical spine in 1960. However, the condition may involve the thoracic spine and produce myelopathy through anterior spinal cord compression.[16] Ossification of the posterior longitudinal ligament is rarely seen in patients until the third decade of life.[19] This disease process is most commonly seen in the Japanese population.[19] The prevalence of thoracic OPLL seen in a Japanese community has been reported to be 0.8%, compared with 3.2% seen for cervical OPLL.[13,22] The incidence of cases of OPLL of the thoracic spine with clinical symptoms is lower than that of the cervical spine.[4] According to Epstein,[2] 70% of OPLL is found in the cervical spine, 15% in the upper thoracic spine, and 15% in the proximal lumbar spine.[12] Ossification of the posterior longitudinal ligament in the thoracic spine usually occurs in the upper- and midthoracic spines of women who are older than 40 years of age.[20]

Symptoms are the result of stenosis that is usually progressive and unaffected by conservative management.[15,16,33] Surgery is the only effective treatment option.[15] For patients with thoracic myelopathy, the most effective method of treatment is relieving pressure off the spinal cord and removing the OPLL.[4,10,30,31,34,41] Although surgical outcome of thoracic OPLL compares unfavorably with that of cervical OPLL, early intervention is imperative.[20,36] A review of the literature, limited to the English language, was performed for surgical management of thoracic OPLL and is summarized in Table 1.

Anatomical Considerations

There are multiple classification schemes in the literature. A classification based on form and morphology includes a continuous or mixed type with a flat shape ("flat-type") and a segmental type with sharp protrusions located behind the disc spaces ("beak-type").[16] Ossification of the posterior longitudinal ligament can also be described morphologically as linear, beaked, continuous waveform, continuous cylindrical, segmental, continuous, or mixed.[15,24] Patterns of ossification can be divided into 4 major subgroups as follows: 1) focal ossification at the posterior margin of the vertebral body; 2) segmental ossification in which each change does not extend beyond the adjacent intervertebral disc level; 3) continuous ossification over multiple levels; and 4) mixed ossification.[19] Kurosa et al.[13] defined a classification system based on the location of the OPLL in the sagittal plane as follows: 1) central part of the S-curve of the cervicothoracic spine (the inflection point often in the upper thoracic spine where the plane shifts from cervical lordosis to thoracic kyphosis); 2) just above the thoracic apex or apical vertebrae; and 3) below the apical vertebrae, typically combined with OLF.

In spinal hyperostosis, OPLL and OLF are the main

Abbreviations used in this paper: JOA = Japanese Orthopaedic Association; OLF = ossification of the ligamentum flavum; OPLL = ossification of the posterior longitudinal ligament.

TABLE 1: Literature review of surgical treatment for thoracic OPLL*

Authors & Year	Disease & Surgical Procedure (no. of patients)
present study 2010	OPLL
	pst decomp & fusion (2)
Matsuyama et al., 2005	flat-type OPLL
	ant decomp & fusion (1)
	ant decomp via pst approach (3);
	laminoplasty (3)
	beak-type OPLL
	ant decomp & fusion (2)
	ant decomp via pst approach (6)
	laminoplasty (6)
Takahata et al., 2008	OPLL
	circumferential decomp via pst approach (30)
Park et al., 2008	OPLL
	thoracic (5)
Min et al., 2008	OPLL
	ant decomp w/ discectomy (3)
	ant decomp w/ partial corpectomy (9)
	ant decomp w/ corpectomy (5)
	ant decomp w/ discectomy & partial corpectomy (2)
Matsumoto et al., 2008	linear-type OPLL
	laminectomy (5)
	ant decomp via pst approach (3)
	beaked-type OPLL
	laminectomy (8)
	laminoplasty (16)
	ant decomp via ant approach (12)
	ant decomp via pst approach (5)
	circumferential decomp via combined ant & pst fusion (2)
	sternum splitting approach (2)
	continuous waveform OPLL
	laminectomy (9)
	laminoplasty (19)
	ant decomp via ant approach (4)
	ant decomp via pst approach (12)
	circumferential decomp via combined ant & pst fusion (2)
	continuous cylindrical OPLL
	laminectomy (7)
	laminoplasty (11)
	ant decomp via ant approach (2)
	ant decomp via pst approach (6)
	mixed-type OPLL
	laminectomy (7)
	laminoplasty (5)
	ant decomp via ant approach (7)
	ant decomp via pst approach (3)
	circumferential decomp via combined ant & pst fusion (4)
	sternotomy approach (3)
Kawahara et al., 2008	pst decomp w/ dekyphosis stabilization (4)
	circumferential decompression via initial pst decomp w/ dekyphosis stabilization followed by ant interbody (11)

(continued)

causes of compressive myelopathy. In the thoracic spine, OPLL and OLF can compress the spinal cord anteriorly and posteriorly, respectively, or they may fuse to circumferentially compress the spinal cord on all sides.[35] Unlike OPLL in the cervical spine, thoracic myelopathy due to ligament ossification may be overlooked, misdiagnosed, or treated inappropriately.[40] Thoracic myelopathy is not as common as cervical myelopathy.[1,40]

TABLE 1: Literature review of surgical treatment for thoracic OPLL* ***(continued)***

Authors & Year	Disease & Surgical Procedure (no. of patients)
Aizawa et al., 2007	OPLL
	laminectomy (15)
	laminectomy w/ fusion (2)
	ant decomp via diagonal ant/pst approach (2)
	ant decomp via pst approach (2)
	OPLL, OLF
	laminectomy (9)
	ant decomp via pst approach (1)
Hanai et al., 2002	OPLL
	transthoracic approach for ant decomp & fusion, occasional use of the scapula-releasing approach (10)
	thoracoabdominal approach for ant decomp & fusion (2)
Yang et al., 2010	OPLL
	pst decomp & ant decomp via posterolat approach
Fujimura et al., 1997	OPLL
	ant decomp via manubrium splitting approach (2)
	ant decomp via extrapleural approach (30)
	combined (1)
Yamazaki et al., 2010	OPLL
	pst decomp w/ fusion (24)
Min et al., 2007	segmental-type OPLL
	partial corpectomy (6)
	discectomy (3)
	partial corpectomy w/ discectomy (2)
	corpectomy (3)
	continuous-type OPLL
	partial corpectomy (3)
	corpectomy (2)
	mixed-type OPLL
	partial corpectomy (1)
Tokuhashi et al., 2006	OPLL
	pst decomp (5)
	pst decomp w/ fusion (11)
	pst decomp w/ fusion via posterolat approach (4)
	ant decomp w/ fusion (2)
Yonenobu et al., 1987	OPLL
	pst decomp (12)
	pst decomp then ant decomp (4)
	pst decomp then pst decomp (3)
	ant decomp (5)
	ant decomp then pst decomp (2)
Tomita et al., 1990	OPLL & OLF
	circumspinal decomp (10)
Tsuzuki et al., 2001	OPLL
	extensive cervicothoracic laminoplastic decomp (3)
	extensive cervicothoracic laminoplastic decomp, pst longitudinal durotomy (5)
	extensive cervicothoracic laminoplastic decomp, pst longitudinal durotomy root release w/ total laminofacetectomy, anterolat dural release (4)
	extensive cervicothoracic laminoplastic decomp, pst longitudinal durotomy root release w/ total laminofacetectomy, anterolat dural release, & OPLL excision or ant transfer, & posterolat fusion (5)

(continued)

Radiographic evaluation consists of the location and extent of OPLL, the type of OPLL, signs of dural penetration, the degree of compression, the presence of cord signal change, and the presence of "tandem ossification" in the cervical spine or the ligamentum flavum. Signs of dural penetration are based on their morphology in relation to the OPLL. Signs of dural ossification include 2 CT findings represented as the "single-layer sign," consisting

TABLE 1: Literature review of surgical treatment for thoracic OPLL* ***(continued)***

Authors & Year	Disease & Surgical Procedure (no. of patients)
Kurosa et al., 1996	OPLL, central part of S-curve
	laminectomy (3)
	laminoplasty (6)
	circumferential decomp (1)
	ant decomp & floating (1)
	ant decomp & floating via manubrium splitting approach (1)
	OPLL, just above apical vertebra
	ant decomp via thoracotomy (9)
	laminectomy (1)
	laminoplasty (1)
	OPLL, combined w/ ossification of ligamentum flavum below apical vertebra
	ant decomp via pst approach (3)
	laminectomy (1)
Kojima et al., 1994	OPLL
	transthoracic anterolat approach (2)
	transsternal approach (1)
Ohtani et al., 1982	OPLL
	ant decomp including partial vertebrectomy (4)
	ant decomp & subtotal vertebrectomy via manubrium splitting approach (1)

* ant = anterior; decomp = decompression; pst = posterior.

of a single homogeneous ossified, focal, uniformly hyperdense OPLL mass, and the "double-layer sign," characterized by anterior and posterior hyperdense ossified rims separated by a centrally hypertrophied, hypodense nonossified posterior longitudinal ligament (more specific for absent dura).[7,18] Min et al.[18] found no statistically significant difference between the double- and single-layer sign group regarding the frequency of dural penetration. Dural defects were present in 60% of patients with a double-layer sign, and in 50% of patients with a single-layer sign.

During evaluation, spinal surgeons perform a detailed history and physical examination. Patients may present with symptoms of lower-extremity numbness, lower-extremity weakness, ambulatory difficulty/gait disturbance, thoracic radiculopathy, urinary retention, bladder and/or bowel incontinence, or myelopathy. Patients may also complain of continuous chest wall or vague back pain. Diagnostic imaging often consists of plain films, myelography, CT scanning, and/or MR imaging. Stenosis can be identified by CT myelography or MR imaging. Computed tomography is helpful to identify the extent of ossification of the ligaments. Surgical outcomes may be assessed using the JOA score for thoracic myelopathy (total of 11 points), which is derived from the JOA scoring system for cervical myelopathy minus the motor and sensory scores for the upper extremity.[15] This scoring system is shown in Table 2. Intraoperative neuromonitoring should be a mainstay of perioperative management.

Items studied during initial evaluation consist of the morphology of the thoracic OPLL, the level of the ossified lesions, the level of maximum ossification, presence of tandem ossification, intramedullary hyperintensity on T2-weighted MR imaging, and the kyphotic angle of the involved thoracic vertebrae. Tandem ossification is important to recognize in patients with myelopathy who plan to undergo surgical intervention for OPLL.[23] Tandem ossification refers to ossification of other spinal ligaments—cervical OPLL or OLF. Park et al.[23] reviewed 68 cases of cervical OPLL and found a frequency of tandem lesions in 23 patients (33.8%)—5 with thoracic OPLL. Patients with symptomatic cervical OPLL frequently had tandem ossification at the upper and mid thoracic spine.[23] Aizawa et al.[1] reviewed a subset of a larger group of 132 patients with thoracic myelopathy. There were 21 patients with OPLL and 10 patients with combined ossification of ligamentum flavum and OPLL. It is often the case that there is ossification of ligamentum flavum with thoracic OPLL.[23,27]

The vascular supply to the thoracic spine is important for the spinal surgeon treating pathology in this region. The midthoracic region is supplied mainly by a single thoracic radicular branch (often from T-7) that is poorly collateralized, making this region more susceptible to the effect of hypotension.[6] The upper thoracic spinal cord is nourished by the blood supply from the cervical vertebral artery and the lumbar artery of Adamkiewicz. There is a concern that since the thoracic cord is in a relative watershed zone of the spinal circulation, the thoracic cord may not recover as well as the cervical cord, even after sufficient decompression.[1] Because of the combination of reduced vascularity and larger occupancy of the spinal canal, the thoracic cord may be subjected more to severe damage by compressive entities.[1,26,34]

Advantages and Disadvantages With Indications and Limitations of Various Surgical Approaches

Surgical decompression is the treatment of choice in cases of compressive myelopathy.[1] The surgical management of thoracic OPLL consists of a multitude of options:

TABLE 2: Evaluation of thoracic myelopathy*

Function	Point Scale
motor in lower extremity	
unable to stand up & walk	0
unable to walk w/o a cane or other support on a level surface	1
walks independently on a level surface, but needs support on stairs	2
capable of fast walking but clumsy	3
normal	4
sensory in lower extremity	
apparent sensory loss	0
minimal sensory loss	1
normal	2
sensory in trunk	
apparent sensory loss	0
minimal sensory loss	1
normal	2
bladder	
urinary retention &/or incontinence	0
sense of retention &/or dribbling &/or thin stream	1
urinary retardation &/or pollakiuria	2
normal	3
total	11

* Based on the JOA scoring system.

posterior decompressive laminectomy, posterior decompressive laminectomy with fusion, anterior decompression through an anterior or lateral approach, anterior decompression through a posterior approach, posterior decompression with fusion followed by anterior or lateral decompression, and laminoplasty.[1,3,4,6,8,9,12,16,20,21,25,28–31,34,36,40] Many studies have highlighted the various approaches, but no protocol, paradigm, or definite standard has been identified.[5,36]

The optimal objective of surgery for OPLL of the thoracic spine is to completely decompress the spinal cord.[4] Although posterior decompression with or without fusion has been reported frequently, the advances in surgical techniques have allowed the possibility of anterior decompression at all levels of the thoracic spine. Furthermore, laminectomy without fusion is often avoided due to risk of worsening neurological status due to the physiological kyphosis of the thoracic spine, and the thoracic spinal cord at the site of compression may be vulnerable to damage from minor trauma due to relative avascularity. Although the thoracic spine is anchored to the rib cage, posterior segmental instrumentation stabilizes the spine and prevents worsening kyphosis after decompression for thoracic OPLL.[16,29,35,36,38] It is thought that posterior stabilization reduces the compressive forces of the OPLL plaque on the spinal cord.[11,16] It also allows for stabilization during anterior decompression.[11]

Anterior decompression for OPLL of the thoracic spine may be accomplished via an anterior (manubrium splitting), posterior (transpedicular, costotransversectomy, or lateral extracavitary), or lateral approach (thoracotomy). The transthoracic extrapleural or transpleural approaches can successfully approach the anterior column via a lateral approach. The combined anterior and posterior approach is an option for treatment of OPLL. Circumferential decompression improves neurological function more efficiently than posterior decompressive laminectomy alone.[27,36] However, this is technically more sophisticated than a posterior decompression.

Matsumoto et al.[15] conducted a multiinstitutional retrospective study involving 34 institutions in which detailed analysis of a survey was performed on patients who underwent surgery for thoracic OPLL. Analysis revealed the following: linear-type OPLL was most frequently treated by laminectomy; beak-type by laminoplasty and anterior decompression and fusion by an anterior approach; continuous waveform type and the continuous cylindrical type by laminoplasty; and mixed type by laminectomy and anterior decompression and fusion through an anterior approach.[15] When the procedures selected for different levels of maximum ossification were assessed, laminoplasty was conducted in 50% of all patients with maximum ossification at the level of T1–4; laminectomy, laminoplasty, and anterior decompression and fusion via anterior approach were conducted at almost the same frequency in patients with maximum ossification at the level of T5–8; and laminectomy was conducted in 52% of all the patients with maximum ossification at the level of T9–12. There was no statistically significant difference in the surgical outcomes among patients treated by different surgical methods.[15] Kurosa et al.[13] thought that that posterior or anterior decompression for the S-curve location OPLL is effective; an anterior approach regardless of the kyphosis is effective for the above apical vertebra OPLL; and a transthoracic anterior decompression is the best for the below apical vertebra OPLL.

Min et al.[17] reviewed 19 patients who underwent anterior decompression for thoracic OPLL and found a significant percentage did not improve clinically and that the nature of the procedure is fraught with a high complication rate (42.1% overall). Results of surgery from thoracic OPLL causing myelopathy are not as satisfactory compared with those for cervical OPLL.[20,40] Reported rates of postoperative neurological deterioration in patients undergoing anterior decompression range from 2.7% to 18.8%.[4,13,17,36]

Surgical complications can range from early to late. The most important perioperative complications noted by spine surgeons include neurological deterioration, infection, epidural hematoma, and CSF leak. Other complications can result that are similar for all surgical procedures. The true etiology of early neurological deterioration has not been fully elucidated.

Laminectomy and Laminoplasty

Posterior decompression of the spinal cord in the thoracic spine can be achieved by laminectomy with or without fusion or laminoplasty. Favorable surgical outcomes can be seen with laminoplasty for lesions with maximum ossification at the upper thoracic spine.[15] The use of instrumentation should be considered with posterior decompression for thoracic OPLL in the middle and lower thoracic spine.[15] This is due to the presence of physiological kyphosis in the thoracic spine, which can lead to unfavorable outcomes for decompression alone. The spinal cord will have limited shift backward with decompression alone due to the kyphosis in the thoracic spine.[1] The spinal cord is more vulnerable at the site of compression due to the relative avascularity of the thoracic spine by being in a watershed zone of spinal circulation.[16,17] Adherence of an ossified ligament to the ventral aspect of the dura makes direct removal difficult and risks spinal cord injury during decompression maneuvers.[14,27] Yamazaki et al.[35] reported a case of postoperative paraparesis after laminectomy that was reversed after posterior instrumented segmental fusion for a case of thoracic myelopathy due to combined OPLL and OLF. The Cobb angle was unchanged between preoperative and postoperative studies.

Tokuhashi et al.[29] described measuring the ossification-kyphosis angle in the thoracic spine as a predictor to neurological outcome. This represents the angle of kyphosis from the posterosuperior margin at the cranial vertebral body of the decompression site, and from the posteroinferior margin of the caudal vertebral body of the decompression site to the prominence of the maximum OPLL.[29] There were no patients with postoperative deleterious paralysis with echo-free space seen between the OPLL mass and the spinal cord on intraoperative ultrasonography.[29] The ossification-kyphosis angle most reflected the presence of echo-free space on ultrasonography.[29] A 23° ossification kyphosis angle is thought to be the critical point for presence of echo-free space and effective posterior decompression. Thus, if the ossification-kyphosis angle is more than 23° on the sagittal view of an MR image, surgical options should be explored other than posterior decompression alone.[29] In the 4 patients with posterior decompression, the ossification-kyphosis angle progressed by an average of 4.0°, and in the 11 patients with posterior decompression with fusion, the ossification-kyphosis angle changed by an average of 0.04°.[29]

Yamazaki et al.[37] performed intraoperative ultrasonography in 24 patients treated with decompression and fusion showed no subarachnoid space between the OPLL and the cord. Although there was persistent impingement of the spinal cord from the anterior direction after decompression, all patients showed neurological recovery after surgical treatment.[37] Posterior instrumented fusion has some positive effect on myelopathy after laminectomy for thoracic OPLL.[37] Also, posterior instrumented fusion and suppression of spinal column mobility was more powerful than correction of kyphosis for producing neurological recovery after posterior decompression and fusion.[37]

Tsuzuki et al.[34] evaluated the extent of posterior shift of the spinal cord after extensive cervicothoracic laminoplastic decompression. If patients were without OPLL-spinal cord separation (signifying lack of anterior decompression of the spinal cord from the OPLL), additional procedures including posterior longitudinal durotomy and others to eliminate the axial inhibiting factors were performed. Complication after cervical decompressive laminoplasty included loss of range of motion of the cervical spine by 10%–30% in all patients.[34] Although CSF leakage was noted to be self-limiting in this series, it took a minimum of 3 months to resolve.[34]

Cervicothoracic or Sternotomy Approach

The spinal curvature at the cervicothoracic junction is usually lordotic or only slightly kyphotic, thereby making laminoplasty and posterior decompression of the spinal cord relatively safe.[15] However, anterior approaches to the cervicothoracic junction have been described in detail.[20] It is believed that the transsternal approach is successful to access lesions at the upper 3 thoracic vertebrae.[12] Ohtani et al.[20] thought that an anterior approach to the upper thoracic spine through partial median sternotomy and dividing the manubrium is effective and allows for direct decompression of OPLL.

Transthoracic Approach

Anterior approaches to the middle and lower thoracic spine can be performed thorough transpleural or transthoracic extrapleural dissection. However, these anterior decompression approaches have a relatively high rate of postoperative complications.[18,36] Anticipation of dural ossification and dural penetration by the OPLL mass is important in avoiding CSF leakage and accidental damage to the spinal cord or nerve roots in planning anterior procedures to treat this condition.[18] Kojima et al.[12] thought that the transthoracic anterolateral approach is effective for extensive OPLL involving more than 2 thoracic vertebral bodies below T-4. Ohtani et al.[20] agreed that an anterior approach through thoracotomy for pathology below T-4 is optimal. Anterior decompression is ideal for spinal cord recovery to treat thoracic myelopathy caused by OPLL on the concave side of the spine.[11] It is the optimal procedure for the best chance of recovery from thoracic myelopathy.[4,10,11,30,31,41] However, anterior decompression and interbody fusion through thoracotomy was less than satisfactory when performed as rescue surgery in patients with thoracic OPLL whose myelopathy worsened after laminectomy.[20,35]

Many authors advocate a circumspinal approach for complete decompression. However, there is always the potential that removal of the OPLL off the anterior cord might result in spinal cord injury during surgery. Extensive involvement of the thoracic spine with OPLL and consideration of circumferential decompression should be closely analyzed by the spine surgeon. Involvement of the dura mater in OPLL is an important issue as leakage of CSF through the resected portion of the dura is a common complication encountered during surgery. Tomita et al.[31] described staged circumspinal decompression consisting of a posterior or lateral decompression followed by anterior decompression via thoracotomy for middle or lower thoracic spine. They recommended drilling a deep gutter bilaterally into the vertebral body after extended laminectomy from a posterior approach, followed by thoracotomy for anterior decompression which features partial vertebrectomy, removal of OPLL, and anterior interbody fusion. Kawahara et al.[11] highlighted 13 of 15 patients who underwent a 2-staged posterior decompression and stabilization followed by the anterior decompression via thoracotomy and interbody fusion.

Lateral Extracavitary, Costotransversectomy, and Transpedicular Approaches

Removal of the OPLL may be the most effective method of relieving pressure off the spinal cord in patients with thoracic myelopathy caused by OPLL.[4,10,39] Factors affecting surgical outcome from an anterior approach in the thoracic spine include the following: duration and severity of myelopathy; extent of anterior decompression; combined procedure for cervical OPLL and/or ossified ligamentum flavum; and type of OPLL.[1] The use of the anterior decompression via a posterior corridor includes the transpedicular, costotransversectomy, and lateral extracavitary approaches. Tomita et al.[31] advocated the use of a posterior decompression via extensive laminectomy followed by costotransversectomy for upper thoracic spine. Takahata et al.[27] performed a retrospective analysis in patients receiving circumferential decompression through a posterior approach for thoracic OPLL between 1992 and 2003. Surgical complications included dural tear, deep infection, and postoperative neurological deterioration. Further analysis demonstrated that more than 5 levels for circumferential decompression was associated with unfavorable surgical outcomes.[27] At final follow-up, 20 of 30 patients recovered or had improved ambulatory function with or without assistive devices.[27] Matsuyama et al.[16] reviewed 21 patients (10 men and 11 women; mean age 54 years) with thoracic OPLL who underwent surgical treatment between 1985 and 2000. They found a lower mean operative time and blood loss in patients who received anterior decompression via a posterior approach compared with anterior decompression with fusion for both flat-type and beak-type OPLL.[16]

Minimally Invasive Approaches (Direct Lateral Interbody Fusion, Minimally Invasive Posterior Decompression With or Without Fusion)

Some authors have tried to prevent postoperative or postlaminectomy kyphosis by laminoplasty or fusion anchored by segmental instrumentation.[16,29] Posterior decompression without fusion or anterior decompression from a posterior approach without posterior fusion increases risk of kyphotic deformity. These procedures do not address the OPLL plaque. Minimally invasive posterior decompression with or without fusion preserves the posterior tension band. In addition, recent advances in technology have allowed for the direct lateral approach to be used in the lower thoracic spine.

