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)

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Korea, the rate in the population is near 3%. In North American populations, it appears that the disease prevalence is much lower. Resnick and Niwayama 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. Furthermore, genetic loci associated with cases of OPLL in Asian populations have also been linked to non-Asian Mediterranean families. 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.

**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). 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%. In sharp contrast to OPLL, this syndrome is uncommon in Asian populations and more common in North American or other Caucasian populations. 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. The coexistence of OPLL and DISH has been previously reported. Ehara et al. 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%. 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 as well as an association between DISH and ankylosing spondylitis.

**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. 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. 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...
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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. 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. 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 quadriplegia. 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. 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. 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. 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.

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. 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 as well as during routine radiographic follow-up in the patient in whom decompression has not been performed. 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.

**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. 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 found superior clinical outcomes when comparing anterior versus posterior approaches in 51 patients treated for OPLL. Fessler et al. found that patients treated by an anterior approach had an average improvement of 1.24 Nurick grades when compared with laminectomy patients.
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.55 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 os- sification. 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
cervical spine. Houten and Cooper29 demonstrated that compression with facet wiring can be successful in ge-

ral 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 unat-

ached, constituting a mobile, “floating” segment relative to native cervical spine. Removal of any residual ligamen-
tous attachments using a small-caliber Kerrison punch al-

lows the entire segment of bony lamina to be removed together.

Following removal of the lamina, careful medial fac-
etectomy 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 in-

stability. However, we have found that in cases of severe lateral facet compression, 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 “dy-
namic” 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, gener-

erally positive. Kato et al.33 noted a 44% rate of neurologi-
cal 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 instabil-

ity or motion. However, posterior decompression should be avoided in patients with a kyphotic alignment, spondylolis-

thesis, 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 pro-

motes subsequent dorsal migration in cases of OPLL.17 It will also decrease cervical ROM across an anterior os-
sified bar. There are multiple fusion techniques that can be used, including facet wiring, lateral mass screws, and pedicle screws. Epstein18 demonstrated that posterior de-

compression with facet wiring can be successful in ge-

neriatric patients with OPLL and an appropriately lordotic cervical spine. Houten and Cooper19 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 myelopa-

thy.26 It is the opinion of many surgeons that laminoplas-
ty 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. 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.

Multiple different approaches have been developed for cervical laminoplasty. These include the open-door or “hinge,” midline “French window,” and the Z-plasty techniques. 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. 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. 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.

The typical cervical laminoplasty performed in our practice is similar to the technique first described by Hirabayashi and Satomi. 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 spino-

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. 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. 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.

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. reported that this can occur in up to 35% of patients treated by anterior corpectomy for advanced OPLL. Yamaura et al. described the operative “anterior floating method” for focal decompression and fusion in
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, 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 ultrasonography 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. 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. 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. 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. Others have proposed either the development of local ischemia or reperfusion injury as a pathological mechanism. Chiba et al. 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-
arthrosis. Complications have been reported following multilevel ACC with and without the use of anterior plates. Saunders et al.\textsuperscript{60} reported on 3 (9.7\%) of 36 patients with acute graft extrusion following 4-level ACC. Vaccaro et al.\textsuperscript{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.\textsuperscript{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\textsuperscript{14} reported a 13\% incidence of pseudarthrosis during the first 6 months. Swank et al.\textsuperscript{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.,\textsuperscript{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.\textsuperscript{32,33} Although progressive kyphosis was seen in 47\% of patients as reported by Kato et al.,\textsuperscript{33} there appeared to be no effect on clinical outcomes. In a recent report by Cho et al.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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
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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." 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

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

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