Case Illustrations

Institutional review board approval was obtained to review all patients undergoing operative intervention for thoracic myelopathy caused by OPLL.

Case 1

This 60-year-old woman had a history of stroke, diabetes mellitus, and hypertension and presented with bilateral lower-extremity weakness and ambulatory difficulty. She had been transferred from an outside facility to our institution for formal evaluation. On examination, she had evidence of bilateral lower-extremity weakness and upgoing toes. The patient had trouble with ambulation, including a fall, thought to be caused by myelopathy. The patient also complained of mild back pain without a radicular component. Magnetic resonance imaging revealed multilevel areas of central stenosis with evidence of cord signal change. Computed tomography scanning demonstrated multiple levels of OPLL involving the upper and midtho-

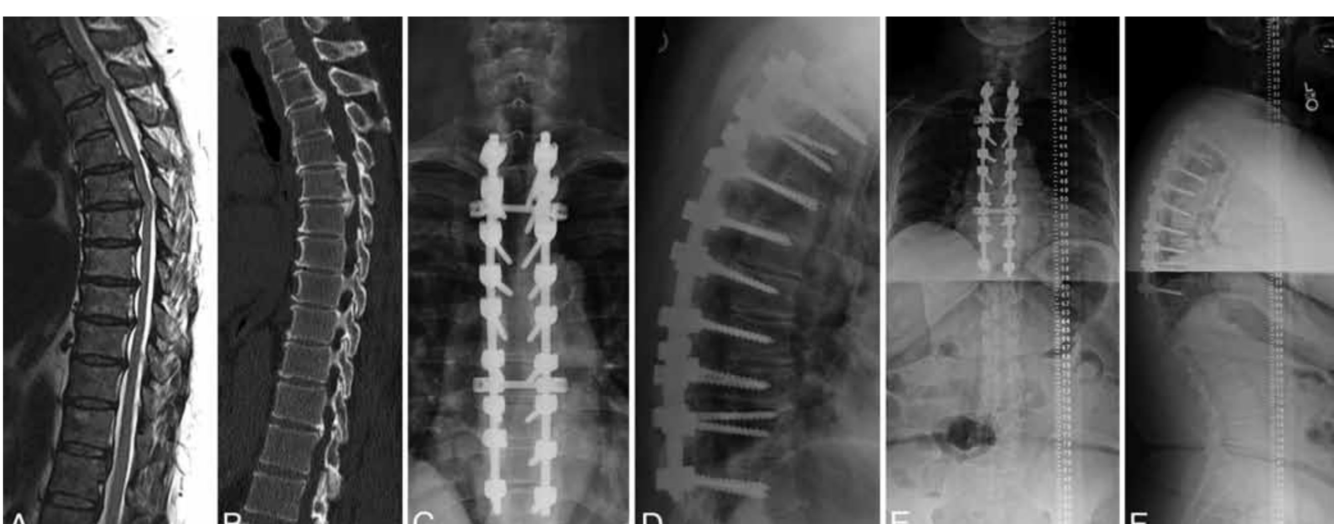

Fig. 1. **A:** Preoperative T2-weighted sagittal MR image of the thoracic spine demonstrating stenosis of the spinal cord by OPLL. **B:** Preoperative sagittal CT scan of the thoracic spine demonstrating areas of spinal cord compression by calcified masses representing OPLL. **C:** Postoperative anteroposterior plain radiograph demonstrating posterior segmental instrumentation following surgical decompression. **D:** Postoperative lateral plain radiograph depicting segmental instrumentation and decompression for OPLL. **E:** Postoperative 14 × 36-in anteroposterior plain radiograph demonstrating postsurgical instrumentation. The entire cervical, thoracic, and lumbar spines can be seen in this study. **F:** Postoperative 14 × 36-in lateral plain radiograph depicting postoperative segmental instrumentation for thoracic OPLL.

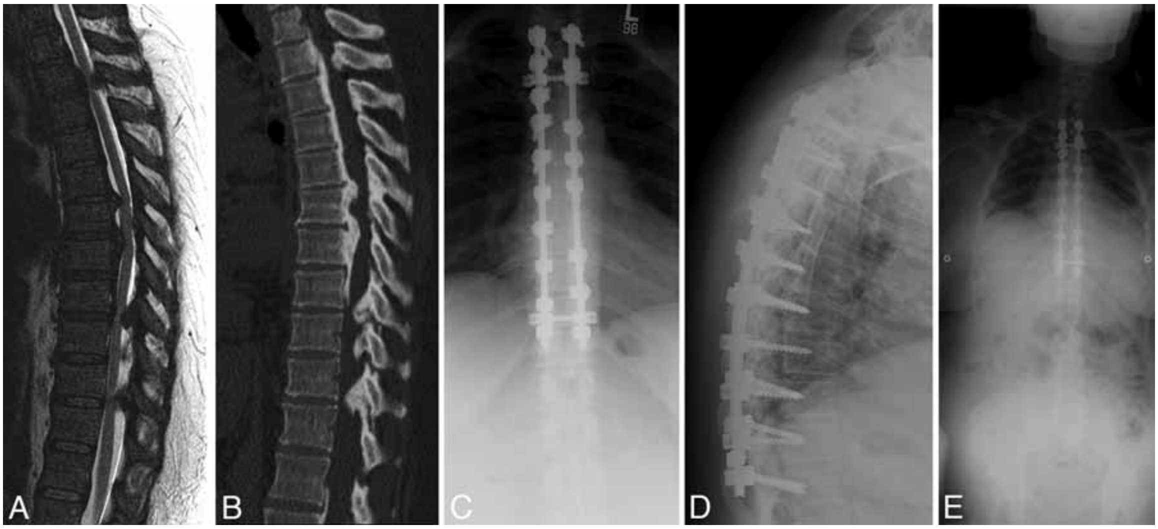

Fig. 2. **A:** Preoperative sagittal T2-weighted MR image of the thoracic spine demonstrating multiple areas of cord compression. **B:** Preoperative noncontrast sagittal CT scan of the thoracic spine showing extensive thoracic cord compression caused by OPLL. **C:** Postoperative anteroposterior plain radiograph showing extensive segmental instrumentation following posterior decompression and fusion. **D:** Postoperative lateral radiograph depicting decompression and segmental instrumentation for treatment of OPLL. **E:** Postoperative 14 × 36-in anteroposterior plain radiograph demonstrating segmental posterior instrumentation. The cervical, thoracic, and lumbar spines can be appreciated in this particular study.

racic spine. The patient was taken to the operating room for T3–9 laminectomy with T2–10 posterior spinal fusion and segmental instrumentation. Postoperatively, the patient did well and maintained stable strength in her lower extremities. The patient was discharged to a rehabilitation center in stable condition 9 days postoperatively (Fig. 1).

Case 2

This 43-year-old woman presented with ambulatory difficulty, back pain, and numbness in her thighs and legs. Additionally, she had evidence of bladder and bowel incontinence. On examination, she had proximal lower-extremity weakness and decreased sensation to light touch and pin prick in the T-11 to L-1 distributions. Magnetic resonance imaging revealed compression of the cord at the upper, middle, and lower thoracic levels with cord signal change. Computed tomography demonstrated that stenosis was related to OPLL at multiple levels. The decision was made to take the patient to the operation room as her symptoms were getting progressively worse. The patient underwent T2–10 decompressive laminectomies with T2–11 posterior spinal fusion and segmental instrumentation in 2 stages. The patient was sent to a rehabilitation facility in stable condition. She required an inferior vena cava filter for development of deep venous thrombosis (Fig. 2).

Conclusions

Thoracic OPLL can present radiographically with complex morphology. The safety of the spinal cord should be at the forefront in deciding the surgical approach for decompression. The ultimate goal provides a subarachnoid space around the spinal cord at the level of OPLL and improvement in the patient's neurological condition. Although there is much debate regarding the approach for decompression, ultimately, each case is different. Regardless of whether an anterior or posterior approach is performed, the main goals every spinal surgeon attempts to achieve are adequate decompression and maintenance or restoration of stabilization in the hopes of improving long-term neurological outcome.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: McClendon. Acquisition of data: Ganju. Analysis and interpretation of data: Sugrue. Drafting the article: McClendon, Sugrue, Ganju. Critically revising the article: McClendon, Ganju, Koski, Liu. Reviewed final version of the manuscript and approved it for submission: Ganju, Koski, Liu.

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Manuscript submitted November 16, 2010.
Accepted December 14, 2010.
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Abstracts of the 2011 Meeting of the AANS/CNS Section on Disorders of the Spine and Peripheral Nerves March 2011

(DOI: 10.3171/2011.2.FOC-SpinePeriphSectionabstracts)

Oral Presentations

100. In Situ Placement of High-Dose rhBMP-2 within Spine Tumors Slows Tumor Growth and Decreases Onset to Paralysis in a Rat Model of Metastatic Breast Cancer

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Introduction: Recombinant human bone morphogenic proteins (rhBMPs) are FDA-approved for specific spinal fusion procedures, but use is contraindicated in spine tumor resection beds due to unclear interaction between tumor tissue and such growth factors. Interestingly, a number of studies suggest that BMPs may slow growth of adenocarcinomas in vitro, and adenocarcinomas represent the majority of histopathologies found in bony spine tumors. In this study, we hypothesized that high concentration rhBMP-2 placed in an intraosseous spine tumor rat model could show tumor suppression and prolong onset to paralysis in such animals.

Methods: 21 female nude athymic rats were randomized into three groups. Group 1 (n=7) underwent transperitoneal exposure and implantation of breast adenocarcinoma (CRL-1666) into the L6 lumbar spine segment, followed by implantation of 15 micrograms of rhBMP-2. Group 2 (n=7) underwent exposure and tumor implantation on the lumbar spine, but no local treatment with rhBMP-2. Group 3 (n=7) solely underwent exposure of the lumbar spine. The Basso-Beattie-Bresnahan (BBB) scale was used to monitor daily motor function regression and time to paresis (BBB score< 7).

Results: No animals in Group 1 were paretic by day 15 (median BBB score of 20, p=<0.0027). All animals in Group 2 were paretic by day 15 (median BBB score of 0, p=0.0024) with a mean time to paresis (±SD) of 13.5±1.4 days. Time to paresis was significantly different between Group 1 and Group 2 (p<0.001). Group 3 (control) exhibited no neurological motor deficit. Gross and microscopic tumor volume was also significantly (p<0.048) different between Groups 1 and 2.

Conclusion: This study shows that high-dose administration of local rhBMP-2 in a rat spine tumor model of breast cancer not only fails to stimulate local tumor growth, but also decreases local tumor growth and onset of paresis in animals. This is the first preclinical experiment showing that local placement of rhBMP-2 in a spine tumor bed may slow tumor progression and delay associated neurological decline.

101. The Effect of Surgery on Health Related Quality of Life and Functional Outcome in Patients with Metastatic Epidural Spinal Cord Compression: Initial Results of the AOSpine North America Prospective Multicenter Study

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Introduction: Metastatic epidural spinal cord compression (MESCC) is common and recent studies have provided evidence that in selected patients combined surgery and radiotherapy provides the optimal neurological recovery. However, patients with MESCC have relatively short life-expectancy and face numerous challenges. Hence, the impact of surgery on improving quality of life outcomes in the setting of MESCC is less clear.

Methods: 72 surgical patients were enrolled in a prospective multi-center, cohort study involving 8 sites in North America. Outcomes were assessed using the pain assessments, ASIA scale, SF-36v2, and EQ-5D.

Results: Average age was 58 years (SD 11), 65% were males. Common primary sites were lungs (32%), prostate (15%), breast (11%), and kidney (11%). The baseline EQ5D was .38; SF36PCS 32; SF36MCS 39, VAS Pain 6.1; ASIA Impairment grade at baseline was 35% (E), 45% (D), 14% (C), 3% (B) and 3% (A). Median survival was 157 days; 93% survived one month; 62% survived 3 months, 41% survived 9 months, 32% survived 12 months. Among the surviving patients, the average improvement at 3 month was for .23 for EQ5D (P< .001), 26 for ODI (P < .001) , 2.6 for VAS Pain (P < .05). Also, there was a significant improvement in ASIA Impairment grade (P < .05). There was no significant change in SF36 PCS and MCS. The gains in EQ5D, ODI and VAS Pain were maintained in patients who survived 6 months.

Conclusion: Surgically treated patients with MESCC have poor survival. Among the surviving patients, the surgical treatment is associated with improvement in symptoms and functional outcomes. However, this does not translate into significant gains in overall health related quality of life. Individuals with less than three month life expectancy may be less than ideal candidates for surgical intervention. Further follow-up and a larger sample size in this ongoing study will help to identify subgroups of patients who may benefit from the surgical intervention.

102. Survival of Patients with Malignant Primary Osseous Spinal Neoplasms from the Surveillance, Epidemiology, and End Results (SEER) Database from 1973-2005

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Introduction: Malignant primary osseous spinal neoplasms are aggressive tumors which remain associated with poor outcomes. To date, prognosis is based upon small single center series. In order to assess national trends in histology-specific survival, we reviewed survival data spanning 30 years from the surveillance, epidemiology, and end results (SEER) registry.

Methods: The SEER registry (1973-2003) was queried to identify primary spinal chordoma, chondrosarcoma, osteosarcoma, or Ewing's sarcoma via ICD-O-2 coding. Survival was assessed via Cox proportional-hazards regression analysis.

Results: 1,892 patients were identified with primary osseous spinal neoplasms (414 chordoma, 579 chondrosarcoma, 430 osteosarcoma, 469 Ewing's sarcoma). Chordomas presented in older (59±17, $p<0.01$) and Ewing's Sarcoma in younger (19±11, $p<0.01$) patients versus other tumors. The incidence of each tumor type remained similar per decade. African Americans comprised a significantly greater proportion of osteosarcoma than other tumors (9.6 vs. 3.5%, $p<0.01$). Mobile spine versus sacrum was more often location for chordomas than other tumors (47% vs. 23%, $p<0.05$). Osteosarcoma and Ewing's Sarcoma were 3-fold more likely to present with metastasis (31% vs. 8%). Surgical resection was performed more frequently for chordoma (88%) and chondrosarcoma (88%) than osteosarcoma (61%) and Ewing's (53%). Median survival was histology specific (Osteosarcoma: 11mo, Ewing's: 26mo, chondrosarcoma: 37mo; chordoma: 50mo) Survival was worse in patients with metastasis at presentation, Figure1, but unaffected by site (mobile spine versus sacrum/pelvis)Figure2. More recent year of diagnosis was associated with greater utilization of surgery (OR1.23, $p<0.001$) and improved survival for isolated spinal Ewing's sarcoma (HR, 0.95, p=0.001), chondrosarcoma (HR, 0.98, p=0.009), and chordoma (HR, 0.98, p=0.10) but was not associated with increased utilization of surgery (OR, 1.01, p=0.43) or survival for osteosarcoma, Figure3.

Conclusion: In our analysis of a 30-year U.S. population based cancer registry (SEER), we provide nationally representative prognosis and survival data for malignant primary spinal osseous neoplasm. Use of surgery and overall survival has improved for isolated spine tumors with advancements in care over the past four decades. These results may be helpful in providing historical controls for understanding the efficacy of new treatment paradigms patient education and guiding level of aggressiveness in treatment strategies.

103. Electrical Stimulation Enhances Axon and Nerve Regeneration

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Introduction: Axon regeneration after peripheral nerve injury is delayed and incomplete. Brief low frequency electrical stimulation (ES) applied immediately after injury is known to improve axonal regeneration. With these findings, we aimed to explore several new features of this interesting property.

Methods: We examined early axon and Schwann cell (SC) outgrowth beyond transection sciatic nerve injuries in mice comparing sham ES to brief ES (3V, 20Hz, and pulse width 0.1 ms for 1 hr) delivered only at the time of injury. In a second approach to examine early axon outgrowth, an identical protocol was examined using harvested adult rat sensory neurons in vitro stimulated over a novel microelectrode array construct.

Results: We identified accelerated outgrowth beyond the repair site of both axons and SCs following ES. These early benefits translated into an ongoing impact of ES on regeneration. There was enhanced myelinated axon repopulation by 21 days across transection sites, with higher numbers of retrogradely labelled motor neurons regenerating their axons. In thy-1 GFP mice with fluorescent peripheral axons, we confirmed the early impact on outgrowth and identified earlier arrival of GFP cutaneous axons in peripheral sensory targets. This was strongly correlated with more rapid recovery of mechanical and thermal sensation in the foot and of compound muscle action potentials beyond the injury site. The in vitro paradigm identified robust immediate rises in neurite initiation of the stimulated neurons and improved outgrowth as compared to control conditions.

Conclusion: These data support the robust role of brief ES following peripheral nerve trunk injuries in promoting axon initiation and outgrowth after transection, in axon maturation and in repopulation of targets. This is a wider repertoire of impact than previously known and its replication in vitro supports the hypothesis that a neuron specific reprogrammed injury response is recruited by the ES protocol.

104. Efficacy and Active Ingredients in an Epidural Analgesic Paste after Lumbar Decompression: A Prospective Randomized Double-Blind Controlled Trial

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Introduction: The purpose of this study was to evaluate the efficacy and active components of a previously described epidural analgesic paste in controlling post-operative pain and facilitating early discharge from hospital after lumbar decompressive surgery.

Methods: A prospective randomized double-blind controlled trial was conducted. Two-hundred and one patients were randomized to one of four analgesic epidural pastes at the time of lumbar spinal surgery: combo paste (morphine + methylprednisolone), steroid paste (methylprednisolone alone), morphine paste (morphine alone), and placebo. The primary outcome measures used were narcotic and non-narcotic use and McGill Pain Questionnaire (MPQ). Secondary outcome measures were: modified ASIA score, SF-36, time to ambulation and discharge from hospital.

Results: Administration of combo and steroid paste, but not morphine paste resulted in a statistically significant reduction in mean PRI and PPI components of the MPQ in the first 3 days after surgery. Narcotic analgesic consumption was reduced on post-operative day 1 in the combo paste and steroid paste groups. No difference in time to ambulation or discharge, general health perception, ABPI scores, or neurological recovery was observed.

Conclusion: We have demonstrated the efficacy of epidural analgesic paste containing methylprednisolone acetate to produce a robust post-operative analgesic effect. This paste should be considered for use in patients undergoing routine lumbar decompressive surgery.

105. Radiographic Same-Level Recurrent Disc Herniation After Lumbar Discectomy: Prospective Longitudinal Study With Two-Year Follow-Up

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Introduction: To date, the incidence of radiographic same-level recurrent disc herniation has not been studied prospectively with sequential imaging. Furthermore, the clinical relevance of radiographic recurrent disc herniation on MRI after discectomy remains unknown, particularly in patients without symptoms or with poorly localized pain after surgery. We previously reported factors associated with symptomatic same-level recurrent disc herniation from this cohort. In a post-hoc analysis, we set out to determine the incidence of asymptomatic same-level recurrent disc herniation and assess their effect on two-year outcome.

Methods: One hundred and eight patients undergoing lumbar discectomy for a single-level herniated disc at five institutions were prospectively followed for two years. CT and MRI of the lumbar spine were obtained every three months to assess re-herniation and disc height loss. Leg and back pain visual analogue scale (VAS), Oswestry Disability Index (ODI), and quality of life (SF-36 physical component) were assessed 3, 6, 12, and 24 months after surgery.

Results: No patients demonstrated residual disc on post-operative MRI. By two years after discectomy, 25 (23.1%) patients had demonstrated radiographic evidence of recurrent disc herniation at the level of prior discectomy (mean 11.8 ± 8.3 months after surgery), the majority of which were asymptomatic [14 (13%)] patients. The occurrence of asymptomatic re-herniation was not associated with disc height loss or any outcome measure (VAS, ODI, SF-36) by two years.

Conclusion: In a prospective cohort study with serial imaging, nearly one-fourth of patients undergoing lumbar discectomy demonstrated radiographic abnormality suggestive of recurrent disc herniation at the level of prior surgery, the majority of which were asymptomatic. Asymptomatic disc herniation was not associated with clinical consequences by two years. Clinically silent recurrent disc herniation is not uncommon after lumbar discectomy. When obtaining MRI evaluation within the first two years of discectomy, providers should expect that radiographic evidence of re-herniation may be encountered and that treatment should only be considered when correlating radicular symptoms exist.

106. Cost Effectiveness of Multilevel Hemilaminectomy for Lumbar Stenosis Associated Radiculopathy

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Introduction: Laminectomy for lumbar stenosis associated radiculopathy is associated with improvement in pain, disability, and quality of life. However, given rising healthcare costs, attention has been turned to question the cost-effectiveness of lumbar decompressive procedures. The cost-effectiveness of multilevel hemi-laminectomy for radiculopathy remains unclear. We set out to assess the comprehensive medical and societal costs of multi-level laminectomy at our institution and determine its cost-effectiveness in the treatment of degenerative lumbar stenosis.

Methods: Fifty-four consecutive patients undergoing multilevel hemi-laminectomy for lumbar stenosis associated radiculopathy after 6 months of conservative therapy were included. Over a two-year period, total back-related medical resource utilization, missed work, and improvement in pain (VAS-LP), disability (Oswestry Disability Index (ODI), quality of life (SF-12), and health-state values [quality adjusted life years (QALYs), calculated from EQ-5D with U.S. valuation] were assessed. Two-year resource use was multiplied by unit costs based on Medicare national allowable payment amounts (direct cost) and patient and care-giver work-day losses were multiplied by the self-reported gross-of-tax wage rate (indirect cost). Mean total two-year cost per QALY gained after TLIF was assessed.

Results: Compared to pre-operative health states reported after at least 6 months of medical management, a significant improvement in VAS-BP, ODI, and SF-12 (physical and mental components) was observed two years after laminectomy, with a mean two-year gain of 0.72 QALYs, Figure 1. Mean ±SD total two-year cost of multilevel hemilaminectomy was $23,477 ±9,912 (Surgery cost: $10,220 ±100; Outpatient resource utilization cost: $2,805 ±1,958; Indirect cost: $10,452 ±9,364). Multilevel hemilaminectomy was associated with a mean two-year cost per QALY gained of $32,606.

Conclusion: Multilevel hemilaminectomy improved pain, disability, and quality of life in patients with lumbar stenosis-associated radiculoapthy. Total cost per QALY gained with multi-level laminectomy was $32,606 when evaluated two years after surgery with Medicare fees, suggesting that multilevel hemilaminectomy is a cost effective treatment of lumbar radiculopathy.

107. Provocative Discography Screening Improves Surgical Outcome

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Introduction: The objective of the study was comparison of surgical outcomes of patients operated on without discography and patients that underwent discography.

Methods: Study was designed as a randomized controlled trial. According to power analysis study comprised 310 patients divided in the experimental (No=207) and the control (No=103) group. Inclusion criteria were low back pain resistant to the nonsurgical treatment for more than 6 months and conventional radiological findings showing degenerative changes without clear generator of the pain. Exclusion criteria were red flags. Before discography patients filled in Oswestry Disability Index (ODI), SFPF36, Zung and MSPGQ Questioners. At 1-year follow-up examination patients filled in ODI, SFPF36, Likert scale which analyzing satisfaction with procedure and answer to the question would he/she repeat discography if it would be necessary.

Results: With independent t-test group without discography preoperative had ODI P 0.002 between patients with DDD and other generator of the pain while the postoperative had P 0.433. Preoperative SFPF had P 0.001 but postoperative P were 0.360. VAS preoperative had P 0.953 and postoperative 0.003. In a group with discography ODI and SFPF preoperative and postoperative had P<0.001. VAS preoperative had P 0.306 and postoperative <0.001. With dependent t-test in both groups with/without discography ODI, SFPF and VAS preoperative and postoperative had P <0.001.

Conclusion: DDD treated surgically without discography didn't reach clinically significant improvement of 15 ODI points as recommended by FDA for the patients treated with fusion. Provocative discography screening with psychological testing in the trial group made improvement following fusion clinically significant. For other degenerative generators of the pain discography didn't prove useful diagnostic tool. As there were no post discography spondilodiscitis and patients are willing to repeat procedure if it would be necessary, our results suggest discography use in preoperative workout of patients with DDD.

108. The Impact of Surgeon Professional Fees to the National Cost of Healthcare

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Introduction: With the increased attention given to the large amount of national funds supporting health care in the United States, there have been significant changes in the reimbursement system for surgical procedures by the federal government. In efforts to decrease overall spending, individual surgeons have seen yearly reimbursement cuts. In this study, we reviewed the charges and reimbursements at a major academic institution for lumbar laminectomy and compared the amounts reimbursed to the hospital and to the surgeon.

Methods: The reimbursement schedule of an academic spine surgeon was collected over twelve months for lumbar laminectomy procedures. Bills and collections by the hospital and professional fees of the surgeon were obtained for comparative analysis.

Results: During a twelve-month period, patients underwent a lumbar laminectomy involving on average 3 levels and stayed in the hospital on average 2.3 days. Complications were uncommon (13%). Average professional-fee billing for the surgeon was $8,200.00 and collection was $1,647.79 (24% for private and 18% for Medicare/Medicaid insurance). Average hospital billing for the inpatient hospital stay minus professional fees from the surgeon was $19,348 and average collection on such bills was $17,758 (92% for Private and 89% for Medicare/Medicaid insurance). Percentage of total costs for such procedures that was allocated to surgeon reimbursement was 12% for private and 7% for Medicare/Medicaid insurance.

Conclusion: Current strategies for containing rising health care costs include decreasing physician reimbursement; unfortunately, overall health care costs continue to rise. Based on this analysis, the proportion of overall costs allocated to professional fees for surgical procedures is small, while those allocated to hospital costs, which includes hospital stay, drugs, implants, imaging, and rehabilitation, etc., are far greater. Findings suggest that the current focus on decreasing physician reimbursement as the principal cost saving strategy will lead to minimal reimbursement for surgeons without substantial drop in the overall cost of national healthcare.

109. Effect of Patient Pain Expectations and Preoperative SF-36 Mental Component Summary Scores on Clinical Outcomes Following Anterior Cervical Discectomy and Fusion

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Introduction: The primary purpose of this study was to analyze if preoperative patient expectations and SF-36 MCS scores have any effect on clinical outcomes.

Methods: A prospective clinical study was performed. This study included 79 (38 males, 41 females) patients who underwent one- to three-level ACDF surgery. Preoperatively, patients were asked to rate their expected pain after surgery and complete VAS neck/arm (0-10), NDI and SF-36 PCS/MCS scales. Patients were divided into two groups for the expectation analyses: complete resolution of pain (n=44) and some pain expected (n=35) postoperatively. The above clinical parameters and patient satisfaction with results scores were measured postoperatively. The mean follow up was 38.8 months (range, 7-59).

Results: Overall, all postoperative measures depicted significant improvement (Table 1). Patient demographics and clinical parameters were comparable preoperatively between the expectation groups (Table 2, 3). Controlling for respective preoperative scores, patients who expected no pain reported lower postoperative neck/arm pain ($p<0.02$), higher SF-36 MCS ($p=0.04$) and higher satisfaction with results ($p=0.007$) scores, although no significant differences were detected in postoperative NDI or SF-36 PCS scores compared with patients that expected some pain. Furthermore, controlling for respective preoperative scores, higher preoperative SF-36 MCS scores significantly predicted lower postoperative neck pain ($p=0.003$) and NDI ($p=0.004$) scores, and higher postoperative SF-36 PCS ($p=0.002$), SF-36 MCS ($p=0.001$) and satisfaction ($p=0.03$) scores.

Conclusion: Patients who expected no pain postoperatively reported better postoperative scores on the more subjective outcome measures (VAS arm and neck, satisfaction with results), as well as the SF-36 mental component score. Patients with higher preoperative mental component scores had better clinical outcomes (VAS neck, NDI, SF-36 PCS/MCS, satisfaction with results). The results suggest that optimism in patients' expectations as well as other potential psychological factors predict improved clinical outcomes and patient satisfaction.

110. Factors Associated with the Occurrence of Perioperative Complications in the Treatment of Cervical Spondylotic Myelopathy Based on 302 Patients from the AOSpine North America Cervical Spondylotic Myelopathy Study

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Introduction: Surgery is often warranted for cervical spondylotic myelopathy (CSM). Our objective was to assess for clinical and surgical factors associated with the occurrence of complications in the surgical treatment of CSM based on a prospective multicenter study.

Methods: The AOSpine North America CSM study is a recently completed prospective multicenter study of patients surgically treated for CSM. Rates of perioperative complications (within 30 days of surgery) were assessed and stratified based on clinical and surgical factors.

Results: 302 patients were enrolled (mean age: 57 years, range: 29-86). Of 332 reported adverse events, 73 were adjudicated to be complications, including 25 major (8%) and 48 minor (16%). Of patients treated with anterior-only (n=176), posterior-only (n=107), and combined anterior-posterior procedures (n=19), 11%, 19%, and 37%, respectively, had one or more complications ($p=0.008$). Procedures including a posterior approach had a significantly higher rate of infection (6.3% vs 0.6%, $p=0.005$). Dysphagia was significantly more common with anterior-only (2.3%) or combined anterior-posterior (21.1%) procedures, compared with posterior-only procedures (0.9%, $p<0.001$). C5 radiculopathy/palsy was not significantly associated with surgical approach ($p=0.8$). Occurrence of complications was significantly associated with increased operative time ($p<0.001$), increased blood loss ($p<0.001$), and inclusion of a fusion ($p=0.01$), but not with age ($p=0.9$), body-mass index (BMI, $p=0.7$), smoking ($p=0.3$), prior surgery ($p=0.09$), or number of operated vertebrae ($p=0.9$).

Conclusion: For the surgical treatment of CSM, operative factors, including surgical approach, operative time and blood loss, have stronger associations with the occurrence of perioperative complications than do patient factors, such as age, BMI, and smoking.

111. Comparative Economic Analysis of Ventral versus Dorsal Surgery for Cervical Spondylotic Myelopathy

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Introduction: The objective of this study was to determine the optimal surgical approach (ventral versus dorsal) for patients with 3-4 levels of stenosis resulting in cervical spondylotic myelopathy (CSM).

Methods: A prospective, non-randomized, 8-center trial was conducted. Patients aged 40-79 years with 3-4 levels of degenerative cervical spondylosis resulting in CSM were enrolled. Four outcome assessments (SF-36, Oswestry Neck Disability Index (NDI), mJOA, EuroQol-5D) were obtained pre-operatively and post-operatively at 6 months and 1 year. A hospital-based economic analysis used costs derived from total hospital charges and year-specific cost-to-charge ratios.

Results: This study enrolled fifty-six patients (mean age – 62 years; gender – 57% male). Ventral decompression and fusion (VF) was performed on twenty-five patients, dorsal laminectomy with fusion (DF) on twenty-four, and dorsal laminectomy without fusion (L) on nine. One-year follow-up data was available on 73% of the cohort. Baseline demographics and outcome assessments were comparable at baseline. DF patients had significantly longer lengths of stay than VF (4.4 days versus 3.1 days, P=0.03). VF patients showed significant 1-year improvements for each of the four outcome measures and DF patients showed significant improvement in the mJOA. VF patients showed larger 1-year improvements than DF in 3 of the 4 assessments (Figure 1). Thirteen VF, seventeen DF, and five L patients were included in the cost analysis (Figure 2). VF was clearly cost-effective when compared to DF.

Conclusion: Of the 3 surgical strategies, ventral decompression with fusion resulted in the most significant 1-year functional improvement when treating 3-4 levels of spondylosis. In addition, ventral decompression with fusion is a cost-effective treatment option for CSM when compared to dorsal laminectomy both with and without fusion.

112. Functional and Quality of Life Outcomes in Geriatric Patients with Type II Odontoid Fracture: One-Year Results from the AOSpine North America Multi-Center GOF Prospective Study

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Introduction: Odontoid fractures commonly occur in the elderly and represent a management challenge. It is unclear whether surgery or conservative management is the best treatment option. Moreover, there is a paucity of information regarding treatment outcomes.

Methods: We conducted a prospective multi-center cohort study of subjects > 65 years old with a Type II odontoid fracture at 13 sites in North America. Patients received nonoperative or surgical treatment at the discretion of the surgical team and were followed for 12 months. Outcomes assessments included the SF36, Neck Disability Index (NDI) and rates of mortality and complications.

Results: A total of 166 subjects were recruited (average age: 80.7 (SD 7.6); 59.6% females of whom 65.6% were treated operatively (15.2% anterior odontoid screw; 76.2% posterior C1- C2 screw fixation; 6.7% posterior transarticular screw fixation and 1.9% other). A total of 26 (15.7%) subjects expired and 5 subjects withdrew from the study. Follow-up was available for 100 (74%) of 135 eligible, surviving subjects. The baseline NDI was 21.9 (SD 17.0) and SF36v2 PCS was 41.0 (SD 10.5). At 12 months, the NDI worsened by 7.5 (SD 18.1) points ($P < .001$) and SF36v2 PCS declined by 2.3 (SD 10.4) points ($P = .03$). There was a significant difference in NDI outcomes between the surgically and the conservatively treated group. The decline in NDI among the surgical cases was 4.7 points compared to 13.0 points in the conservatively treated group ($P = .017$). There were no differences in the SF36v2 PCS outcomes between the treatment groups.

Conclusion: In spite of treatment, elderly patients with type II odontoid fracture experience significant mortality and decline in functional outcomes at one year follow-up. Our results do suggest that NDI outcomes may be better in the surgical group, though the possibility of selection bias needs to be carefully considered.

113. Prospective, Randomized, Multicenter Study of Cervical Arthroplasty: 269 Patients from the Kineflex/C Metal-on-Metal Artificial Disc IDE Study with Minimum Two Year Follow-up

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Introduction: This prospective, randomized, multicenter study evaluates the safety and efficacy of a new metal-on-metal cTDR implant (Kineflex/C) by comparing it to ACDF.

Methods: The study was a prospective, randomized FDA IDE pivotal trial conducted at 21 centers across the US. The primary clinical outcome measures included the Neck Disability Index (NDI), visual analog scales (VAS), and a composite measure of clinical success. Patients were evaluated clinically and radiographically preoperatively and at 1.5, 3, 6, 12, and 24 months after surgery.

Results: A total of 269 patients were enrolled and randomly assigned to either cTDR (n=136) or to ACDF (n=133). The overall success rate was significantly greater in the cTDR group (74%) compared to the ACDF group (62%) ($p=0.05$). In both the cTDR and ACDF groups, the mean NDI and VAS scores improved significantly by 6 weeks after surgery and remained significantly improved throughout the 24-month follow-up ($p<0.001$). The range of motion (ROM) in the cTDR group was significantly greater than the pre-op at 12- and 24-month follow-up. Adjacent level degeneration was also evaluated in both groups from pre-op to 2 year follow-up and classified as: none, mild, moderate or severe. Pre-op, there were no significant differences between groups when evaluating the different levels of adjacent level degeneration. However, at 2 year follow-up, there were significantly more patients in the ACDF group with severe adjacent level radiographic changes ($p<0.01$).

Conclusion: Kineflex/C was associated with a significantly greater overall success rate compared to fusion while maintaining motion at the index level. Furthermore, there were a significantly fewer Kineflex/C patients showing severe adjacent level radiographic changes at two year follow-up. These results from a prospective, randomized study support that Kineflex/C cTDR is a viable alternative to ACDF in select patients with cervical radiculopathy.

114. Cervical Disc Replacement: Interim Five-Year Follow-Up Results from the United States Prospective Randomized Bryan Clinical Trial

Richard G. Fessler MD (Northwestern University); Rick Sasso MD; Paul Anderson MD; John Heller MD

Introduction: The purpose of this study is to evaluate the currently available data at half of a decade to determine their consistency over time and to assess complications and revision surgeries.

Methods: 463 patients were enrolled and received the study surgical treatments in a prospective, randomized, controlled, multi-center study with a 1:1 randomization scheme. No statistical differences were seen between the groups for demographics and preoperative measures. As of May 28, 2010, 5-year follow-up data were available for 193/242 (79.8%) of the arthroplasty patients and 159/221 (71.9%) of the control patients. The study's primary outcome measure, overall success, as well as secondary functional outcome measures (NDI, SF-36, arm and neck pain scores), were collected at pre-defined time points out to 60 months postoperatively.

Results: At 60 months: Overall success rate: 160/193 (82.9%) for the arthroplasty group, 119/159 (74.8%) for the control group, $p=0.043$; NDI score: 15.9 arthroplasty, 19.1 control, $p=0.020$ (Change from preop: -35.6 arthroplasty, -30.2 control, $p=0.020$); Neck pain score: 23.8 arthroplasty, 28.8 control, $p=0.031$ (Change from preop: -51.3 arthroplasty, -45.2 control, $p=0.031$); and SF-36 PCS: 47.3 arthroplasty, 44.0 control, $p=0.006$ (Change from preop: 14.4 arthroplasty, 11.8 control, $p=0.006$); Cumulatively up to 60 months: Second surgery at index level: 11 (4.5%) arthroplasty, 11 (5.0%) control; Possibly device-related AEs: 9 (3.7%) arthroplasty, 14 (6.3%) control; Possibly device-related and serious (grade 3 or 4) AEs: 4 (1.7%) arthroplasty, 9 (4.1%) control.

Conclusion: Excellent results continue out to 5 years in both the arthroplasty and ACDF groups. Statistically significant differences are present for overall success that favor the arthroplasty cohort. The NDI, SF-36 PCS and neck pain scores also showed improvement in the arthroplasty group that was statistically significant at 60 months compared to the control group. Second surgery and adverse events were very low in both groups with no statistically significant differences between groups at half a decade postoperatively.

115. Are Closed Suction Drains in Posterior Spinal Surgery "The Devil's Highway" for Infection?

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Introduction: Surgeons advocate placement of extra-axial subfascial drains after posterior spine surgery to reduce post-operative collections (ie: hematomas). This may potentially decrease neurologic complications and possibly decrease infectious rates. However, the potential adverse consequences of increased infection rate due to foreign body placement have not been determined.

Methods: A retrospective analysis of an infection control prospective database of a single tertiary care surgery population was performed over a one-year period. Posterior instrumented spinal fusion procedures were assessed for surgical site infections (SSIs) and analyzed against case-controls (1:3 ratio). Specifically, the placement of subfascial drains and their duration of placement and how this correlated was explored.

Results: 1587 fusion procedures were performed during this one-year period of which 42 posterior instrumented fusions developed wound site infections (2.6%). Infections were diagnosed a mean of 14.6 ±9 days post-procedure and skin flora (Staphylococcus aureus) was the most common pathogen (65%). Infected instrumented posterior spinal fusion procedures had a longer duration of subfascial drains than controls (median 5 days vs. 3 days, respectively [$p<0.0001$; log-rank test]). At a breakpoint of drain duration > 5 days, the OR of infection was 14.2 (95% CI = 5.6-35.9; $p < 0.0001$) Multivariate logistic regression indicated that likelihood of infection increased with drain duration (Odds Ratio, 1.5 per day drain present [95% CI, 1.2 - 2.0; $p < 0.0001$]) and was higher for males (OR 2.8; 95% CI 1.2-6.6; $p = 0.01$). Proportional hazards test determined that the probability of drains being removed on any given day was lower (i.e., longer drain duration) for infected cases (Risk Ratio 0.4, 95% CI=0.3-0.6, $p < 0.0001$) and possibly for longer surgeries (RR per hour 0.9, 95% CI = 0.8-1.01, $p=0.08$).

Conclusion: The increased duration of time after the placement of posterior subfascial closed suction drains after instrumented spinal fusions appears to correlate with an increased incidence of surgical site infection. Therefore, shorter durations of time (specifically lesss than four days) or elimination of these drainage catheters may decrease the overall infection rates in this subpopulation of spine surgery patients.

116. Clinical and Radiographic Factors Driving the Transition from Nonoperative to Operative Treatment in Elderly Adults with Degenerative Scoliosis

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Introduction: Few studies report the long-term outcomes of elderly adult degenerative scoliosis patients treated nonoperatively. In addition, the rate of crossover of nonoperatively managed patients and the factors influencing this crossover has not been demonstrated. In order to address these questions, we prospectively followed a cohort of such patients presenting to a surgical clinic for evaluation.

Methods: 92 consecutive adult degenerative scoliosis patients (age >60, mean 69) were followed prospectively upon presentation to the surgical clinic. All were initially managed nonoperatively. Quantitative measures of health status (SF-12 and ODI), VAS pain scores, and radiographic parameters were recorded. Patient follow-up was recorded at specified biennial time points or when a patient was treated operatively. Statistical analysis was performed via T-Test with a $P<0.5$ considered significant.

Results: 73 patients (79%) were followed for a minimum of 2 years (mean 2.64 years) or became operative patients. Of these 18 (25%) went on to have surgery in the follow-up period with a mean time to surgery of 1.6 years. There were no differences at presentation in age, health status (SF-12, ODI), leg pain, back pain, or sagital balance between those that crossed over and those that were "successfully" treated conservatively. At last follow-up or pre-surgical follow-up, crossover patients had lower SF-12 scores ($P=.033$), higher disability scores ($p=0.04$), and worse back (6.8 vs. 4.8 ($p=0.002$)) and leg (5.4 vs. 3.0 ($p=0.002$)) pain. There were no differences in radiographic parameters. Of note there was no significant overall progression of sagittal balance or maximum coronal curve. Patients continuing conservative therapy did not demonstrate significant changes in SF -12 and ODI scores.

Conclusion: There is a significant rate of crossover in nonoperatively managed elderly scoliosis patients. Those crossing over reported higher disability and worse pain and health. Patients continuing nonoperative therapy report stable, but not improved, outcome measures.

117. Incidence of Vascular Encroachment Resulting from Free Hand Placement of Pedicle Screws in the Thoracic and Lumbar Spine: Analysis of 6,816 Consecutive Screws

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Introduction: Iatrogenic major vascular injuries during anterior instrumentation procedures have been reported by several authors, but there is a paucity of data regarding major vascular injuries during posterior instrumentation procedures. The purpose of this study is to evaluate the incidence and clinical significance of vascular encroachment resulting from free-hand placement of pedicle screws in the thoracic and lumbar spine.

Methods: We retrospectively reviewed records of all patients undergoing free-hand pedicle screw placement without image guidance in the thoracic or lumbar spine between June 2002-June 2009. Incidence and extent of vascular encroachment by a pedicle screw was determined by review of routine post-operative CT scans obtained within 24 hours of all surgeries. Vascular encroachment was defined as a screw touching or deforming the wall of a major vessel.

Results: Nine-hundred sixty-four patients received 6816 free-hand pedicle screws in the thoracic or lumbar spine. Fifteen (0.22%) screws were identified to encroach upon a major vascular structure. Ten (67%) thoracic screws encroached on the aorta, 4 (27%) lumbar screws on the common iliac vein, and 1 (6%) S1 screw on the internal iliac vein, Figure 1. The spinal level of involvement is depicted in Figure 2. Consultation with vascular surgery was utilized to determine if revision surgery was recommended and the technique/approach for the revision procedure. Two (11.7%) patients required revision surgery to remove the encroaching pedicle screw (T5 and T8) due to concern for vascular injury. Both patients requiring revision were asymptomatic and recovered without further complications after revision surgery.

Conclusion: Vascular encroachment of major vessels occurs rarely in the setting of free-hand pedicle screw placement in the thoracic and lumbar spine. Although rare, delayed vascular injury from errant pedicle screw placement has been reported in the literature. Aorta is the vessel at highest risk of injury. Routine intra-operative and post-operative

CT scanning allows for early identification of screws encroaching on vascular structures thereby facilitating early revision surgery.

118. Evidence of Descending Supraspinal Control of Nociception and Pain Behavior in Experimental Disc-Herniation Radiculopathy

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Introduction: Disc-herniation induced radiculopathy involves both mechanical compression and biochemical inflammation of apposed neural elements.(1-3) Recent evidence suggests heterotopic disc placement induces early and persistent allodynia alongside transient pathological gait asymmetry.(1) This suggests divergent molecular effects at spinal and supraspinal levels. This study evaluated the inflammatory and analgesic molecular profile observed at the dorsal root ganglion (DRG) and midbrain periaqueductal grey and red nucleus in an animal disc-herniation disease model.

Methods: Sprague-Dawley rats underwent surgical procedure including harvesting autologous nucleus pulposus (NP) from a tail intervertebral disc and exposure of the L5 dorsal root ganglion (DRG). Control animals (n=12) underwent exposure only and experimental animals received NP placement onto the DRG (n=12). Animals were evaluated for mechanical allodynia and for stance and gait symmetry. Following sacrifice (1 or 4 weeks), the DRG and midbrain were evaluated by immunohistochemistry for inflammatory activation and neurotransmitter receptors respectively.

Results: Persistent mechanical allodynia occurred in rats subjected to NP stimulation at 1 and 4 weeks, although this heightened sensitivity had the functional consequence of early gait asymmetry (1 week) with late normalization (4 weeks) (Figure 1). Injured animals revealed early and persistent inflammatory glial cell activation at the DRG, paralleling the allodynia phenotype. Conversely, midbrain studies reveal persistently high glutamate receptor expression, high serotonin receptor expression at 1 week with late normalization, and early normal opioid receptor expression with late escalation at 4 weeks (Figure 2).

Conclusion: Persistent mechanical allodynia with only transient gait abnormality in this model of non-compressive disc herniation suggests deficits to be mediated by both spinal and supraspinal mechanisms. Inflammatory DRG activation may generate persistent allodynia and promote gait asymmetry. Early midbrain serotonin and glutamate receptor expression may aggravate this deficit while late opioid receptor expression may permit adaptive response to normalize behavior.

119. Perioperative Use of Dexamethasone in Multilevel Anterior Cervical Spine Surgery: Preliminary Results of a Prospective, Randomized, Double-Blinded Trial

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Introduction: Anterior approaches to the cervical spine involve some retraction affecting the midline structures of the anterior neck. Steroids given intraoperatively may reduce the incidence of adverse outcomes, such as dysphagia and airway compromise. Their use has historically been controversial during spinal arthrodesis procedures due to concern that anti-inflammatory agents could reduce bony fusion rates.

Methods: A prospective, randomized, double-blinded study in patients undergoing multilevel anterior cervical spine surgery is being conducted at Albany Medical Center. Our hypothesis is that perioperative steroids decrease postoperative swallowing and airway complications and don't impact long-term fusion rates. The target enrollment is 200 subjects with 2-year follow-up. This preliminary data reflects an interim analysis of the first 53 patients. We studied patients undergoing multilevel (>2 motion segments) anterior cervical spine procedures. Patients were randomized to receive intraoperative doses of either intravenous dexamethasone (0.2 mg/kg IV; n=28) or an equivalent volume infusion of saline (n=25). Four postoperative doses of 0.06mg/kg of steroid or placebo were administered every 6 hours for the first 24 hours. Preoperative parameters, including baseline demographics, smoking history, pain and functional status (mJOA, NDI, SF-12, VAS), swallowing function (functional outcome swallowing scale, FOSS) and diagnosis were reviewed. Postoperative data included length of inpatient stay, FOSS, mJOA, VAS, SF-12, and fusion status, assessed by CT, at 6 months. Any postoperative complications were noted.

Results: There were no statistical differences in preoperative parameters of age, gender, diagnosis, smoking history, number of operative levels, mJOA, FOSS, NDI, SF-12, or VAS between the 2 groups. FOSS, when assessed in the immediate postoperative period, was significantly lower in the steroid(S) group when compared to the placebo(P) group (S:0.59±0.80, P:1.23±0.92, p=0.01). This significance was lost at the 1, 3, and 6-month follow-up. There were no significant differences in any of the other postoperative measures, including 6 month fusion status. One patient in the placebo group required postoperative re-intubation, and one patient in the steroid group required PEG tube placement secondary to prolonged dysphagia.

Conclusion: Our preliminary data suggests that perioperative steroids decrease postoperative swallowing complications without negatively impacting long-term fusion rates.

120. Analysis of the Three United States FDA-IDE Cervical Arthroplasty Trials

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Introduction: There are three randomized, multicenter, United States FDA IDE, industry sponsored studies comparing arthroplasty with anterior cervical discectomy and fusion (ACDF) for single level cervical disease with complete 2-years of follow-up. The studies evaluated the PRESTIGE ST, BRYAN, and ProDisc-C artificial discs. We analyzed the combined results of these three trials.

Methods: A total of 1,213 patients with symptomatic, single-level cervical disc disease were randomized into two treatment arms in the 3 randomized trials. 621 patients received an artificial cervical disc and 592 patients were treated with ACDF. 94% of the arthroplasty group and 87% of the ACDF group have completed two years of follow-up. We analyzed the 2-year data from these three trials including previously unpublished source data. Statistical analysis was performed with both fixed and random effects models.

Results: Analysis demonstrated preserved segmental sagittal motion with arthroplasty (preoperatively 7.26 degrees and postoperatively 8.14 degrees) at the two-year timepoint. The fusion rate for ACDF at two years was 95%. The NDI, SF-36 MCS, SF-36 PCS, VAS neck pain, and VAS arm pain scores were not statistically different between groups at 24-months follow-up. The arthroplasty group demonstrated superior results at 24-months in neurological success (RR 0.595, I^2=0%, p=0.006). The arthroplasty group had a lower rate of secondary surgeries (RR 0.508, I^2=0%, p=0.018). The reoperation rate for adjacent level disease was lower for the arthroplasty group when we analyzed the combined data set using a fixed effects model (RR 2.23, I^2=2.9%, p=0.026).

Conclusion: Both ACDF and arthroplasty demonstrate excellent two year surgical results for the treatment of one level cervical disc disease with radiculopathy. Arthroplasty is associated with a lower rate of secondary surgery and a higher rate of neurological success at 2 years. Arthroplasty may be associated with a lower rate of adjacent level disease at 2 years.

Oral Posters

200. Pulsed Electromagnetic Field Bone Growth Stimulation for High Risk Fusion Patients: An Analysis of 452 Consecutive Cases

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Introduction: Pseudarthrosis occurs in up 10-15% of instrumented spinal fusion cases, often requiring revision surgery (1). High risk patients including diabetics, smokers, and those undergoing multi-level fusion or revision surgery have demonstrated higher pseudarthrosis rates(1,2). Patients with multiple risk factors pose an even greater treatment challenge(3,4). Bone Morphogenetic Protein (BMP) has been used increasingly to help promote fusion in high risk patients, but due to side effects, risks and cost may not be suitable for all patients(5). The authors describe their experience with a consecutive series of patients undergoing adjunctive treatment with an external bone growth stimulator to achieve successful fusion.

Methods: Between 2001-2009, 452 high risk patients underwent instrumented fusion surgery at the Mayo Clinic Arizona. 95 cervical and 357 lumbar cases were identified. Fusion was performed with iliac crest autograft and allograft in the lumbar spine and allograft alone in the cervical spine. No BMP was used. Each patient was fitted with an external pulsed electromagnetic field bone growth stimulator within two weeks of surgery which was worn for at least 2 hours/day for a minimum of 6 months. Follow-up was obtained at two week, three month and one year post-operatively with radiographs and CT scans.

Results: In the cervical fusion group there were 88 solid fusions and 7 pseudarthroses (92.6% fusion rate). In the lumbar group there were 339 solid fusions and 18 pseudarthroses (94.9% fusion rate). There were no complications or side effects associated with the use of the stimulator.

Conclusion: Bone growth stimulation following standard fusion techniques in this large series of high risk patients led to fusion rates greater that 90% in both the cervical and lumbar spine. Based on efficacy and safety, external bone growth stimulation appears to be a reasonable adjunctive treatment to promote fusion in high risk patients.

201. Preservation of Segmental Motion with Anterior Contra–lateral Cervical Microdiskectomy and Interbody Fat Graft: Prospective Study

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Introduction: The aim of our study is to evaluate the results and effectiveness of this minimal invasive technique with or without interbody fat graft replacement in patients with cervical paramedian disc herniations.

Methods: This prospective observational study was undertaken for the analysis of 330 patients with cervical paramedian disc herniation who underwent one -or adjacent two-level anterior contralateral microdiskectomy without fusion between 1992 and 2009. Interbody fat graft raplacement were performed on 91 of 340 patients (Group 2). The mean follow up time was 10 years (range 1 - 16 years). Preoperative and postoperative lateral dynamic cervical radiographs were obtained and, the presence of a reduction in the height of interspace and spontaneous osseous union at the diskectomy level were investigated. Surgeries were done by the senior author (YA). Clinical outcomes were assessed using the Neck Disability Index and Short Form 36.

Results: Despite fusion procedures were not performed, spontaneous radiological fusion signs were obtained in 12% of group 1 patients. Follow-up radiological studies revealed healing without fusion in group 2 patients. There was no significant change in the mean overall cervical curvature (C2 - 7) angles postoperatively in late follow-up findings ($p = 0.77$). It represented a statistically significant mean loss of 2.24 degree of segmental lordosis ($p < 0.001$). The NDI scores decreased significantly in both early and late follow-up evaluations and the SF-36 scores demonstrated significant improvement in late follow-up results in two groups. Analysis of clinical outcome showed no statistical differences between two groups ($p = 0.77$).

Conclusion: Anterior contralateral microdiscectomy without fusion achieves better exposure for resection of the offending foraminal or far lateral lesions, ventral osteophytes, or a disc fragment under direct microscopic visualization. Collapse, loss of motion and, instability of the involved disc level can also be avoided via this less invasive technique and interbody fat graft.

202. Radiographic Outcomes in Two-Level ACDFs: Comparison of PEEK and Allograft Interbody Devices at 1 and 2-Year Follow-Up

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Introduction: In our single-site prospective series of 184 two-level ACDF patients, 100 had the PEEK interbody device, and 84 had the Allograft device. To date, 60 patients have presented for 24-month follow-up.

Methods: 184 patients underwent instrumented 2-level ACDFs. Patients were assigned to one of two treatments arms that included a composite of DBM plus autogenous endplate reamings, incorporated into allograft bone dowels or PEEK spacers and stabilized with dynamic anterior plating. Fusion was defined as uninterrupted bridging of well mineralized bone across the interbody space and no significant motion on flexion-extension radiographs. Both operative levels were assessed for fusion using a modified Lenke score. Any pseudarthrosis at either level was considered a failure.

Results: Of 184 patients, 84 were treated with allograft interbody dowels (27M, 57F; age 60.8 yrs; 33 smokers) and 100 were treated with PEEK spacers (23M, 42F; age 52.4yrs; 15 smokers). Average 12-month Lenke score across all subsets was 1.07 (allograft 1.15; PEEK 1.01). At 24 months, average Lenke scores across all subsets was 1.03 (allograft 1.10, PEEK 1.00). There were no infections, neurologic complications or plate breakages. Only one patient (allograft) developed a clear pseudarthrosis.

Conclusion: The combination of a demineralized bone matrix-local bone composite contained within allograft dowels or PEEK spacers resulted in similar fusion rates (> 97%) at 12 months post-operatively. Based on Lenke scores, allograft dowels appear to fuse more slowly than PEEK spacers but this may be perceptional.

203. Safety, Efficacy, and Dosing of Recombinant Human Bone Morphogenetic Protein-2 (rhBMP-2) for Posterior Cervical and Cervico-Thoracic Instrumented Fusion with a Minimum Two-Year Follow-Up

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Introduction: Considerable attention has focused on concerns of increased complications with rhBMP-2 use for anterior cervical fusion, but few reports have assessed its use for posterior cervical fusions. This study evaluates the safety, efficacy, and dosing of recombinant human bone morphogenetic protein (rhBMP)-2 as an adjunct for instrumented posterior cervical arthrodesis using a retrospective consecutive case series.

Methods: All patients were treated by the senior author with posterior cervical or cervico-thoracic instrumented fusion augmentated with rhBMP-2 and had minimum follow-up of two-years. Diagnosis, levels fused, rhBMP-2 dose, complications, and fusion (Lenke grade applied by two neuroradiologists) were assessed.

Results: 53 patients (22 men/31 women) met inclusion criteria, with a mean age of 55.7 years and an average follow-up of 40 months. Surgical indications included basilar invagination (n=6), fracture (n=6), atlanto-axial instability (n=16), kyphosis/kyphoscoliosis (n=22), osteomyelitis (n=1), spondylolisthesis (n=1), cyst (n=1). 15 patients had confirmed rheumatoid disease. The average rhBMP-2 dose was 1.79mg/level with a total of 282 levels treated. Among 53 patients, only 2 complications (3.8%) were identified, a superficial wound infection and an adjacent level degeneration. At last follow-up, all patients had achieved fusion.

Conclusion: Augmentation of posterior cervical fusion with rhBMP-2 appears to be safe and has a very low complication rate. Despite complex pathology and/or rheumatoid arthritis, a 100% fusion rate was achieved, which is considerably higher than comparable historical comparisons without rhBMP-2 (62-94%). Collectively, these data suggest that use of rhBMP-2 as an adjunct for posterior cervical fusion is safe and effective at an average dose of 1.8mg per level.

204. Prospective Results from the US IDE Feasibility Study of a Novel Peek-On-Peek Nucleus Replacement Device With Minimum Two-Year Follow-Up

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Introduction: Nucleus replacement (partial disc replacement) offers a less invasive alternative to traditional fusion or total disc replacement techniques in the treatment of symptomatic lumbar degenerative disc disease (DDD). NUBACTM is the first PEEK-on-PEEK articulated intradiscal arthroplasty device. The authors report the results of 20 consecutive patients treated with NUBAC nucleus replacement in the prospective, multi-center US FDA IDE feasibility clinical study. On the strength of the results of this pilot feasibility study, NUBAC became the first nucleus replacement device to enter US IDE pivotal study.

Methods: Patients with symptomatic DDD at L4-5 were enrolled at three investigational sites in the IDE feasibility study. All devices were placed via a lateral transpsoas approach. Effectiveness is evaluated by prospectively recording pre-op and post-op (at 1.5, 3, 6, 12 and 24 months) Oswestry Disability Index (ODI) and Visual Analog Scale (VAS) scores.

Results: A total of 20 NUBAC devices were implanted in 20 patients. Average OR time was 124 minutes; EBL was 47 cc. Average time to discharge home was 1.4 days. There were no major intra- or postoperative neurological or vascular complications. Average age=41 years. Clinical results showed statistically significant improvement in pain relief and function compared to preop at all time intervals. The mean preoperative VAS (7.1) and ODI (53.9) scores improved significantly at six weeks (3.4 and 30.7, respectively) and were maintained through 2 years (1.8 and 6.3, respectively). There were no device expulsions or reoperations.

Conclusion: This early, prospective clinical experience with NUBAC PEEK-on-PEEK nucleus replacement is promising. NUBAC is currently in prospective, randomized, multicenter FDA IDE pivotal study and those results will continue to define the role of nucleus replacement in the treatment of symptomatic DDD.

205. Pre-Operative Grading Scale To Predict Survival in Patients Undergoing Resection of Malignant Primary Osseous Spinal Neoplasms

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Introduction: Large population-based studies of malignant primary osseous spinal neoplasms are lacking and are necessary for sufficient power to determine prognostic factors. Using a 30-year U.S. national cancer registry (SEER), we introduce a pre-operative grading scale that is associated with survival in patients undergoing surgical resection for malignant primary osseous spinal neoplasms.

Methods: The SEER registry (1973-2003) was queried to identify adult patients undergoing surgical resection of histologically confirmed primary spinal chordoma, chondrosarcoma, or osteosarcoma via ICD-O-2 coding. Variables independently associated with survival were determined via Cox proportional-hazards regression analysis for all tumor types. A grading scale comprised of these independent survival predictors was then developed and applied to each histology-specific tumor cohort.

Results: 342 patients were identified that underwent surgical resection of a malignant primary osseous spinal neoplasms (114 chordoma, 156 chondrosarcoma, 72 osteosarcoma). Overall median survival after surgical resection was histology specific (osteosarcoma: 22 months; chordoma: 100 months; chondrosarcoma: 160 months). Increasing age (years) and increasing tumor extension (1. confined to periosteum; 2. invasion through periosteum into adjacent tissues; 3. distal site metastasis) were the only variables independently associated with decreased survival ($p<0.05$) for all tumor types. For spinal chordoma, sacrum/pelvic location ($p<0.05$) and earlier year of surgery ($p<0.005$) were also independently associated with decreased survival. Utilizing variables of patient age, extent of local tumor invasion, and metastasis status in a five-point grading scale, increasing score (1-5) closely correlated ($p<0.001$) with decreased survival for chordoma, chondrosarcoma, and osteosarcoma, Figure 1.

Conclusion: In our analysis of a U.S. population based cancer registry (SEER), a grading scale consisting of age, metastasis status, and extent of local tumor invasion was associated with overall survival after surgical resection of chordoma, chondrosarcoma, and osteosarcoma of the spine. This grading scale may offer valuable prognostic data based on variables available to the surgeon and patient prior to surgery and may help guide level of aggressiveness in subsequent treatment strategies.

206. Clinical Outcomes Following En Bloc Sacrectomies via Posterior Approach

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Introduction: En bloc resection of primary sacral tumors has a demonstrated survival benefit. Total and high sacral amputations traditionally involved both an anterior and posterior approach. However, we have found that en bloc resection and biomechanical reconstruction is possible from a posterior-only approach in many cases.

Methods: Sixty-nine consecutive patients underwent sacral resections for tumor at our institution between 2004 and 2009. Medical records of all patients were reviewed, and patients were excluded if they had an intentional intralesional resection, hemipelvectomy or were previously operated. The records of the resulting 37 consecutive patients who underwent primary posterior-only en bloc sacral resections and all 4 patients who underwent a traditional anterior-posterior en bloc sacrectomy were retrospectively reviewed.

Results: All posterior-only patients underwent midline posterior approaches for en bloc sacral resection. Surgical level was defined by the anatomic level of the rostral osteotomy site: total with lumbopelvic reconstruction (L5S1; n=5), high (S1S2; n=9), middle (S2S3; n=17), and low (below S3; n=6). Chordoma was the most common tumor (n=30) and wide surgical margins were attained in 35 cases. The level of sacral amputation correlated with estimated blood loss ($p<0.005$), and length of stay ($p<0.001$). There were 14 complications including 9 wound infections/revisions. In the anterior-posterior cohort (n=4), rectal carcimoma was the most common diagnosis. Patients required anterior-posterior procedures because of rectal invasion (n=3) or tumor extending above the L5S1 disc space (n=1). All 4 patients suffered wound complications, and there was 1 life-threatening hemorrhage. Operative time, blood loss, and length of stay was higher than similar posterior-only procedures. In both cohorts, extent of root sacrificed correlated with functional outcome.

Conclusion: It may be possible to perform a posterior-only approach to en bloc sacral resections/reconstructions in patients with tumors that do not extend beyond the lumbosacral junction or invade the bowel.

207. Generation of Chordoma Cell Line, JHC7, and the Identification of Brachyury as a Novel Molecular Target

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Introduction: Recent genomic interrogation of chordomas has identified Brachyury gene duplication as a major susceptibility mutation in familial chordomas. Current understanding of the role of this transcription factor in chordoma is limited due to the lack of a fully characterized chordoma cell line expressing Brachyury. We report the establishment of the first fully characterized primary chordoma cell line (JHC7) expressing Brachyury and demonstrate that silencing of Brachyury using shRNA leads to complete growth arrest in vitro.

Methods: Establishment of Chordoma Cell Line Intraoperatively obtained chordoma specimen was dissociated into single cells using techniques published previously. Confluent cells were passaged to adherent cell culture flasks for expansion. Chordoma cells (JHC7) were maintained in DMEM/F12 (10% FBS) with antibiotic/antimycotic. Lentiviral Transduction A pKLO.1-based lentiviral vector containing shRNA targeting Brachyury was obtained from the TRC-Hs1.0 library from Open Biosystems. Brachyury shRNA and empty plasmids were packaged into lentivirus by transfecting 10μg of packaging plasmids in packaging cells. Forty-eight hours after transfection, lentiviral supernatant was used to infect JHC7 chordoma cells. Growth curve studies were performed using the MTT assay 10 days after transduction.

Results: A novel chordoma cell line was created (JHC7). Cultured cells were morphologically identical to classical chordoma, including the characteristic physaliferous phenotype (Figure 1A). The presence of Brachyury was confirmed by Western Blot and immunohistochemistry (Figure 1B, C). Loss of Brachyury expression after shRNA transduction was confirmed by Western Blot (Figure 2A). Loss of Brachyury expression abolished the classical phenotype of chordoma cells and led to a more differentiated, epithelial-like state (Figure 2B) with a near complete loss of proliferation capacity (Figure 2C).

Conclusion: The JHC7 chordoma cell line represents the first in vitro system with chordoma cells characterized for Brachyury expression. We propose that shRNA-mediated suppression of Brachyury is a novel and attractive therapeutic target in the treatment of chordoma.

208. Reconstruction of Extensive Defects from Posterior En Bloc Resection of Sacral Tumors Using Human Acellular Dermal Matrix and Gluteus Maximus Myocutaneous Flaps

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Introduction: Performing a sacrectomy solely from a posterior approach allows for the en bloc resection of tumors without the additional morbidity of a laparotomy. However, the reconstruction of the resultant extensive soft-tissue defects is challenging, particularly as a vertical rectus abdominis myocutaneous flap is not harvested. We report the largest series (with the longest follow-up) of sacral reconstructions using a combination of human acellular dermal matrix (HADM) and gluteus maximus myocutaneous flaps.

Methods: 34 patients with sacral tumors who had a follow-up of at least one year were reviewed retrospectively. Intra-operatively, after the tumor was excised, HADM (AlloDerm) was secured to create a pelvic diaphragm. Subsequently, the gluteus maximus muscles were freed from their origins, elevated, rotated or advanced in the midline to cover the HADM, and sutured together.

Results: The mean age of the patients was 50 years and the histopathology revealed a chordoma in 82.4%. 8 patients (23.5%) developed a post-operative wound dehiscence, of whom 6 (17.6%) required operative debridement. An estimated blood loss of >2500 mL and an operative time of >9 hours during sacrectomy, as well as post-operative bowel or bladder incontinence, were all associated with a significantly higher rate of subsequent debridement procedures ($p=0.018$). The average length of hospital stay was 12.2 (range 3-66) days; the development of a surgical site infection and the performance of a debridement procedure were both associated with a longer length of hospital stay ($p=0.037$). With a mean follow-up of 45.7 months, only 1 patient developed an asymptomatic para-sacral hernia, which was adjacent to a local tumor recurrence.

Conclusion: Reconstruction of posterior sacrectomy defects with HADM and gluteus maximus myocutaneous flaps may be a valid technique. This approach may have rates of wound dehiscence comparable to other techniques and low rates of para-sacral herniation.

209. En Bloc Resection of Cervical Chordomas: Series of 12 Patients and Clinical Outcomes

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Introduction: Chordomas of the mobile spine often undergo en-bloc resection with reconstruction to optimize local control and possibly offer cure. In the cervical spine, local anatomy is challenging and obtaining clean margins may be limited. Complications may also be higher due to juxtaposition of the skull base, vasculature, aerodigestive system and upper spinal cord. In this review, we present a series of 12 cases of cervical chordomas removed en-bloc. Particular attention was paid to clinical outcome, complications, and recurrence. In addition, outcomes were assessed according to position of tumor in C1/C2 versus the subaxial spine.

Methods: The patients undergoing en-bloc resection of cervical chordoma were reviewed from two large spine centers. Patients were included if the lesion epicenter was involving C1 to C7 vertebral bodies. Demographics, details of surgery, follow-up course, and complications were obtained. Outcome was correlated with presence of tumor in C1/2 versus subaxial spine (C3-C7) via a student's t-test.

Results: 12 patients were identified with a mean age at presentation of 60. 7/12 (58%) and 5/12 (42%) of cases involved the C1/C2 and subaxial spine, respectively. En-bloc resection was attempted via an anterior approach in 33% of cases (29%-C1/C2; 40%-subaxial), a posterior approach in 25% of cases (43%-C1/C2; 0%-subaxial), and a combined approach in 42% of cases (29%-C1/C2; 60%-subaxial).

Tumor margins were found to be wide in 2/12 (17%-overall; 14%-C1/C2; 20%-subaxial), marginal in 6/12 (50%-overall; 29%-C1/C2; 80%-subaxial), or contaminated in 3/12 (25%-overall; 43%-C1/C2; 0%-subaxial) of cases. No operative complications were encountered. Postoperative complications occurred in 5/12 (42%-overall; 57%-C1/C2; 20%-subaxial; $p<0.05$) patients and included: hoarseness, dysphagia, prolonged/permanent use of a feeding tube, and pneumonia. Average follow-up was 42 months (range 30-60 months). Recurrence occurred in 5/12 (42%-overall; 57%-C1/C2; 20%-subaxial; $p<0.05$) cases. Of note, in comparing C1/C2 tumor resections with subaxial lesions, we found a greater incidence of post-operative complications and rates of recurrence.

Conclusion: En-bloc resection of cervical chordomas involving the upper cervical spine (C1-2) are associated with poorer outcomes such as higher rates of complications, and recurrence.

210. Identification of Cancer Stem Cells in Human Chordoma

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Introduction: Chordomas are the most common malignant primary tumor of the osseous spine. The mechanisms underlying the resistance of chordoma to chemotherapy and radiation therapy is unknown. The role of cancer stem cells (CSCs) in chordoma pathophysiology has not been defined. We have performed a series of experiments that provide evidence for the presence of CSCs within human chordoma.

Methods: Establishment of Chordoma Sarcospheres: Chordoma tumor samples were dissociated into single cells, plated in adherent conditions, and expanded to confluence. Cells were then transferred into serum-free, non-adherent conditions to form sarcospheres. Differentiation Studies: For adipogenic differentiation, chordoma sarcospheres were plated at 100% confluency and differentiated using a commercial human adipogenic differentiation kit. Differentiation was evaluated using oil red staining using normal human mesenchymal stem cells as a positive control. For neuronal and astrocyte differentiation, chordoma sarcospheres were maintained in serum free media and plated in 10% FBS for 10 days. Xenograft Studies: BALB/c male nude mice were injected subcutaneously with either chordoma sarcospheres (500,000, 1 million, or 2 million cells) or non-sphere chordoma cells in 50 ul PBS:Matrigel (1:1).

Results: We have established a stable chordoma cell line that is morphologically identical to classic chordoma with expression of brachyury, S100 and keratin. Using this cell line, we have isolated and characterized chordoma sarcospheres that are self-perpetuating and exhibit higher expression of the functional stem cell marker ALDH1 compared to typical chordoma cells. Furthermore, sarcospheres can be successfully differentiated into neuroepithelial and mesodermal cell types. Subcutaneous injection of chordoma sarcospheres into an athymic mouse host induced the formation of tumors that successfully recapitulated the phenotypic characteristics of the parent chordoma.

Conclusion: We present the first evidence for the existence of chordoma CSCs and have developed the first animal model for this disease.

211. Sacral Laminoplasty for the Treatment of Symptomatic Sacral Perineural (Tarlov) Cysts, Clinical Outcomes and Surgical Observations

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Introduction: The surgical treatment of symptomatic sacral perineural cysts or Tarlov cysts remains controversial. Traditional approaches have been described using sacral laminectomy. Our aim was to evaluate the efficacy and potential complications of treatment of these cysts with microsurgical fenestration, local muscle/fat grafting, and laminoplasty of the sacral lamina.

Methods: This is a retrospective study of 17 prospectively followed patients with 19 large sacral perineural cysts (averag-2.40 cm, range 1.1-8.0 cm) of the sacrum treated by the senior author between May 2004 and June 2010. All patients presented with symptoms non-responsive to medical treatment. Presenting symptoms included coccydynia (n=17), radiculopathy (n=14), back pain (n=11), perineal parasthesias (n=8), incontinence (n=8), and weakness (n=6). We performed a sacral laminoplasty with fenestration of the cyst with intraoperative electromyography in all patients. All patients had closures reinforced with either fat or muscle graft with fibrin glue with subsequent fixation of the sacrum with titanium mini-plates. Outcomes were evaluated by telephone questionnaire or clinic follow-up at average 12.5 months (range 4-44 mo).

Results: After surgery, coccydynia (13/17 pts, 76.5%), radicular pain (11/14 pts, 78.6%), and perineal parasethesias (6/8, 75.0%) improved most consistently following operation. One patient without pre-existing sensory symptoms developed new perineal parasethesias. Bladder control returned in 5 of 8 patients (62.5%) and a single patient developed new bowel and bladder incontinence. There was a single cerebrospinal fluid leak that required return to OR. MRI was completed in all 14 patients with >6-month follow-up and no imaging demonstrate evidence of recurrence.

Conclusion: Microsurgical fenestration with laminoplasty is a safe and effective treatment for carefully selected patients with large, symptomatic Tarlov cysts. The authors describe their results for this subset of patients who may benefit from surgery.

212. Hydrostatic Strength Dural Patch Repair Materials

Michael A. Finn MD (University of Colorado); Paul Anderson MD; Nathan Faulkner MD (University of Wisconsin)

Introduction: We hypothesize that different dural patch materials will vary in their initial hydrostatic strength and that the use of a biologic glue will increase the hydrostatic strength of dural patch repairs.

Methods: Twenty-four calf thoracic spines were prepared with laminectomies and spinal cord evacuation, leaving the dura intact. Foley catheters were inflated on either side of a planned dural defect and baseline hydrostasis was measured using a fluid column at 30, 60 and 90 cm of water. A standard dural defect (1x2cm) was created and 8 patches of each material (human fascia lata, Duragen, and Preclude) was sutured in place using a 5-0 Prolene HS running suture. Hydrostasis was again tested at the same pressures. Finally, Duraseal was placed over the defect and hydrostasis was again tested. Results were analyzed with ANOVA.

Results: Leakage rate increased significantly at each pressure tested for all conditions. All patch materials allowed significantly greater leakage than the intact condition. There was no difference in leakage between the three patch materials. The use of duraseal reduced leakage significantly at all pressures when used with Duragen, and at 90 cm of water when used with Preclude. There was a trend towards reduced leakage with duraseal under the remaining conditions. There was no significant difference between the Duraseal group and the intact dura.

Conclusion: The use of all three dural patch materials were of similar hydrostatic strength and allowed greater leakage than intact. The use of Duraseal reduced leakage rates to levels similar to intact.

213. Hydrostatic Comparison of Titanium Clip and Suture Repair of Durotomy

Michael A. Finn MD (University of Colorado); Paul Anderson MD; Nathan Faulkner MD (University of Wisconsin)

Introduction: We hypothesize that the hydrostatic strength of durotomy repairs will vary with the type of suture used and between suture and non-penetrating titanium dural clips.

Methods: Twenty-four calf thoracic spines were prepared with laminectomies and spinal cord evacuation, leaving the dura intact. Foley catheters were inflated on either side of a planned dural defect and baseline hydrostasis was measured using a fluid column at 30, 60 and 90 cm of water. A standard 1 cm durotomy was created and was repaired in 8 specimens each using 5-0 Surgilon, 5-0 Prolene HS, or non-penetrating dural clips. Hydrostasis was again tested at the same pressures. The time required for each repair was measured. Results were analyzed with ANOVA.

Results: Leakage rate increased significantly at each pressure tested for all conditions. There was no difference between the intact condition and the titanium clip repair at any pressure. There was significantly greater leakage than intact in both suture repair groups detected at all pressures. There was no difference between the suture types. Clip repairs took approximately 1/2 as long as suture repairs, a significant difference.

Conclusion: The use of non-penetrating titanium dural clips provided better immediate hydrostasis and took less time than tradition suture repair.

214. Prospective Randomized Controlled Trial in Spine Patients to Compare Low Swell Formulation of a Polyethylene Glycol Hydrogel Spinal Sealant with Other Methods of Dural Sealing

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Introduction: As an adjunctive measure to sutured dural repair, spine surgeons utilize a variety of methods to ensure that no active leak is present before closing the wound. In 2009, the FDA approved the DuraSeal? spinal sealant specifically as an adjunct to sutured repair during spine surgery. This IDE study compared the safety and efficacy of low swell (10% and 39% of its original volume) PEG hydrogel formulation to other methods of dural sealing.

Methods: Prospective, multicenter, randomized controlled study was conducted to compare a low swell formulation of a PEG hydrogel with other common dural sealing methods as an adjunct to sutured dural repair. To evaluate those patients operated only in spine, Chiari malformation surgery was excluded. The primary endpoint was the efficacy of intraoperative watertight dural closure confirmed by Valsalva maneuver at 20-25 cm H2O. Safety was measured by the assessment of postoperative CSF leak and surgical site infection.

Results: 51 patients were randomized to low swell PEG hydrogel spinal sealant (treatment) and 16 patients to other methods of dural sealing such as additional sutures and/or adhesive glue (control). Efficacy measured by intraoperative watertight closure was higher in the treatment group compared to the control (98% vs. 75%, p=0.010). Also treatment group had lower rate of postoperative CSF leak compared to the control (2% vs. 12.5%, p=0.143) and lower rate of surgical site infection (6% vs. 18.8%, p=0.148).

Conclusion: Common methods for achieving a watertight dural closure during spine surgery include the use of additional sutures and adhesive glue. With this method, however, about 3 out of 4 patients fail to achieve a watertight dural closure. Low swell PEG hydrogel spinal sealant is much more effective in achieving intraoperative watertight dural closure without compromising the safety of the patients.

215. Assessment of Thoracic Laminar Dimensions in a Pediatric Population: A CT-Based Feasibility Study for Pediatric Thoracic Translaminar Screw Placement

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Introduction: Translaminar screws (TLSs) were originally described by Wright as a safer alternative to pedicle screw fixation at C2.1 More recently, TLSs have also been used as bail-out procedure following failed pedicle screw placement in the treatment of adolescent idiopathic scoliosis.2,3 To date, there are no studies that report the anatomical features of the thoracic lamina in the pediatric population.

Methods: 52 patients (26 male, 26 female), average age 9.5 4.8 years, were selected by retrospective review of a trauma registry database after IRB approval. Study inclusion criteria were ages 2 to 16, standardized axial bone-windowed CT images of the thoracic spine, and an absence of spinal trauma. For each thoracic lamina the following anatomical features were measured using eFilm Lite software: width (outer cortical and cancellous), maximal screw length, optimal screw trajectory, and laminar height. Subjects were stratified by age as follows: <8 yrs. of age(yo) vs. >8 yrs. of age(yo) based on presumed spinal maturity.

Results: Collected data (Table 1) demonstrate the following trends: 1) decreasing maximal screw length, 2) stable lamina width (Figure 1), 3) increasing laminar height, and 4) increasing ideal screw trajectory angle as one descends the thoracic spine from T1-T12. When stratified by age, subjects >8yo had significantly larger lamina in both width and height, and allowed significantly longer screw placement at all thoracic levels than the <8yo subgroup (p<0.05). Importantly, all thoracic spinal levels had an average bicortical diameter greater than 3.5 mm, indicating that a 3.5 mm screw could be placed in the majority of cases.

Conclusion: The data collected provide preliminary information regarding optimal TLS length, diameter, and trajectory for each spinal level in the pediatric thoracic spine. Furthermore, based on CT evaluation, bicortical width provides no anatomical limitation to the placement of translaminar screws in the pediatric population.

216. CT Hounsfield Units for Assessing Bone Mineral Density: A Tool For Osteoporosis Management

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Introduction: Osteoporosis is a common disease with enormous implications for affected individuals and society as a whole. Measurements obtained from computed tomography (CT) examinations obtained for other reasons, may yield information regrading decreased bone mineral density, without added expense to the patient. The purpose of this study was to determine if Hounsfield Units, the standardized computed tomography attenuation coefficient, correlate with bone mineral density (BMD) as measured by DEXA.

Methods: Twenty-five patients mean age 71.3 years undergoing both lumbar spine Dual-Energy X-Ray Absorptiometry (DEXA) scans and CT were evaluated. In a region of interest, the Hounsfield Units was measured and correlated with DEXA BMD and DEXA T-scores. Normative data was generated from CT performed on 80 trauma patients.

Results: HU decreased relatively linearly by decade ranging from a mean of 255.1 in the second decade to 78.7 in the ninth decade. Mean HU for the 25 subjects was 107.1(36.8). Mean T-score was -1.42(1.51) and BMD 1.104(0.186)g/cm^2. Strong correlations were found between Hounsfield Units and bone mineral density, age, T-scores (p < 0.0001), Figure1 and 2. The mean HU and 95% confidence intervals for normal, osteopenic, and osteoporotic subjects were 133.0(CI 118.4 - 147.5), 100.8(CI 93.1 - 108.8), and 78.5(CI 61.9 - 95.1).

Conclusion: CT Hounsfield Units correlate strongly with DEXA scores, and can potentially provide an alternative method in determining regional bone mineral density at no additional cost to the patient. The information could conceivably be applied toward fracture risk assessment, diagnosis of osteoporosis, and early initiation of needed treatment. While we are not recommending CT as a substitute for DEXA, when a CT has been obtained for other reasons, regional HU can be measured to aid surgical decision making and as a guide for further testing.

217. Effects of Epidural Steroid Injections on Blood Glucose Levels in Patients with Diabetes Mellitus

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Introduction: Epidural steroid injections (ESI) are commonly used in the treatment of multiple spinal disorders. Corticosteroid injections have been evaluated in the total joints and hand literature showing systemic effects to diabetics. There has not been a clinical study to evaluate if ESI cause systemic effects in diabetics.

Methods: Diabetic patients who were scheduled for an ESI were given an opportunity to enroll in our IRB approved study. We collected the patient's most recent hemoglobin A1c (hA1c) and then asked them to track their blood glucose numbers at least twice per day for two weeks prior to and after their ESI.

Results: We noted a statistically significant increase in blood glucose levels in diabetic patients (N=30) after epidural steroid injection. The mean blood glucose level prior to ESI injection was 157.97 ± 45.71 and after ESI it was 304.00 ± 112.63. This represents an average 146.03 ± 88.5 increase in blood glucose levels after injection, which was significantly higher than 0 (p=0.0001, Wilcoxon signed-rank test). Using a nonlinear mixed effect model the estimated half life of this increase was 1.54 days (95% CI 0.86, 7.37), meaning that the patients were back within their normal standard deviation mean glucose levels within two days of injection. The Spearman correlation when evaluating the association between pre injection hA1c levels and maximum blood glucose change was 0.174 (p=0.502) indicating there is no correlation between pre injection hA1c levels and systemic response to ESI.

Conclusion: Epidural steroid injections were noted to cause a significant increase in the blood glucose levels in diabetics. There was no correlation between pre injection diabetic control, represented by hA1c levels, and post injection response. Diabetics who are candidates for ESI should be counseled that a blood glucose increase may be apparent post intervention but effects should not last longer than approximately two days.

218. The Prognostic Value of a Cervical Selective Nerve Root Block: A Correlation with Surgical Outcomes

Luis M. Tumialan MD; David C. LoPresti M.D.; Angelina N. Garvin BA; Wayne Gluf MD

Introduction: To compare the results of a selective nerve root block in the cervical spine with surgical outcomes from posterior cervical foraminotomy or anterior cervical discectomy for management of a single level cervical radiculopathy.

Methods: The authors prospectively followed patients with a unilateral single level cervical radiculopathy. All patients in this study had radicular symptoms which correlated with clinical history, neurological examination and MR imaging findings and had failed nonoperative management for a minimal period of 3 months. All patients were initially managed with a CT guided selective nerve root block. Pre-injection, post-injection and postoperative visual analogue scores (VAS) were obtained at 0, 30 and 90 days. Duration of relief was also documented.

Results: A total of 42 patients underwent a transforaminal cervical selective nerve root block for initial management of their unilateral single level cervical radiculopathy. Fifteen of these patients experienced recurrence or only temporary relief of their symptoms and opted for operative management. At 6 months, the remaining 37 patients required no further intervention. The mean preinjection/preoperative VAS was 57.1 mm (21-97). The mean post-injection VAS was 15.2 mm (0-45). The mean duration of relief was 20.3 days (1-75). The mean postoperative VAS at 30 days was 18.4 mm (0-60). A regression analysis demonstrated that reduction in pain from the baseline VAS to the postinjection VAS was highly predictive of outcomes 30 days after surgery (p =0.034). The coefficient of determination was 32%.

Conclusion: The pain reduction at 30 days after a posterior cervical foraminotomy or anterior cervical discectomy is well predicted by the initial reduction from the selective nerve root block. There is prognostic value in the cervical selective nerve root block for prospective surgical patients.

219. The Prognostic Value of a Lumbar Selective Nerve Root Block: A Correlation with Surgical Outcomes

Luis M. Tumialan MD; David C. LoPresti M.D.; Angelina N. Garvin BA; Wayne Gluf MD

Introduction: To compare the results of a selective nerve root block in the lumbar spine with surgical outcomes from a microdiscectomy for management of a single-level lumbar radiculopathy.

Methods: The authors prospectively followed patients with a unilateral single-level lumbar radiculopathy. All patients in this study had radicular symptoms which correlated with clinical history, neurological examination and MR imaging findings and had failed nonoperative management for a minimal period of 3 months. All patients were initially managed with a CT guided selective nerve root block. Pre-injection, post-injection and postoperative visual analogue scores (VAS) were obtained at 0, 30 and 90 days (when applicable) along with preinjection/preoperative and postoperative Owestry Disability Indices (ODI).

Results: A total of 51 patients underwent a transforaminal selective nerve root block for initial management of their unilateral single level radiculopathy. Fifteen of these patients experienced recurrence or only temporary relief of their symptoms and opted for operative management. At 6 months, the remaining 36 patients required no further intervention. The mean preinjection/preoperative VAS and ODI was 56.8 mm (17-98) and 23.5 (11-35) respectively. The mean postinjection VAS was 17.25 mm (0-38). The mean duration of relief was 18.3 days (0-70). The mean postoperative VAS and ODI at 30 days were 21.4 mm (0-57) and 13.4 (1-33) respectively. A regression analysis demonstrated that reduction in pain from the baseline VAS to the postinjection VAS was highly predictive of outcomes 30 days after surgery (p < 0.001). The coefficient of determination was 81%.

Conclusion: The pain reduction at 30 days after a microdiscectomy is well predicted by the initial reduction from the selective nerve root block. There is prognostic value in the selective nerve root block for surgical patients.

220. Proximal Junctional Kyphosis in Adult Thoracolumbar Instrumented Fusion: Time to Development, Clinical and Radiographic Characteristics, and Management Approach in 32 Consecutive Cases

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Introduction: Proximal junctional kyphosis (PJK) is a common mode of failure following instrumented thoracolumbar deformity surgery and often necessitates revision. Our objective was to assess the clinical and radiographic factors in a consecutive series of adults who developed PJK.

Methods: Consecutive cases of adults treated for thoracolumbar deformity that developed PJK from the contributing authors from 2004-2009 were identified. PJK was defined based on previously published criteria. Clinical records were reviewed and standard radiographic measurements were performed.

Results: 32 cases of PJK were identified (mean age 66 years, range: 46-80; 24 women/8 men). 17 (53%) had surgery prior to the index procedure. The most common comorbidities included osteopenia/osteoporosis (31%), hypothyroidism (31%), osteoarthritis (22%), and movement disorder (13%). The most common diagnosis for the index procedure was degenerative scoliosis (n=26, 81%). The uppermost instrumented vertebrae were T4 (n=1), T10 or T11 (n=30), or L1 (n=1), and the lower-most instrumented levels were: L4 (n=1), L5 (n=1), S1 (n=5), or ilium (n=25). Mean follow-up was 34 months. 16 (50%) required revision (mean of 1.7 revisions, range: 1-3) at a mean of 9.6 months (range: 0.7-40), and 16 (50%) did not require revision at last follow-up. Respective comparison of pre- and post-index surgery radiographic parameters showed no significant change in sagittal balance (9.6 vs. 8.0 cm, p=0.76), but there was a significant increase of lumbar lordosis (24 vs. 42 degrees, p<0.001) and T5-T12 kyphosis (30 vs. 53 degrees, p<0.001) and reduction of pelvic tilt (29 vs. 23 degrees, p=0.011).

Conclusion: Collectively, these data suggest that susceptibility to PJK may relate to development of an exaggerated postoperative compensatory thoracic kyphosis to offset a significant, intended surgical correction of lumbar lordosis. The resulting inadequate maintenance of sagittal balance, combined with the increased kyphosis, may predispose to development of PJK.

221. Direct Vertebral Body Derotation: A Comparison of Different Techniques

Amer F. Samdani MD; Steven Wei-Hung Hwang MD (Tufts University/New England Medical Center); Michelle Marks PT, MA; Tracey Bastrom MA; Randal Betz MD; Patrick Cahill

Introduction: Pedicle screw fixation has permitted the application of rotational forces to assist in correcting the 3-D deformity of the scoliotic spine. Surgeons may routinely apply a combination of derotation techniques when correcting deformity, but little is known of the impact from each maneuver. Theoretically, unnecessary derotation maneuvers may weaken the screw-bone interface. We sought to compare outcomes of various direct vertebral body derotation (DVBD) techniques as defined by inclinometer measures.

Methods: A large, multicenter, prospective database was retrospectively queried for patients with the diagnosis of AIS who have undergone posterior spinal fusion with application of DVBD techniques. All patients had at least 2 years of follow-up, and those having undergone thoracoplasty were excluded. Segmental derotation was defined as corrective rotational forces applied to one vertebral level, whereas en-bloc derotation referred to maneuvers involving more than one level.

Results: A total of 195 patients were identified. 104 patients underwent segmental derotation, 20 had en-bloc derotation performed, and 71 patients had both. No significant radiographic or clinical differences existed between the groups preoperatively or postoperatively. When subdivided into categories based on the magnitude of preoperative inclinometer measures (0-9 degrees, 10-15 degrees, and 16+ degrees), no significant difference in postoperative inclinometer measures were identified (p=0.43 to 0.95) (Table 1).

Conclusion: The use of varying derotation techniques in the correction of AIS deformity did not correlate with any difference in outcomes based on inclinometer measures. The additional use of en-bloc derotation to segmental maneuvers does not provide any more rib prominence correction.

222. Direct Vertebral Body Derotation, Thoracoplasty or Both: Which is Better with Respect to Inclinometer and SRS-22 Scores?

Amer F. Samdani MD; Steven Wei-Hung Hwang MD (Tufts University/New England Medical Center); Peter Newton; Baron Lonner; Michelle Marks PT, MA; Tracey Bastrom MA; Patrick Cahill; Randal Betz MD

Introduction: Direct vertebral body derotation (DVBD) and thoracoplasty (Th) are powerful tools for correction of rib deformities in patients with AIS. We evaluated Th, DVBD, and both (Th/DVBD) with respect to postoperative inclinometer readings and SRS scores to determine which provides the best correction of rib deformity and better patient satisfaction.

Methods: A prospective longitudinal database was queried to identify AIS patients who underwent a posterior spinal fusion with pedicle screws and 2 years' follow-up. 203 patients were identified grouped as follows: 1) Th alone (N=30), 2) DVBD alone (N=122), and 3) both Th/DVBD (N=51). Patients were subdivided based on their preoperative inclinometer reading: 1) = 9 degrees (mild), 2) 10-15 degrees (moderate), and 3)=16 degrees (severe). Pre- and postoperative inclinometer readings and SRS scores were compared using ANOVA.

Results: Overall, the groups were similar preoperatively except for the DVBD group having higher percent thoracic flexibility. The preoperative rib deformity values were Th=13.2, DVBD=14.0, and Th/DVBD=12.9 (p=0.27). Taken collectively, the post-op 2 year inclinometer readings were similar for all three groups (Th=5.2, DVBD=7.0, Th/DVBD=5.6, P=0.66). However, the SRS-22 self-image scores were significantly better for patients having both Th/DVBD (Th=3.4, DVBD=3.4, Th/DVBD=3.8, P<0.01). When patients were stratified by severity of pre-op rib deformities, all with mild prominences achieved similar corrections, although SRS self-image scores were highest in the Th/DVBD group. In patients with moderate and severe preoperative rib prominences, the addition of Th was necessary for optimal rib deformity correction, but there was no difference in SRS-22 domains (Table 1).

Conclusion: Our results suggest that Th alone, DVBD alone, or both provide equivalent inclinometer results in patients with mild preoperative rib deformities, but higher SRS-22 self-image scores are achieved using both Th/DVBD. For more severe rib prominences (> 10 degrees), better inclinometer readings are achieved with thoracoplasty, although SRS-22 self-image scores are comparable.

223. Differences in Treatment and Inpatient Outcomes for Hospitalized Scoliosis Patients in the United States from 1998 to 2007

Doniel Drazin MD, MA; Miriam Nuno; Frank L. Acosta MD

Introduction: Differences in access to treatment and outcomes have been documented in a variety of conditions in recent years. This study evaluates potential disparities in treatment selection and outcomes for hospitalized scoliosis patients. Patient- and hospital-specific factors were analyzed as independent variables for predicting surgical versus non-surgical management of these patients, as well as for in-hospital patient outcomes.

Methods: Using Nationwide Inpatient Sample (NIS) administrative 1998-2007 data, we captured cases having a primary diagnosis of scoliosis. Univariate and multivariate analyses evaluated race, gender, socioeconomic factors, and hospital characteristics as predictors of treatment (surgical versus non-surgical) and in-hospital outcomes (discharge, mortality, and complications).

Results: The study analyzed 9522 (surgical) and 2617 (non-surgical) cases. Univariate analysis showed both patient-and hospital-level variables as strongly associated with treatment selection and outcomes. Concerning treatment selection, multivariate analysis revealed African-Americans and Hispanics as less likely to be treated surgically, while Caucasians and private insurance patients were more likely to undergo surgery ($p<0.05$). These differences in treatment selection for minorities persisted even when controlling for comorbidities. Additionally, Caucasians showed a reduced risk of mortality, complications and adverse discharge compared to African-Americans and Hispanics ($p=0.01$). Large hospitals had higher surgical treatment rates than small or medium-sized facilities as well as a lower risk of mortality. Higher proportions of Caucasian patients were admitted to large teaching hospitals than African-American or Hispanic patients.

Conclusion: Significant disparities were found in the selection of operative versus non-operative treatments, as well as in in-hospital morbidity and mortality for hospitalized scoliosis patients based on racial and socioeconomic variables. This may in part be due to differences in access to the resources of large teaching hospitals for different racial and socioeconomic groups. Additional reasons for these disparities, and their impact on quality-of-life measures and future health resource utilization for scoliosis patients requires additional research.

224. The Safety and Efficacy of Transforaminal Lumbar Interbody Fusion for Deformity Correction in Degenerative Scoliosis with Spinal Stenosis

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Introduction: The utilization of a TLIF (Transforaminal Lumbar Interbody Fusion) approach for scoliosis offers patients deformity correction without the morbidity associated with more invasive reconstructive surgeries. The purpose of this study was to analyze intra- and postoperative complications associated with the TLIF surgical approach in patients undergoing surgery for spinal stenosis and degenerative scoliosis correction.

Methods: This study included a total of 29 patients that underwent TLIF for degenerative scoliosis with neurogenic claudication and painful lumbar degenerative disc disease. TLIF surgery was performed using a posterolateral pedicle screw construct. The average follow-up time was 27.4 months (range, 6 47).

Results: The average age of patients was 65.9 years (range, 49-83). TLIF procedures were performed at 2.2 levels on average (range, 1-4) in addition to 7.0 (range, 3 - 11) levels of posterolateral fusion. The mean preoperative coronal Cobb angle was 32.3 degrees (range, 15 - 55) compared to the mean of 15.4 degrees (range, 1 - 49) postoperatively. The mean operative time was 8.8 hours (range, 4.6-15.1), EBL - 1091.7 mL (range, 150-2500) and hospitalization time was 8.0 days (range 3 - 28). Clinical outcome was excellent/good in 17 (77%) of patients. The overall patient satisfaction rate was 77% (range, 42 - 100). Mean VAS decreased from 7.6 (range, 4 - 10) preoperatively to 3.6 (range, 0 -8) postoperatively. There was a total of 14 (48.3%) hardware and/or surgical technique related complications, 8 (27.6%) of which required additional surgeries. The systematic complications (31%) included death (1), cardiopulmonary arrest with resuscitation (1), myocardial infarction (1), pneumonia (5) and pulmonary embolism (1). A total of 5 patients (17.2%) had pseudoarthrosis.

Conclusion: This study suggests that the TLIF approach is a feasible and effective approach to treat degenerative adult scoliosis, but is still associated with a high rate of intra- and postoperative complications and a long recovery process.

225. Biomechanical Analysis of Iliac Screws versus S2 Alar-Iliac Screws

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Introduction: Current techniques of pelvic fixation have been associated with high rates of lumbo-sacral pseudarthrosis, failure of fixation and hardware complication. Hence, newer techniques were devised that allow for placement of screws into the ilium across the lumbosacral pivot point to improve biomechanical stability. However, some of these techniques require additional incisions and extensive soft-tissue dissection. This study describes and compares the biomechanical strength of two techniques that provide low-profile, in-line fixation without the necessity of additional incisions or soft-tissue dissection.

Methods: Embalmed cadaveric specimens (n=8, 4-male, 4-female) were utilized. Anatomically-referenced iliac screws and S2 alar-iliac screws measuring 7.5mm by 80mm were placed in-situ on opposite sides of each specimen, alternating between right and left for each type of fixation. Appropriate placement of screws was confirmed with fluoroscopy and direct examination after dissection of each pelvis. The pelvi were then harvested, hemi-sectioned and potted for biomechanical testing. Utilizing an MTS Bionix 858 Machine, screws were coaxially loaded at a rate of 5 mm/minute and pull out strength was measured in Newtons.

Results: Mean pull-out strength for anatomically-referenced iliac screws and S2 alar-iliac screws were 576 N (SD- 185) and 933 N (SD- 440), respectively. A statistically significant higher pull-out strength was noted in the S2 alar-iliac screws as compared to standard iliac screw ($p<0.05$).

Conclusion: Iliac fixation is often performed in a revision setting to successfully achieve arthrodesis across the lumbosacral junction. In this study, we demonstrate that utilizing an S2 alar-iliac fixation technique provides superior pullout strength potentially avoiding these complications and helping achieve arthrodesis.

226. Reduced Surgical Site Infections in Patients Undergoing Posterior Spinal Stabilization of Traumatic Injuries Using Vancomycin Powder

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Introduction: Despite improvements through the use of prophylactic systemic antibiotics, surgical site infections remain a significant problem in the treatment of traumatic spine injuries. Infection rates as high as 10% have been reported in this population. The impact on patients and cost of treating such infections is profound. Local delivery of antibiotics has been found to be efficacious in animal and human studies as an adjunct to systemic antibiotics in surgical site infection prophylaxis. We set out to evaluate the efficacy of using vancomycin powder in surgical sites to prevent infections.

Methods: Fifty-eight consecutive patients with traumatic spine injuries treated with instrumented posterior spine fusions at a single academic center received intra-operative vancomycin powder applied to their surgical site and prospectively followed for infection. This prospective cohort was compared to 60 consecutive patients undergoing posterior fusion for trauma immediately prior to the prospective cohort. History of previous spine surgeries, substance use, diabetes, and body mass index were compared. Incidence of infection was the primary outcome evaluated.

Results: The control (N=60) and treatment groups (N=58) were statistically similar, Table 1. There were no adverse reactions to the vancomycin powder. A statistically significant difference in infection rate was found between the treatment group (0%) and control group (12%, $p=0.02$), Table 2. No adverse effects were noted from use of the vancomycin powder.

Conclusion: The use of vancomycin powder in surgical wounds may significantly reduce the incidence of infection in patients with closed traumatic spine injuries treated with instrumented posterior spine fusion. Applying vancomycin powder to surgical wounds is a promising means of preventing costly and harmful post-operative wound infections.

227. Intra-Operative Glucose Levels and Its Association With Developing Post-Operative Surgical Site Infections Following Spine Surgeries

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Introduction: Post-operative wound infections following major surgical procedures continue to be a significant source of morbidity and mortality in the United States. Current recommendations from ICU and cardiac surgery management indicate that aggressive management of intra-operative glucose levels result in lower rates of surgical site infections. This study is a retrospective cohort analysis to determine the incidence of surgical site infections following elevated intra-operative glucose levels during spine surgeries.

Methods: Peri-operative glucose levels and infection control surveillance data were analyzed for 2208 patients who underwent cervical, thoracic, or lumbar spine surgical procedures at the Cleveland Clinic Center for Spine Health between March 2005 and March 2010.

Results: Out of 2208 patients, 112 (5.1%) developed a surgical site infection during the 30-day post-operative period. Non-infected patients had a mean intra-operative glucose level of 132.11 mg/dl (95% CI 130.72 - 133.5) compared to infected patients with a mean intra-operative glucose level of 130.95 mg/dl (95% CI 126.03 - 135.87 mg/dl. An independent two sample t-test found no significant difference in mean intra-operative glucose level between these two groups ($p = 0.6523$). Univariate logistic regression revealed a risk ratio per unit glucose of 1.00116 (95% CI 0.9953 - 1.0075, $p = 0.7081$). Chi-square analysis found no association between high glucose level (>110 mg/dl) and surgical site infection (chi-square value = 0.232, $p = 0.6304$). Follow-up analyses will be repeated to account for diabetes status.

Conclusion: We did not find a significant association between elevated intra-operative glucose levels and a higher incidence of post-operative surgical site infection. Our results add to previous case-control studies exploring the same association in neurosurgery. Because the causes of surgical site infection are multi-factorial, the role of other peri-operative variables in decreasing SSI incidence should be explored.

228. Multiple-Day Drainage When Using BMP for Long Segment Thoraco-Lumbar Instrumented Fusions Results in Low Reoperation Rates for Infection and Seroma

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Introduction: Concerns over increased infection and seroma rates have been raised when BMP is employed as an aid to fusion in spinal surgery. Few studies have explicitly documented these complications. In this study we evaluated 87 consecutive patients undergoing long segment thoracolumbar spinal fusions with BMP to assess drain output and the rates of reoperation for infection or seroma.

Methods: Inclusion criteria included: patients undergoing 4 or more levels of posterior instrumented thoracolumbar fusion, use of BMP for posterolateral arthodesis, age >18 years, and a perioperative followup of 60 days. 87 consecutive cases from a single institution were assessed. Typically, 2 1/8th inch hemovac drains were placed at surgery and discontinued when two consecutive shifts (8 hrs) demonstrated less than 30cc of output. Drain output, length of time of drainage, and need for reoperation for wound seroma or infection were retrospectively reviewed.

Results: Mean age was 58.5 (SD 16.2, range 20- 81). Primary operative indications were deformity, with 43 patients undergoing revision surgery. The average number of levels instrumented and arthrodesed with BMP was 9.2 (SD 3.7, range 4-18). The average dose of BMP was 31.2 mg or 2.6 large sponges (SD 9.6mg, range 12-48). Patients required drainage for a mean of 4.9 days (SD 1.3 days, range 3-9 days). The average total output was 1856cc (SD 787, range 530- 4310cc). There were no significant differences between dose of BMP used and amount or days of drainage ($p=0.3$ and $p=0.3$, respectively). The wound infection rate was 2.3% (2 cases, deep wound infection, required reoperation), and 2 (2.3%) sterile seroma occurred that required reoperation for drainage. No other wound complications were noted.

Conclusion: Use of BMP for long-segment posterior thoracolumbar fusions may be associated with significant drain output, requiring multiple days of drainage. However, when drained adequately, reoperations for infections and seromas occur infrequently

229. Efficacy of Prophylactic Preoperative Inferior Vena Cava Filters for Major Spinal Surgery in Adults: A Review of 219 Patients at a Single Institution

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Introduction: Venous thromboembolism (VTE) is a serious complication following major spinal reconstructive surgery in adults. Specifically, pulmonary embolism (PE) can result in significant morbidity and mortality, and has been reported in up to 13% of patients. Placement of prophylactic inferior vena cava filter (IVCf) was initiated as standard protocol for all high-risk spine patients after a pilot study demonstrated decreased VTE-related morbidity and mortality.

Methods: After IRB approval, medical records of all patients receiving an IVCf at a single institution were reviewed. Age, sex, surgical approach, postoperative deep vein thrombosis (DVT), postoperative superficial thrombus, presence of PE or paradoxical embolus, mortality, and IVCf complications were reviewed. Placement indications included history of DVT or PE, malignancy, hypercoagulability, prolonged immobilization, staged procedures > 5 levels, combined anterior/posterior approaches, iliocaval manipulation during exposure, and anesthesia > 8 hours. Descriptive statistics were used for the analysis of patient characteristics. Non-parametric, frequency statistics (odds ratios, chi-square) were used for analysis of main outcomes.

Results: 219 patients (150F, 69M) were analyzed with mean age of 58.8 years (range 17-86 years). There were two complications from IVCf placement (66 Greenfield and 157 retrievable). Incidence of lower extremity DVT was 18.7% in 36 patients. PE incidence was 3.7% (8/219), and the paradoxical embolus rate was 0.5% (1 patient). Prophylactic IVCf use reduced the odds of developing PE ($OR=3.7$, $p<0.05$) compared to population controls. Mean follow-up was >2 years. Patients receiving Greenfield filters had significantly higher VTE incidence compared to those receiving retrievable filters ($OR=2.8$, $p=0.008$). Anesthesia duration longer than 8 hours significantly increases VTE incidence ($p=0.029$). There were 14 deaths, none related to PE or paradoxical embolus.

Conclusion: VTE-related morbidity and mortality have heightened the awareness within the spine community to the peri-operative management of patients receiving major spinal reconstruction. Prophylactic IVCf placement significantly lowers PE rate.

230. Defining the Role of Early Surgical Decompression After Traumatic Spinal Cord Injury: Results of a Canadian Multicenter Study

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Introduction: Although there exists compelling experimental evidence supporting early spinal cord decompression after spinal cord injury (SCI), in practice, the role of surgery remains controversial in the absence of well-designed clinical studies. We present the results of a multicenter Canadian effort evaluating the impact of early versus late surgical decompression post SCI on neurologic outcome, length of hospital stay and development of complications.

Methods: A prospective cohort study of patients within the Ontario Spinal Cord Injury Rehabilitation (OSCIR) program was performed. Eighty-six ASIA A-D SCI patients, from six Ontario trauma centers were enrolled between 2007 and 2009. Patient information was collected preoperatively, postoperatively, at acute care discharge and at discharge from rehabilitation. A grouped analysis was performed comparing the cohort of patients who received early surgery (<24 hours after SCI) to those receiving late surgery (=24 hours after SCI). Fisher's exact test was used to examine for differences in baseline characteristics and outcomes between early versus delayed surgery patients.

Results: Of the 86 patients treated surgically there were 69 males and 17 females, with a mean age of 46.3 years. There was a trend towards older age and increased number of co-morbidities within the late surgery group. More patients had a 2 grade or more improvement in their ASIA Impairment Score (AIS) from admission to rehabilitation discharge in the early surgery group ($p<0.05$). This improvement was most marked amongst the early surgery ASIA A subgroup as compared to injury matched patients who underwent late surgery. Early surgery patients also experienced significantly greater improvements in ASIA sensory score over follow-up. The only significant predictor of acute care and overall length of stay was the admission AIS.

Conclusion: The results of this study support the growing body of literature which supports the principle of early intervention in the setting of spinal trauma and SCI.

231. Age Related Changes in Neurologically Intact Human Spinal Cords Assessed Using Diffusion Tensor MR Imaging

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Introduction: Diffusion Tensor MR Imaging (DTI) is an important imaging modality that can be useful for monitoring changes in tissue structure in the brain and spinal cord. We present the largest dataset of DTI derived indices in the cervical spinal cord of a cohort of non-myelopathic individuals. The aim of this study was to characterize diffusion characteristics in the human cervical spinal cord at various ages.

Methods: With appropriate IRB approval, twenty-eight neurologically intact age and sex matched subjects, 22 -85 years old, were enrolled in this study. A single-shot, twice-refocused, spin-echo, echoplanar pulse sequence was used to obtain axial images throughout the cervical segments of the spinal cord (C1 - C8) on a 1.5 Tesla Clinical MR imaging Scanner in 45 minutes.

Results: Diffusion images indicated a significant decrease ($p<0.05$) in fractional anisotropy (FA) and an increase in mean diffusivity (MD) after 65 years of age in both male and female subjects. Cervical mean diffusivity averaged 0.98+/- 0.03 x 10(-3) mm(2)/s, fractional anisotropy averaged 0.63+/- 0.02 mm(2)/s.

Conclusion: To date, this is the largest study of DTI indices in a non-myelopathic population. This study provides evidence of changes in diffusion characteristics in the cervical spinal cord after the age of 65 years. Changes in spinal cord diffusion with increasing age likely reflect changes in spinal cord tissue structure. We believe that the definition of the normative values of DTI indices in these individuals will assist in evaluating DTI index differences in patients with spinal cord disease in the future. These significant changes in diffusion characteristics should be accounted for when using DTI to diagnose abnormalities in older patients.

232. A Combined Neuroprotective Immuno-Modulatory Therapy Mitigates Early Bladder Dysfunction After Experimental Spinal Cord Injury

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Introduction: Traumatic spinal cord injury (SCI) can result in devastating motor and sensory deficits. Of these, impaired bladder function is particularly significant as urinary tract complications rank among leading causes of morbidity and mortality in acute and chronic SCI. Experimental SCI in a rat contusion model demonstrates characteristic bladder dysfunction that parallels clinical SCI including abnormal micturition, urinary retention, and pathologic changes in functional bladder wall compliance. Previously, our group demonstrated that a combined immuno-modulatory strategy of cAMP elevation and peripheral macrophage depletion improves not only late but early hindlimb motor function after SCI. In the present study, we investigated the same combined immuno-modulatory therapy to determine if it confers similar neuroprotective benefit in mitigating early bladder dysfunction after SCI.

Methods: 12 rats were subjected to T8 weight-drop contusion injury. Post-SCI, animals either were treated with combined cAMP elevation + peripheral macrophage depletion (treated=6) or were untreated (control=6). Early bladder dysfunction was assessed using 2 techniques. First, severity of urinary retention was evaluated by measuring residual urine volumes (RUV) after daily timed manual bladder expression. Second, on post-SCI day 7, functional bladder wall compliance was assessed by measuring bladder capacity at micturition during transurethral single cycle filling cystometry (0.125ml/min).

Results: Animals had equivalent initial thoracic SCI (hindlimb BBB score<1, post-SCI day 1) with resulting abnormal micturition. Control animals, however, demonstrated progressively increasing daily RUV signifying worsening urinary retention, whereas treated animals did not ($p<0.05$)(Figure1). On post-SCI day 7, bladder capacity with filling cystometry was significantly increased ($p<0.01$) in control (4.9±0.7ml) compared to treated (3.5±0.6ml) animals, signifying increased disturbance in functional bladder wall compliance among control animals.

Conclusion: Experimental SCI results in early bladder dysfunction characterized by urinary retention and abnormal functional bladder wall compliance. A combined immuno-modulatory strategy reduces these pathophysiologic findings in acute experimental SCI. Clinical translation of this therapy may decrease risk of urinary complications in SCI patients.

233. The Role of Nitric Oxide in Secondary Spinal Cord Injury: Insights from a New Transgenic Model

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Introduction: Acute spinal cord injury (SCI) occurs worldwide with an annual incidence of 15-40 cases per million per year. Recent advances have led to better understanding of the pathophysiology of SCI. Alterations in nitric oxide (NO), a neurotransmitter produced by Nitric oxide synthase from L-arginine have been implicated with different isoforms showing distinct temporal patterns. Arginase negatively regulates NO production through competition with NOS for the substrate L-arginie. Our aim is to develop a transgenic mouse model that over-expresses arginase in distinct cell populations to understand their role in NO production after SCI.

Methods: We used standard techniques to develop transgenic mouse models over-expressing the enzyme Arginase exclusively in neurons as well as in astrocytes. Plasmids containing the gene for arginase were cloned under the neuronal specific thy1 promotor as well as the Glial specific GFAP promotor. Transgenic founders were generated by pronuclear injections of the plasmids. Transgenic mice were identified at birth by eye pigmentation and confirmed by PCR using primers specific for Arginase. Western blot analysis, RNA extraction, enzyme essays as well as histology were established in the transgenic models and compared to control animals.

Results: Our transgenic animals show an up to 30 fold overexpression of Arginase with comparable enzyme activity. Arginine and citrulline levels are reduced in plasma of transgenic animals when compared to wild type controls. Despite these physiological discrepancies, our animals sustain normal growth. Under nonstressful conditions, these animals survive comparably to wild type litters, are fertile with offsprings born in mendelian ratio and have no histological abnormalities.

Conclusion: We were able to generate viable and fertile mice overexpressing Arginase specifically in neurons and glial cells. These mice will be a valuable tool to understand the role different cells play in the pathophysiology of acute spinal cord injury.

234. The Impact of Weekend Hospital Admission on the Timing of Intervention and Outcomes After Surgery for Acute Spinal Cord Injury in the United States, 2005-2008

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Introduction: Many studies haves suggested that patients who are admitted on the weekend have inferior outcomes compared to those admitted on a weekday. However, the impact of weekend admission on the timing of intervention and outcomes after surgery for acute spinal cord injury has not been previously evaluated.

Methods: Data from the national inpatient sample (2005-2008) were retrospectively extracted. Patients were included if they had a diagnosis of acute spinal cord injury, underwent spinal decompression with or without fusion and were admitted emergently or urgently. Multivariable logistic regression analyses were conducted to calculate the odds of death, the development of a post-operative complication and the performance of surgery on the day of or day after admission depending on if the hospital admission day was a weekend or a weekday. Logarithmic multivariate regression was used to evaluate the association of admission on a weekend with length of stay and hospital charges. All analyses were adjusted for differences in patient age, gender, co-morbidities, race, primary insurance, admission type and hospital characteristics.

Results: A total of 4,991 admissions were evaluated, of which 35% were on the weekend. Weekend admission was not significantly associated with a higher adjusted odds of in-hospital mortality (OR: 1.00. 95% CI: 0.70. 1.44). Patients admitted on the weekend did not have significantly different adjusted odds of performance of surgery on the day of or day after surgery (OR: 0.91, 95% CI: 0.77, 1.07). Post-operative complications, length of stay and total hospital charges were not significantly different between patients admitted on the weekend or a weekday.

Conclusion: Unlike other surgical diseases, the outcomes of patients admitted in the United States for acute spinal cord injury during the weekend do not differ from those admitted during the week. Nationwide, surgery is not delayed for patients with acute spinal cord injury who present on the weekend.

235. Long-Term Outcomes of Patients with Multilevel Ossification of the Posterior Longitudinal Ligament After Laminectomy, Laminoplasty and Laminectomy and Fusion: A Meta-Analysis of Observational Studies

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Introduction: Although posterior decompression is preferred for multilevel cervical ossification of the posterior longitudinal ligament (OPLL), few studies have evaluated the long-term outcomes of patients undergoing different posterior techniques. We report a meta-analysis of observational studies comparing the improvement in myelopathy and long-term complications including the development of post-operative kyphosis, the prevalence of axial pain and the progression of OPLL in patients with multilevel disease undergoing laminectomy, laminoplasty and laminectomy & fusion.

Methods: A literature search was performed using MEDLINE of studies indexed between January 1980 and June 2010. Predetermined study inclusion criteria included reporting outcomes for patients with OPLL separately from other etiologies of myelopathy; studies were excluded if they reported a total of ten or fewer patients. Data on the severity of myelopathy (measured by the Japanese Orthopedic Association (JOA) scale) and long-term complications were extracted and pooled assuming random effects.

Results: 40 studies with a total of 1,549 patients were included of which 8 reported laminectomy, 34 reported laminoplasty and 2 reported laminectomy and fusion. Among studies with a long-term mean follow-up (of at least four years), patients undergoing laminectomy and fusion had a non-significantly higher recovery rate of JOA score 62.5%, compared to 57.2% after laminoplasty and 53.4% after laminectomy. With an intermediate mean follow-up (of at least two years), kyphosis developed in 28.4% after laminectomy, 7.5% after laminoplasty and 0% after laminectomy and fusion. Axial pain was present in 35% of patients who underwent laminoplasty; progression of OPLL was noted in 70% after laminectomy and 66% after laminoplasty.

Conclusion: Substantial long-term improvement in myelopathy was seen regardless of the posterior technique utilized. However, long-term complications – particularly the development of kyphosis or neck pain and progression of OPLL – were common after laminectomy or laminoplasty. Additional research is needed on the long-term outcomes of patients with OPLL after laminctomy and fusion.

236. Assessment of Potential Predictors of Long-Term Outcomes of Surgery for Cervical Spondylotic Myelopathy: Clinical, Demographics and MR imaging Factors

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Introduction: Cervical spondylotic myelopathy (CSM) is the commonest cause of spinal cord dysfunction worldwide, leading to severe neurological impairments and major socio-economical costs. Nevertheless, prospective data on factors which predict surgical outcomes are lacking.

Methods: 65 consecutive patients with CSM were treated at a university-based centre. After excluding 4 patients who were lost to follow-up, 61 (follow-up: 94%) were analyzed for prediction of surgical outcomes. There were 42 males and 19 females with mean age of 57 years (range: 32 to 86 years). The mean mJOA score improved from 12.8 ± 2.7 points pre-operatively to 15.8 ± 2.3 points at 12 months post-operatively ($p<0.0001$). The modified Japanese Orthopaedic Association Scale (mJOA) was used as the primary outcome measure to quantify functional disability at admission and at 12-months follow-up. Potential predictors of functional outcomes included age, gender, duration of symptoms, severity of myelopathy, number of compressed segments, antero-posterior diameter [AP] and transverse area [TA] of the spinal cord at the site of maximal compression, three patterns of MRI spinal cord signal intensity changes. Data were analyzed using Spearman's rank correlation test, ANOVA and Mann-Whitney test, and stepwise multivariable regression.

Results: Higher baseline mJOA scores were associated with younger age (p=0.0002), shorter duration of symptoms (p=0.03), fewer compressed segments (p=0.04) and less severe cord compression (p=0.02). Moreover, better post-operative mJOA scores were associated with younger age (p<0.0001) and shorter duration of symptoms (p=0.07). Using multivariate analysis, baseline and follow-up mJOA scores were best predicted by age.

Conclusion: The data suggest that functional outcomes can be predicted by age and baseline mJOA scores. Moreover, age negatively affects functional outcomes following surgical treatment.

237. The AOSpine North America Cervical Spondylotic Myelopathy Study: Perioperative Complication Rates Associated with Surgical Treatment Based on a Prospective Multicenter Study of 302 Patients

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Introduction: Cervical spondylotic myelopathy (CSM) often warrants surgical treatment. Our objective was to assess complication rates associated with the surgical treatment of CSM based on a prospective multicenter study.

Methods: The AOSpine North America CSM study is a recently completed prospective multicenter study of patients surgically treated for CSM. Standardized forms were used to collect clinical and surgical data. Perioperative complication rates (within 30 days of surgery) were assessed.

Results: A total of 302 patients (178 men/124 women) were enrolled, with a mean age of 57 years (range: 29-86). Surgical approaches included anterior-only (n=176, 58%), posterior-only (n=107, 35%), and combined anterior-posterior (n=19, 6%). Fusion, laminoplasty, and corpectomy were performed in 27%, 13%, and 18% of cases, respectively. Of 332 reported adverse events, 73 were adjudicated to be complications, including 25 major (8%) and 48 minor (16%). The most common complications included: cardiopulmonary events (3.3%), infection (7 superficial/2 deep, overall 3.0%), dysphagia (3.0%), C5 radiculopathy/palsy (1.7%), worsened myelopathy (1.3%), new radiculopathy other than C5 (1.0%), epidural/wound hematoma (1.0%), instrumentation malposition/migration (1.0%), durotomy (1.0%), other neurological deficit (0.7%), renal complications (0.7%), and altered mental status (0.7%). Single cases of death, stroke, re-operation (not otherwise specified), thromboembolism, wound dehiscence, worsened neck pain, and pneumonia were reported. Ten miscellaneous complications were documented.

Conclusion: These data provide benchmark rates for perioperative complications associated with the treatment of CSM and demonstrate a remarkably low rate of neurological complications, with the vast majority complications being treatable and without long-term impact.

238. Spinal Injuries in Children and Adolescents

Jan Stulik; Jan Kryl; Michal Barna (FN Motol); Petr Nesnidal MD (FN Motol)

Introduction: In this retrospective study, the effectiveness of conservative and surgical treatment of injured spines in children is evaluated in a 10-year period.

Methods: All patients from birth to the completed 18th year of age treated in our departments between 1996 and 2005 were included in this study. The patients, evaluated in three age categories (0-9, 10-14, 15-18), were allocated to two groups according to the treatment used.

Results: During 1996 through 2005, we treated a total of 15 646 patients with injury to the skeleton, aged 0 to 18 years. The spine was affected in 571 cases, which is 3.6%. We used conservative treatment in 528 (92.5%) and surgery in 43 (7.5%) children. The group of patients treated conservatively consisted of 292 boys (55.3%) and 236 girls (44.7%); 219 (41.5%) were in the 0-9 year category, 251 (47.5%) were between 10 and 14 years old and 58 (11%) were 15 to 18 years old. In all age categories, injury to the thoracic spine was most frequent (340; 64.4%). Multi-segment injury in 124 patients (23.5%). The thoracolumbar spine was affected in 22 patients (4.2%), and lumbar vertebrae in 28 patients (5.3%), upper cervical spine in 4 (0.8%) and lower cervical spine in 10 (1.9%) patients. None of the patients showed neurological deficit. The surgically treated group included 29 (67.4%) boys and 14 (32.6%) girls; two (4.7%) children were between 0 and 9 years, nine (20.9%) between 10 and 14 years, and 32 (74.7%) between 15 and 18 years. The upper cervical spine was operated on in 5 (11.6%), lower cervical spine in 8 (18.6%), thoracic spine in 13 (30.2%), thoracolumbar spine in 5 (11.6%) and lumbar vertebrae in 12 (27.9%) patients. Neurological deficit was recorded in 9 (20.9%) patients.

Conclusion: Childhood spinal injuries account for only 2 to 5% of all spinal injuries and for 3.6% of all skeletal injuries in children. Conservative treatment is preferred; surgery before 12 years of age is strictly individual, while after 12 years therapy is similar to that used in adults.

239. Diffusion Tensor MR Imaging in Rats with Varying Spinal Contusion Severity

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Introduction: Diffusion Tensor Imaging (DTI) is a promising novel MRI based technique for spinal cord tractography. We have previously shown that DTI derived indices, including mean diffusivity (MD), fractional anisotropy (FA), lateral and transverse apparent diffusion coefficients (lADC and tADC) correlate with structural and functional changes after SCI in the zone of injury. We present the preliminary results of our recent investigations in the validation of DTI FA as a biomarker for distal changes in the cervical spinal cord after experimental thoracic injuries of varying severity.

Methods: Four groups of rats were used for the experiments. These included animals with sham surgery, mild, moderate and severe thoracic injuries derived from a standard NYU impactor. Animals were imaged in vivo using a 9.4T magnet, and axial diffusion weighted images were collected at a b-value of 500 seconds/mm(2). Average FA values were calculated in axial sections of the cervical spinal cord with five slices representing C2-3/C3-4/C4-5/C5-6 and C6-7 respectively.

Results: In all three injury groups, average FA values showed a progressive decreasing trend in a caudal cephalad direction ranging from 0.69 to 0.59 mm(2)/s in FA. Severely injured rats showed the greatest reduction in FA values (average of 0.9 decrease in FA) with moderate and mild injured animals showing slightly lesser reduction (average of 0.6 and 0.4 mm(2)/s decrease in FA respectively). FA values in the severe injury group were significantly different (analysis of variance [ANOVA], p > 0.05) than the other two groups. No significant difference was observed between the mild and moderate groups.

Conclusion: We have demonstrated that FA can be a reliable biomarker for estimating spinal cord structural changes in the cervical spinal cord after thoracic injury. In addition, our studies show that FA changes in the cervical cord can reflect injury severity in the thoracic cord. These observation carry important implications in further refining DTI indices to assess SCI severity.

240. CTA Screening for Vertebral Artery Injury in Transverse Foramen Fractures in 320 Patients

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Introduction: Transverse foramen fractures are a common finding after cervical spine trauma. Computed tomography angiography (CTA) is a rapid method to screen for vertebral artery injury in patients who sustain these fractures.

Methods: We reviewed the prospective trauma database of 2084 consecutive cervical spine fractures from 2000 to 2009. We identified 320 patients with transverse foramen fractures and computed tomography angiography. The primary goal is to identify the incidence of vertebral artery injury in this blunt trauma population.

Results: CTA results were obtained on all 320 patients with cervical transverse foramen fractures. In this population, 19% of patients were found to have sustained vertebral artery injury on CTA.

Conclusion: Transverse foramen fractures of the cervical spine should undergo screening with CTA to evaluate for vertebral artery injury. Fracture patterns associated with vascular injury will be discussed. Outcomes of various treatment methods employed will be discussed.

241. Dens Fractures in Patients Over 65 Years of Age: Anterior Screw Fixation of the Dens Versus Posterior Fixation of C1-C2

Jan Stulik; Jan Kryl; Petr Nesnidal MD (FN Motol)

Introduction: This study is a retrospective evaluation of dens fractures in patients over 65 years of age treated with anterior screw fixation of the dens (ASF) or posterior atlantoaxial fixation and fusion (PF).

Methods: We treated surgically 28 patients older then 65 years with dens fractures, with a mean age of 77.4 years (65-90 years). According to the type of treatment the whole cohort was divided into 2 groups that were subdivided into two age groups of patients 65-74 years old (N=8, mean age 68.5) and older then 75 years (N=20, mean age 81). Neurological deficits were found in three patients, Frankel D type. All patients underwent radiograph examination in two projections, CT scans and in most cases also MRI examination. Based on these examinations, the type of injury was determined and method of treatment indicated. Follow-up was 12 to 78 months after the surgery (mean 31.3 months) with consideration on aetiology and type of injury, neurological finding, method of treatment, union of the fracture lines or C1-C2 fusion, stability of the spine and the final outcome.

Results: There was statistically significant difference in the mortality ($p<0.05$), with 0 % in the younger group and 40 % in the older group. Mortality within 6 weeks after the injury was 28.6 %. Mortality after ASF was 21.4% and mortality after PF was 35.7% ($p>0.05$). Of the 20 surviving patients, 11 were treated with ASF and 9 with PF. We found only one case of nonunion of the dens (9.1 %) and one fibrous callus in the region of C1-C2 fusion and the fracture line in the dens (11.1 %) ($p>0.05$).

Conclusion: Active surgical treatment conduces the improvement of the quality of life of elderly patients after dens fractures. Mortality is influenced by the age rather than by the surgical technique used. Elderly patients with a neurological deficit mostly die of associated diseases.

242. A Pilot Evaluation of the Role of Bracing in Stable Thora–columbar Burst Fractures

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Introduction: The management of thoracolumbar burst fractures may depend on clinical presentation of neurological deficit as well as radiographic features of fracture severity suggestive of instability.[1] When patients are neurologically intact and have mild deformity on computed tomography (CT), conservative therapy may be applied, conventionally involving bracing over months to permit fracture stabilization.[2,3] We investigated the utility of bracing versus no bracing among stable thoracolumbar burst fractures.

Methods: Patients with stable thoracolumbar burst fractures, single level between T12 and L2, without neurological deficit or lower extremity injury were entered into this study. Randomization was computer-generated in sealed envelopes. Investigated endpoints were at time of presentation and at 6-months follow-up and included radiographic outcomes of kyphotic progression and loss of vertebral height and clinical outcomes of self-reported pain and disability. Continuous variables were analyzed by two-factor ANOVA (time and treatment as factors), at the 0.05 level of significance.

Results: There were no differences between patients treated with or without bracing regarding the level of injury ($p=0.18$) and initial spine geometry including extent of fragment retropulsion ($p=0.97$), anterior loss of height ($p=0.56$), or Cobb angle ($p=0.26$). Progressive loss of height occurred to by additional 17±4% in both groups ($p=0.96$) and degree of kyphotic progression was also no different by treatment (brace 6±2, no brace 8±2, $p=0.59$). Improvements in self-reported pain and disability were observed in both treatment groups, to similar extent regardless of management arm (Figure 1, $p=0.40$).

Conclusion: Patients with stable thoracolumbar burst fractures treated with or without bracing had similar outcomes at 6 months. Radiographic outcomes of fracture geometry and clinical outcomes of pain and disability scores were no different by treatment type. These patients may benefit from conservative therapy simply involving sequential imaging without brace immobilization, although larger series of patients may be required.

243. Clinical Outcome and Risk of Reoperation for Recurrent TCS in 99 Consecutive Children Operated for Tight or Fatty Filum

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Introduction: For operative division of a tight or fatty filum in pediatric patients, the clinical outcome is often assumed to be favorable, while complications and risk of reoperation for recurrent tethered cord syndrome (TCS) are frequently considered negligible.

Methods: In this retrospective study, the authors reviewed the medical records of 99 consecutive children who underwent initial division of the filum terminale at Cincinnati Children's Hospital Medical Center (November 1995 - May 2006) for a tight or fatty filum. Presenting symptoms/signs, MRI findings, complications, postoperative symptoms/signs, and need for reoperation were recorded. Mean follow-up for all patients was 32 months; 79 were followed for greater than or equal to 6 months and 67 were followed for greater than or equal to 12 months.

Results: The most common presenting symptoms were bladder and/or bowel dysfunction, followed by gait abnormality, back pain, and spasticity. At last follow-up, 86 patients were improved or stable, while 11 patients had at least one symptom/sign which had worsened. There were a total of 12 complications in 9 patients including 5 wound infections, 4 CSF leaks, 1 pseudomeningocele, 1 stitch abscess and 1 transient headache. Five children underwent a reoperation for recurrent TCS with further detethering of the spinal cord. Worsening back pain was the most common symptom in those patients requiring reoperation. Mean time to reoperation was 58 months (range 22 - 73 months). Arachnoid adhesions were found to have accounted for the retethering at the time of reoperation in four of the five patients.

Conclusion: Division of a tight or fatty filum, in this consecutive series of pediatric patients, resulted in improved or stable symptoms in 89% of patients. However, the complication rate and 5.1% rate of reoperation for recurrent TCS are not insignificant.

244. Determination of the Minimum Improvement in Pain, Disability, and Health State Associated With Cost-Effectiveness: Introduction of the Concept of Minimum Cost Effective Difference (MCED)

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Introduction: Spinal surgical outcome studies rely on patient-reported-outcomes (PRO) to assess effect. A shortcoming of these outcome-metrics is that extent of change in numerical scores lack a direct meaning or clinical significance. Hence, the concept of minimum clinical important difference (MCID) was adopted as smallest improvement in PRO needed to achieve treatment-effectiveness. While total cost of <$50,000 per QALY-gained is considered cost-effective for a particular treatment, a measure for smallest improvement in PRO that is associated with cost effectiveness has yet to be introduced. Here we utilize a common MCID-calculation method with a cost-utility threshold-anchor to introduce the concept of minimum cost effective difference (MCED).

Methods: Forty-five patients undergoing trans-foraminal lumbar interbody fusion (TLIF) for degenerative spondylolithesis were included. BP-VAS, LP-VAS, ODI, EQ-5D were administered before and 2-years post-operatively. Cost was calculated from Resource use x Medicare national allowable payment amounts (direct cost) and Missed work x self-reported gross-of-tax wage rate (indirect cost). Total cost per QALY gained was assessed for each patient. The MCED for each PRO was determined using receiver operating characteristic (ROC) curve analysis with <$50,000/QALY as cost-effective anchor and MCID determined with the health transition index (HTI) of the Short Form-36 as anchor.

Results: A significant improvement in all outcome measures was observed two years after TLIF (Figure 1), with a mean two-year gain of 0.86 QALYs per patient. Cost was <$50,000/QALY gained for 27 (60%) patients. MCED was greater than MCID for each PRO: 3.1 vs. 2.1 for VAS-LP, 3.1 vs. 2.1 for VAS-BP, 19 vs. 14 for ODI, and 0.32 vs. 0.15 for EQ-5D, Table 1. For MCED, area under the ROC curve ranged from 0.78-0.98, suggesting the four PRO change scores were accurate predictors of cost-effectiveness. Mean cost per QALY-gained was lower for patients achieving versus not-achieving MCED in VAS-LP ($43,560 vs. $112,087), VAS-BP ($41,280 vs. $129,440), ODI ($30,954 vs. $121,750), and EQ-5D ($35,800 vs. $189,412).

Conclusion: Minimum cost effective difference serves as the smallest improvement in outcome metric that represents a cost-effective response to surgery. The extent of improvement associated with cost-effectiveness was consistently greater than that associated with patient-reported clinical effectiveness (MCID). MCED following TLIF is 3.1 points for BP-VAS, 3.1 points for LP-VAS, 19 points for ODI, and 0.32 QALYs for EQ-5D.

245. Comparative Effectiveness of Minimally Invasive Versus Open Transforaminal Lumbar Interbody Fusion: Two-year Assessment of Narcotic Use, Return to Work, Disability, and Quality of Life

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Introduction: Minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) for lumbar spondylolithesis theoretically allows for surgical treatment of back and leg pain while minimizing blood loss and tissue injury. While prior studies have demonstrated shorter hospital stay and equivocal six and twenty-four month outcomes with MIS- versus open-TLIF, the effect of MIS techniques on post-operative narcotic use and return to work are poorly understood

Methods: Forty patients undergoing MIS-TLIF (n=20) or open-TLIF (n=20) for grade I degenerative spondylolithesis-associated back and leg pain were enrolled. Two-year outcomes were prospectively assessed via phone interview and included pain [visual analogue scale (VAS)], low-back disability [Oswestry disability index (ODI)], quality of life [EuroQol (EQ-5D)], occupational disability, and narcotic use.

Results: MIS versus open-TLIF cohorts were similar at baseline. Median [IQR] length of hospitalization following surgery was significantly less for MIS- vs. open-TLIF (3 [3-3] vs. 5.5 [4-6] days), p=0.001. MIS- versus open-TLIF patients demonstrated similar two-year improvement in VAS-BP, VAS-LP, ODI, and EQ-5D scores, Figure3. Overall, median [IQR] length of post-operative narcotic use was 3.0 [1.4-4.6] weeks and significantly shorter for MIS- vs. open-TLIF patients (2.0 [1.0-3.0] vs. 4.0 [1.4-4.6] weeks, p=0.008),Figure 1. Overall, median [IQR] time to return to work was 13.9 [2.2-25.5] weeks and significantly shorter for MIS- vs. open-TLIF patients (8.5[4.4-21.4] vs. 17.1 [1.8-35.9] weeks, p=0.02), Figure 2.

Conclusion: Both minimally invasive and open-TLIF provide long-term improvement in pain, disability, and quality of life in patients with back and leg pain from grade I degenerative spondylolithesis. However, MIS-TLIF may allow for shortened hospital stays, reduced post-operative narcotic use, and accelerated return to work, influencing factors associated with direct medical costs and indirect costs of lost work productivity.

246. Comparative Analysis of Surgical Site Infection after Minimally Invasive Versus Open Posterior/Transforaminal Lumbar Interbody Fusion: Analysis of Hospital Billing and Discharge Data from 5,328 Patients

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Introduction: Surgical site infection (SSI) following posterior or transforaminal interbody fusion (P/TLIF) of the lumbar spine is associated with significant morbidity and medical resource utilization. To date, there have been no studies conducted with sufficient power to compare the incidence of SSI following minimally invasive (MIS) versus open P/TLIF procedures. We assess the incidence and direct costs of SSI in patients undergoing MIS versus open P/TLIF from a hospital-system database representing more than 600 hospitals and 5 million discharges per year.

Methods: In a retrospective longitudinal analysis of hospital discharge and billing records from the Premier PerspectiveTM database, all patients undergoing P/TLIF were identified via International Classification, 9th Revision, Clinical Modification (ICD-9-CM) procedure codes. MIS procedures were identified by instrumentation trade name. SSI was defined as a subsequent diagnosis of postoperative infection or administration of intravenous antibiotics 1-8 weeks postoperatively. Medicare reimbursement rates and commercial payer charge data were used to estimate the direct medical costs of SSI.

Results: 3,793 patients underwent open P/TLIF (1,625 one-level, 2,168 two-level) and 1,535 patients MIS-P/TLIF (882 one-level, 653 two-level). Overall, MIS- vs open-P/TLIF was associated with a reduction in SSI [71 (4.6%) vs 228 (6%), p=0.047], Table 1. Stratified by levels fused, SSI was similar for one-level P/TLIF [41 (4.6%) vs 77 (4.7%), p=0.919], but significantly reduced for two-level MIS-P/TLIF [30 (4.6%) vs. 151 (7.0%), p=0.030], Table 2. The estimated cost of surgically managed SSI was $23,380 and medically managed SSI $12,419. For two-level fusion, estimated SSI-associated cost per 100 P/TLIFs performed was $115,959 for open- and $72,306 for MIS-P/TLIF (cost savings: $43,653 per 100 two-level P/TLIFs performed).

Conclusion: This population-based study of data from over 600 hospitals in the US indicates that MIS- versus open-P/TLIF was associated with a decreased incidence of post-operative infections after two-level lumbar fusion. Considering the morbidity and costs associated with SSIs, MIS- lumbar fusion may be a valuable tool in reducing hospital infection rates and costs associated with spine care.

247. Endoscopic Image-Guided Transcervical Odontoidecomy: Long-Term Outcomes of 15 Patients with Basilar Invagination

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Introduction: Ventral decompression with posterior stabilization is the preferred treatment for symptomatic irreducible basilar invagination (BI). However, the standard (and expansile) transoral approaches to the dens can be associated with substantial morbidity. Endoscopic image-guided transcervical odontoidectomy (ETO) may allow for decompression to be performed with less morbidity. We report the largest series with the longest follow-up of patients undergoing odontoidectomy for BI via an endoscopic transcervical approach.

Methods: 15 patients who had a follow-up of at least 9 months were retrospectively reviewed. Intra-operatively, the vertebral body of C2 was removed and the odontoid was resected in a "top-down" manner using endoscopic visualization and frameless stereotactic navigation. Posterior instrumented stabilization was subsequently performed.

Results: The average (± standard deviation) age of the patients was 42.6±24.5 (range 11-72) years; the mean pre-operative degree of basilar invagination (measured above the McGregor line) was 12.0±9.9 (range 0-35) mm. Post-operative complications occurred in 6 patients, including a urinary tract infection (n=2), upper airway swelling (n=2), dysphagia (n=2), gastrostomy tube placement (n=1) and an asymptomatic pseudomeningocele (n=1). The average length of hospital stay was 9.1±4.9 (range 2-23) days. With a mean follow-up of 34.9±14.4 months, myelopathy improved in all patients and the mean modified Japanese Orthopedic Association (mJOA) score increased from 11.1±4.0 to 16.0±1.4 (p=0.0001). Patients with a diagnosis other than rheumatoid arthritis (p=0.003) or who a higher pre-operative mJOA score (p=0.026) were significantly more likely to have a complete neurological recovery; improvement in neurological function was not significantly associated with pre-operative severity of basilar invagination. At the final follow-up, all patients had evidence of solid arthrodesis and resolution of their pre- or post-operative dysphagia. No patients experienced late neurologic deterioration.

Conclusion: ETO may be a valid treatment for patients with symptomatic irreducible basilar invagination that avoids some of the morbidity of transoral surgery and leads to long-term improvement in myelopathy.

248. Minimally Invasive Treatment of Adjacent Segment Degeneration via XLIF

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Introduction: The XLIF approach provides a minimally disruptive alternative to anterior column access that allows for large graft placement, disk height restoration, and indirect decompression, while avoiding posterior scar tissue from the previous procedure. Results of ASD treated with XLIF are presented.

Methods: Of our single-site consecutive series of 932 XLIF patients, 276 were treated for ASD. Clinical and radiographic measures were prospectively collected and evaluated.

Results: Age ranged from 29-91 years (average 61.6 years). 90.6% had one or more comorbidity. 144 patients (52%) were obese or morbidly obese. All but one case included supplemental fixation: 47% unilateral pedicle screws, 4% bilateral pedicle screws, 12% lateral embroidered plate, and 43% laterally tabbed interbody implant. In 15 cases with prior posterior instrumentation, the pre-existing rods were removed unilaterally and revised on that side; in all other cases with prior instrumentation, adjunctive lateral fixation was used. Hospital stay averaged 1.3 days, with 2 blood transfusions and one wound infection. Complications included intraoperative hardware failure (4, revised during same procedure with no incident), ileus (5), gallstone pancreatitis (1), urinary retention (3), kidney stone (1), peritoneal catheter occlusion (1), pulmonary embolism (1), subcutaneous hematoma (1), delirium (1), atrial fibrillation (3), MI at 6 weeks post-op (1), compression fracture at an adjacent level (5), sacral fracture (1), and postoperative quadriceps weakness (1, resolved within 4 weeks of surgery). Average VAS scores improved by 4.6 points from pre-op to 12 months. Average disk height improved from 6.4 to 10.6 at post-op, settling to 8.7mm at 24 months; slip from 3.5 to 0.6mm. Definitive signs of fusion (Lenke 1-2) were present in 74% at 3 months, 91% at 6 months, 96% at 12 months and 95% at 24 months.

Conclusion: Our experience using XLIF in the ASD population has shown that clinical and radiographic indicators improve commensurately and the overall outcome is encouraging.

249. Comparative Clinical Outcomes Following Minimally Invasive L5-S1 Interbody Fusion, Comparison of TLIF, ALIF, and AxiaLif for Single-Level Arthrodesis

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Introduction: The development of new minimally invasive spine (MIS) techniques for lumbosacral fusion has provided the spine surgeon multiple methods for fusion at the L5-S1 interbody space. The authors compare clinical and radiographic outcomes from a cohort of prospectively followed patients treated with three modern techniques, MIS-TLIF, ALIF, and AxiaLIF.

Methods: Between June 2003 and January 2009, 58 patients were treated for isolated degenerative disk disease of the L5-S1 segment. All patients presented with back pain with or without radiculopathy and had failed conservative management. The average patient age was 43.34 years. Twenty patients were treated with TLIF, 19 with ALIF, and 19 with AxiaLIF. All patients were prospectively followed with pre- and post-operative visual analog score (VAS) and Oswestry-Disability Index (ODI) scores as well as routine radiographic follow-up.

Results: Clinical outcome with ODI demonstrated a decrease in ODI of -25 with TLIF, -22 with ALIF, and -24 with AxiaLIF. VAS leg scores decrease 92% in patients treated with TLIF, 76% with ALIF and 71% with AxiaLIF. The time of access to the interbody space was most rapid with AxiaLIF (65m) and slightly longer with ALIF (85m) and TLIF (105m). Radiographic outcomes showed that ALIF produced the best distraction of the interbody space (8.6mm); TLIF (6.3mm), AxiaLIF (5.9mm). Fusion with TLIF and ALIF was 95% and AxiaLIF 90%. Subsidence was greatest with AxiaLIF 16% followed by TLIF (12%) and ALIF (9%). Complications included 2 patients with radiculitis following TLIF. There was a single CSF leak (TLIF) and a single lumbar plexus injury (ALIF). There was a single vascular injury (ALIF) and a single visceral injury (AxiaLIF).

Conclusion: MIS-TLIF, ALIF, and AxiaLIF are all modern, MIS-type approaches to the L5-S1 interbody space. Patient outcomes suggest each has unique clinical strengths and specific disadvantages. Complications with each approach is unique and primarily related to anatomy of the access route.

250. Cost-Utility Analysis of Minimally Invasive Versus Open Multilevel Decompression for Lumbar Stenosis

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Introduction: Minimally invasive (MIS) multi-level hemilaminectomy for degenerative lumbar spinal stenosis allows for effective treatment of back and leg pain while theoretically minimizing blood loss, tissue injury, and post-operative recovery. No studies to date have evaluated the comprehensive healthcare costs associated with multilevel laminectomy procedures, nor assessed the cost-effectiveness of MIS versus open- multilevel laminectomy.

Methods: Fifty-four patients undergoing MIS paramedian tubular (n=27) or open multilevel hemilaminectomy (n=27) for lumbar stenosis associated radiculopathy were prospectively studied. Total back-related medical resource utilization, missed work, and health-state values (quality adjusted life years (QALYs), calculated from EQ-5D with U.S. valuation) were assessed after two-year follow-up. Two-year resource use was multiplied by unit costs based on Medicare national allowable payment amounts (direct cost) and work-day losses were multiplied by the self-reported gross-of-tax wage rate (indirect cost). Difference in mean total cost per QALY gained for MIS- versus open-laminectomy was assessed as incremental cost-effectiveness ratio (ICER: COSTmis - COSTopen/QALYmis - QALYopen).

Results: MIS versus open cohorts were similar at baseline, Table 1. Both MIS and open laminectomy were associated with a two-year gain of 0.72 QALYs, Figure 1. Mean direct medical costs ($13,334 vs. $14,291), indirect societal costs ($9,775 vs. $11,130), and total two-year cost ($23,109 vs. $25,420, p=0.21) were similar between MIS- and open-hemilaminectomy, Table 2. MIS was associated with similar total costs and utility, making it a cost equivalent technology compared to the traditional open approach.

Conclusion: MIS- versus open- multilevel hemilaminectomy was associated with similar cost over two years while providing equivalent improvement in quality adjusted life years. In our experience, MIS- versus open- multilevel hemilaminectomy is a cost equivalent technology for patients with lumbar stenosis associated radicular pain.

251. Minimally Invasive Lateral Access Surgery for Symptomatic Thoracic Disc Herniation: Initial Clinical Experience With Clinical and Radiographic Outcomes

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Introduction: Symptomatic herniated thoracic discs remain a surgical challenge and historically have been associated with high levels of complications. While the neurologic outcomes have improved with the abandonment of the decompressive laminectomy; surgical complications, morbidity and the need for fusion have continued. The purpose of this study is to demonstrate the safety and reproducibility of the minimally invasive lateral thoracic approach for symptomatic thoracic herniated intervertebral discs with clinical and radiological outcomes.

Methods: We retrospectively studied 24 patients to assess the clinical and radiographic results using minimally invasive surgery for the treatment of thoracic herniated discs. All patients underwent a lateral transthoracic approach utilizing an expandable tube retractor. Follow up times were an average of 21 months. The patients were followed with neurologic examination, visual analog score (VAS) and Oswestry disability index (ODI). Post-operative computed tomography was performed to assess the extent of bony resection.

Results: The mean blood loss was 415 ml. The mean visual analog scale score improvement for thoracic pain was 4.1. The Oswestry disability index improved an average of 36%. All discs were successfully removed except in one patient. One case was complicated by durotomy and one case was complicated by worsened myelopathy Asia D to ASIA C. There was no incidence of wrong-level surgery.

Conclusion: Our early experience suggests that the minimally invasive lateral transthoracic approach is safe, reproducible and effective for achieving adequate decompression in thoracic disc herniations in a less invasive manner than traditional surgical treatment options. This surgical technique allows the surgeon to directly visualize and protect the dura prior to visualizing the lesion without the need to collapse the lung. As this technique is advanced, the applicability of minimally invasive surgery will likely be expanded and will afford the opportunity for reduced complications.

252. Early Radiographic Outcomes of XLIF in the Minimally Invasive Treatment of Adult Scoliosis: Results from a Prospective Multicenter Non-Randomized Study of 107 Patients

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Introduction: Surgical intervention in adult scoliosis patients has traditionally been performed using large open anterior and/or posterior procedures. This report summarizes the early radiographic outcomes of a minimally-invasive approach (XLIF) for the treatment of adult scoliosis, as part of an ongoing prospective, multi-center study.

Methods: 107 patients were treated for adult scoliosis with XLIF at 14 US centers. Radiographs were collected preoperatively and postoperatively at 2 weeks, 3, 6, 12, and 24 months. Radiographic analysis included measures of lumbar lordosis (L1 to S1), coronal Cobb angle, device subsidence, and device migration.

Results: Radiographic follow-up was available for 103 patients who were treated at 310 levels between T11 and L5. Procedures included 1-6 levels. 73.8% of patients were female, average patient age was 67.8 years, BMI was 28.4 kg/m2, and 10.7% were smokers. Supplemental fixation included bilateral pedicle screws (49%), unilateral pedicle screws (26%), and anterolateral plating (7%); the remaining 18% were standalone. At 3 months incidence of migration was 0% and subsidence was 26.2%, none requiring revision. On average, patients had normal lordosis preoperatively, with 33 patients having abnormal lordosis (>-40°) measuring an average of -28.5°. Lordosis was significantly corrected in hypolordotic patients from preoperative to 2 weeks (p<0.001) which was maintained at 3 months (average 3 month lordosis = -35.4°). Significant corrections in average coronal Cobb angle were observed from preoperative to 2 weeks (p<0.001) and maintained at 3 months. Coronal correction was significantly affected by supplemental fixation (p=0.027) with the greatest corrections in patients with bilateral posterior pedicle fixation and the least in patients with no supplemental fixation (average 12.6° vs. 2.6°).

Conclusion: Significant reduction in deformity was observed with respect to coronal Cobb angle and lordosis, and was maintained through the three month evaluation, providing evidence that the XLIF technique can effectively correct deformity in the adult scoliosis population.

253. Economic Impact of Minimally Invasive Spine Surgery Open Versus MIS Spinal Fusion Costs in the Perioperative Period (First 45 Days)

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Introduction: Improved clinical and radiographic outcomes have been reported of minimally invasive spinal surgery techniques in comparison to traditional open approaches. We seek to determine if fewer complications, reoperations, additional therapies and diagnostics yields a lower overall cost among minimally invasive patients.

Methods: Hospital costs were retrospectively obtained for all our center's two level spinal fusions from 2005-2008. 101 patients had a traditional open procedure, and 109 underwent a minimally invasive fusion. Patients were not randomized; procedure methods were employed sequentially. After our transition to minimally invasive techniques in late 2006, no further open procedures were performed. Costs obtained include surgical procedure and hospitalization, in addition to ensuing hospital costs occurring in the first 45 days postop.

Results: Average cost of the original procedure and hospitalization was 6% less expensive in the MIS group overall, despite higher implant costs in the MIS group. When combined with all perioperative costs within the first 45 days after surgery, the average procedure cost reduction was 10.4%, a savings of $2,825.37 per procedure.

Conclusion: Results indicate an overall reduction of costs of MIS two level procedures compared to traditional open approaches. Costs of the surgical procedure and hospitalization are lower in the MIS group. Early numbers indicate that cost savings increase as length of time postop increases. The open group, although with longer follow-up, has demonstrated a significantly higher incidence of reoperation than the MIS group comparatively. Thus, our continued cost evaluation into the intermediate and long-term follow-up period may demonstrate an ever-increasing improvement in overall costs.

254. Perioperative Outcomes and Complications Following XLIF for the Treatment of Adult Scoliosis: Results of a Prospective, Non-Randomized, Multi-Center Evaluation

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Introduction: Combined anterior/posterior instrumented fusion is often performed for the surgical treatment of adult scoliosis. Such procedures have been associated with a high risk of complication, particularly in the elderly patient population. Less invasive surgical approaches to neural decompression and fusion have recently been applied in the treatment of degenerative scoliosis. This report summarizes the perioperative complications following lateral fusion for the correction of degenerative scoliosis.

Methods: In a prospective multicenter observational study of patients who underwent the XLIF procedure for the treatment of degenerative scoliosis, perioperative measures were compiled to identify the short-term outcomes of the procedure. Intraoperative data collection included surgical details, operative time, estimated blood loss, and complications. Postoperative complications, length of hospital stay, and neurological status were recorded.

Results: 107 patients (mean age 68 years; range 45-87) were treated with XLIF. 28% had at least one comorbidity. A mean of 4.4 levels/patient (range 1-9) were treated. Supplemental pedicle screw fixation was used in 75.7% of patients, 5.6% had lateral fixation and 18.7% had standalone XLIF. Mean operative time and blood loss were 178min and 50-100cc. Mean hospital stay was 2.9 days (unstaged), 8.1 days (staged; 16.5%), 3.8 days overall. 5 patients (4.7%) received a transfusion, 3 (2.8%) required ICU admission, 1 (0.9%) required rehabilitation services. Major complications occurred in 13 patients (12.1%): 2 (1.9%) medical, 12 (11.2%) surgical. Of procedures that involved only less invasive techniques (XLIF standalone or with percutaneous instrumentation), 9.0% had one or more major complications. In those with supplemental open posterior instrumentation, 20.7% had one or more major complication. Early reoperations (3, for deep wound infections) were associated with open posterior instrumentation.

Conclusion: The morbidity in adult scoliosis surgery is minimized with less invasive techniques. The rate of major complications in this study (12.1%) compares favorably to reports from other studies of surgery for degenerative deformity.

255. Correlation of Pre-Operative Depression and Somatic Perception Scales With Post-Operative Disability and Quality of Life After Lumbar Discectomy

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Introduction: Lumbar discectomy is a common surgical procedure performed in the U.S. for patients experiencing back and leg pain. However, patients with certain psychological predispositions may be especially vulnerable to poor clinical outcomes. The goal of this prospective longitudinal study was to determine the role that pre-operative depression and somatic anxiety have on long-term back and leg pain, disability, quality of life for patients undergoing single-level lumbar discectomy.

Methods: 67 adults undergoing discectomy for single-level herniated lumbar disc underwent prospective quantitative measurement of leg and back pain (visual analogue scale; VAS), quality of life (Medical Outcomes Short Form-36; SF-36), and disease-specific disability (Oswestry Disability Index; ODI) pre-operatively, at 6 weeks, 3, 6, and 12 months after surgery. Degree of pre-operative depression and somatization were assessed using Zung Self-Rating Depression Scale and modified somatic perception questionnaire (MSPQ). Multivariate regression analyses were performed to assess associations between Zung and MSPQ scores with achievement of a minimum clinical important difference (MCID) in each outcome measure by 12 months post-operatively.

Results: Overall, a significant improvement in VAS-leg, VAS-back, ODI, and SF-36 PCS was observed by 6 weeks after surgery and maintained throughout 12-months follow-up. Increasing pre-operative depression (Zung score) was associated with a decreased likelihood of achieving MCID in disability ($p=0.006$) and quality of life ($p=0.04$) but was not associated with leg ($p=0.96$) or back pain ($p=0.85$) by 12 months, Fig1&Table 1. Increasing pre-operative somatic anxiety (MSPQ score) was associated with decreased likelihood of achieving MCID in disability ($p=0.002$) and quality of life ($p=0.03$) but was not associated with leg ($p=0.64$) or back pain ($p=0.77$) by 12 months, Fig1&Table 1.

Conclusion: Zung and MSPQ are valuable tools at pre-operatively risk stratifying patients who may not experience clinically relevant improvement in disability and quality of life after discectomy. Efforts to address these confounding and underlying contributors of depression and heightened somatic anxiety may improve overall outcomes after lumbar discectomy.

256. Microdiskectomy Improves Pain-Associated Depression, Somatic Anxiety, and Mental Well Being in Patients With Herniated Lumbar Disc

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Introduction: In a multi-center, prospective, longitudinal outcome study, we assessed the prevalence of preoperative depression, somatization, and mental well-being in patients with herniated lumbar discs and the effect that microdiskectomy had on these psychological disturbances.

Methods: Patients undergoing surgical discectomy at five medical institutions for a single-level, herniated lumbar disc were prospectively assessed pre-operatively, at 6 weeks, 3, 6, and 12 months after surgery for visual analog scale for low back pain (BP-VAS) and leg pain (LP-VAS), depression via Zung Self-Rating Depression Scale, heightened anxiety somatic perception via the Modified Somatic Perception Questionnaire (MSPQ), and mental well-being via the SF-36 mental component summary (MCS).

Results: 100 patients were available for 1-year follow-up. Mean BP-VAS and LP-VAS was significantly improved at 6 weeks and remained improved at 3, 6, 9, and 12 months post-operatively, Figure 1. A significant improvement in SF-36 MCS was also observed by 6 weeks after surgery (42±14 vs. 48.2±12, p<0.01), and it continued to improve over 12-months, Figure 2. A significant improvement in MSPQ score was not observed until 3 months after surgery (9±7 vs. 6.6±6.9, p<0.05). A significant improvement in ZUNG depression score was not observed until 12 months after surgery (19±11 vs. 14.4±10.9, p<0.05). 67% of somatasized patients (MSPQ>12) became non-somatsized one year post-surgery. 70% of clinically depressed patients (ZUNG>33) became non-depressed one year post-surgery. Improvement in SF-36 MCS, ZUNG, and MSPQ each significantly correlated (p<0.001) with improvement in BP-VAS and LP-VAS.

Conclusion: The majority of patients defined as somatized and depressed pre-operatively returned to good mental well-being following surgery. Improvement in pain and overall mental well-being were seen acutely after microdiskectomy, while improvement in somatic anxiety and depression occurred months later. Microdiskectomy significantly improves pain-associated depression, somatic anxiety, and mental well-being in patients with a herniated lumbar disc. In addition, future comparative effectiveness research on surgical versus nonoperative treatment of disc herniation should include mental well being as an outcome measure.

257. Management of Degenerative Lumbar Stenosis Related to Meyerding Grade I Spondylolisthesis: The Reappraisal of Unilateral Laminotomy

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Introduction: The management of degenerative lumbar stenosis related to Meyerding Grade I sponsylolisthesis is still a matter of debate: both laminectomy and laminotomy have been advocated, but sometimes fusion may represent an overtreatment. A prospective trial was conducted in 38 patients to evaluate the impact of unilateral laminotomy for bilateral decompression of the lumbar canal in such cases.

Methods: On admission, patients (ratio F:M = 27:11; mean age 69y) underwent clinical evaluation using the Beaujon Scoring System (BSS) and VAS scale. Segmental instability detected on dynamic x-rays were considered exclusion criteria. CT and/or MRI studies of the lumbar spine were performed in all cases preoperatively and 12 months following surgery. Outcome was evaluated in two stages: at discharge using the BSS and VAS scales, and at long-term follow-up time (12 months minimum) using the MacNab classification (grade I-excellent, II-good, III fair, IV-poor).

Results: At discharge, clinical improvement assessed by BSS and VAS scales was significant in all patients; but more interestingly it was sustained even at long-term follow-up (mean 40 months): 81% of the patients were still in excellent conditions according to MacNab classification. Following surgery the lumbar spinal canal diameters (anteroposterior, transpedicular, interapophyseal) were significantly larger than the preoperative measurements, and no cases of vertebral instability were found.

Conclusion: The results of our study indicate that, whenever evidence of spinal instability is ruled out, unilateral laminotomy is a valid surgical option in the treatment of degenerative lumbar stenosis related to Meyerding Grade I spondylolisthesis.

258. Determination of Minimum Clinically Important Difference (MCID) in Pain, Disability, and Health State Utility After Transforaminal Lumbar Interbody Fusion (TLIF) for Degenerative Lumbar Spondylolithesis

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Introduction: Spinal surgical outcome studies rely on patient reported outcomes (PRO) to assess treatment effect. Commonly used health-related quality-of-life questionnaires include pain scales for back and leg pain (Visual Analog Scale), the Oswestry Disability Index (ODI), and the EuroQol-5D health survey (EQ-5D). A shortcoming of these questionnaires is that their numerical scores lack a direct meaning or clinical significance. Hense, the concept of minimum clinical important difference (MCID) has been put forth as a measure for the critical threshold needed to achieve treatment effectiveness. By this measure, treatment effects reaching the MCID threshold value imply clinical significance and justification for implementation into clinical practice.

Methods: In 45 patients undergoing trans-foraminal lumbar interbody fusion (TLIF) for low-grade degenerative lumbar spondylolithesis associated back and leg pain, PRO measures of BP-VAS, LP-VAS, ODI, and EQ-5D were administered pre-operatively and 2-years post-operatively and 2-year change scores calculated. Four established anchor-based MCID calculation methods were utilized to calculate MCID (1. average change, 2. minimum detectable change (MDC), 3. change difference, 4. receiver operating characteristic curve analysis) for two separate anchors (health transition index (HTI) of the Short Form-36 and satisfaction index).

Results: The mean±SD two-year improvement in BP-VAS, LP-VAS, ODI, and EQ-5D were 4.3±2.9, 3.8±3.4, 19.5±11.3, and 0.43±0.44, respectively(Figure1). The four MCID calculation methods generated a range of MCID values for each of the PROs(BP-VAS:2.1-5.3, LP-VAS:2.1-4.7, ODI:11-22.9, EQ-5D:0.15-0.54), Table 1. The mean area under the ROC curve (AUC) from the four PRO-specific calculations was greater for the HTI versus satisfaction anchor (HTI AUC: 0.73 vs. satisfaction AUC: 0.69), suggesting HTI as a more accurate anchor.

Conclusion: TLIF specific MCID is highly variable based on calculation technique. The MDC approach with SF-36 HTI anchor appears to be most appropriate for calculating MCID because it provided a threshold above of the 95% confidence interval of the un-improved cohort (greater than the measurement error), was closest to the mean change score reported by improved and satisfied patients, and was least affected by the choice of anchor. Based on MCD method with HTI anchor, MCID following TLIF are 2.4 points for BP-VAS, 2.5 points for LP-VAS, 15.6 points for ODI, and 0.40 QALYs for EQ-5D.

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