Ossification of the cervical posterior longitudinal ligament: a review

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Ossification of the cervical posterior longitudinal ligament (OPLL) represents a continuum beginning with hypertrophy of the posterior longitudinal ligament (PLL) followed by progressive coalescence of centers of chondrification and ossification. Early OPLL mimicking disc disease appears opposite multiple disc spaces associated with significant retrovertebral extension, helping to differentiate it from spondylosis. On computerized tomography examinations, the single- and double-layer signs indicate possible dural penetration with the increased potential for an intraoperative cerebrospinal fluid fistula during dissection. Direct ventral resection of OPLL in patients younger than 65 years of age is optimal and includes single- or multilevel anterior corpectomy with fusion, the latter accompanied by posterior fusion. For patients older than the age of 65 years, with a well-preserved cervical lordosis, laminectomy with or without fusion and/or laminoplasty may suffice in providing indirect dorsal decompression. Patients undergoing circumferential procedures with halo devices are managed with a specific anesthetic protocol, including awake intubation and positioning with intraoperative monitoring of somatosensory evoked potentials, electromyography, and the option of undergoing motor evoked potential monitoring. Intubation is maintained during the 1st postoperative night. When circumferential procedures are performed intubation is always maintained during the 1st postoperative night, and fiberoptic postoperative extubation is electively performed by specifically trained anesthesiologists when deemed appropriate. Patients exhibiting three or more major risk factors are considered candidates for delayed extubation and rarely, tracheostomy. Repeated anterior surgery, operations lasting more than 10 hours, involving four or more levels (including C-2), obesity, asthma, and blood transfusions of more than 4 U (1000–1200 ml) are all considered major risk factors.

KEY WORDS • cervical spine • ossification • posterior longitudinal ligament • spinal surgery

COMPOSITION OF THE POSTERIOR LONGITUDINAL LIGAMENT

Collagen and elastin fibers are densely concentrated centrally in the PLL, beginning at the clivus and extending to the sacrum. This ligament is widest at the disc spaces and narrowest at the mid-vertebral levels. It is approximately 1 to 2 mm thick centrally and thins out laterally. Initial hypertrophy of the PLL due to fibroblastic hyperplasia is followed by increased collagen deposition. Progressive mineralization and cartilaginous ingrowth

form ossification centers that eventually mature into Haversian canals.

Osteogenicity of the PLL has been well-documented in both Japan and the United States, the latter in non-Asian patients.^{38,47,50,55} In Japan, immunohistochemical evaluation of PLL cells obtained from anterior cervical surgery revealed "up-regulation of proliferating cell nuclear antigen."⁶⁵ In the United States Epstein and colleagues^{6,38} showed that osteocalcin synthesis occurs in patients with radiographically confirmed OPLL while confirming its absence in spondylotic tissues.

GENETICS

A genetic locus for OPLL is most likely located close to the HLA site on chromosome 6-p.^{54,55} Patients with DISH, half of whom have OPLL, test positive for HLA antigen.⁶⁹ An autosomal-dominant mode of OPLL inheritance is frequently inferred as one quarter of the siblings of OPLL patients manifesting the disease and demonstrating two concurrent strands of HLA.^{59,70,74} Other genetically modulated factors, including increased concentrations of growth hormone receptors, activins, and the bone morphogenetic proteins, BamHI 10/10 kb, and HindIII 19/19 kb were also found in OPLL patients.^{47,54,55,78}

Abbreviations used in this paper: ACF = anterior corpectomy with fusion; ADF = anterior discectomy with fusion; CSF = cerebrospinal fluid; CT = computerized tomography; DISH = diffuse idiopathic skeletal hyperostosis; Gd-DTPA = gadolinium-diethylenetriamine pentaacetic acid; HLA = human leukocyte antigen; JOA = Japanese Orthopaedic Association; MEP = motor evoked potential; MR = magnetic resonance; OALL = ossification of the anterior longitudinal ligament; OPLL = ossification of the posterior longitudinal ligament; PLL = posterior longitudinal ligament; PWF = posterior wiring and fusion; SSEP = somatosensory evoked potential; VB = vertebral body; 2D = two-dimensional; 3D = three-dimensional.

CLASSIFICATION OF OPLL

One quarter of North Americans and Japanese patients with cervical myelopathy exhibit OPLL.^{12,30,35,73} Seventy percent of the time OPLL is found in C2–4 and 15% is found in T1–4, and 15% in L1–3. Neural injury occurring in the presence of OPLL stems from direct mechanical or indirect ischemic compromise. Cervical OPLL also appears twice as often in males as in females.^{11,30,31,72}

MYELOPATHY SCALES

Two myelopathy grading scales are used: the Nurick Scale and the JOA Scale. The Nurick Myelopathy Scale includes: Grade 0, intact, mild radiculopathy without myelopathy; Grade I, mild myelopathy; Grade II, mild-to-moderate myelopathy; Grade III, moderate myelopathy; Grade IV, moderate-to-severe myelopathy; and Grade V, severe myelopathy, quadriplegia.^{11–14,20,22,25,30,31,35} The JOA Scale catalogues the severity of myelopathy by using a 17-point scale.^{68,80,81} Yononbu, et al.,⁷⁹ recently investigated and confirmed the reliability of the JOA scoring system.

CLINICAL PRESENTATION OF OPLL

Patients with early OPLL typically present in their mid-40s with radiculopathy or mild myelopathy. Those with more mature OPLL usually become symptomatic in their mid-50s with moderate-to-severe myelopathy. Although symptoms are usually gradual in onset, 10% may precipitously develop myelopathy after mild trauma, and many new deficits may prove irreversible despite surgical decompression.^{43,50}

NEUROIMAGING OF OPLL

Plain X-Ray Films

Absolute cervical stenosis (canal diameter < 10 mm) and relative cervical stenosis (canal diameter 10–13 mm) predispose patients with OPLL to developing more severe deficits earlier in the clinical course. When the “occupancy ratio” is greater than 40% as defined by the thickness of OPLL divided by the canal diameter, the risk of symptomatic myelopathy increases.⁶³

Magnetic Resonance Imaging

Early OPLL appears slightly hyperintense on MR imaging without contrast administration, and inhomogeneously enhances with Gd-DTPA administration compared with disc herniations, which are uniformly hypointense. Between 30 and 60% of OPLL patients have accompanying disc protrusions.^{20,36,56} Early OPLL originates opposite multiple interspaces, which may be visualized on transaxial, coronal, and sagittal MR studies. These examinations provide an overview extending from the cervicomedullary junction through the cervicothoracic junction. Mature OPLL appears densely hypointense on both T₁- and T₂-weighted MR studies, which demonstrate hyperintense foci within the ossified ligament indicating foci of active bone marrow production in mature haversian canals in 50% of patients with continuous OPLL.⁵⁶ Greater detail of intrinsic changes in the cord may be seen on T₂-weighted MR studies; hyperintense foci reflecting edema, myelomalacia, or

gliosis may also be seen. These factors constitute poor prognostic indicators for patients with spondylotic myelopathy compared with OPLL-related myelopathy.^{3,56} Enhanced MR studies may differentiate postoperative scarring from disc intrusions and may also confirm the adequacy of postoperative decompression (Fig. 1). Accompanying vascular anomalies are readily revealed by MR angiography.

Computerized Tomography Evaluations

Early OPLL may contain punctate ossification or pearls of ossification on CT studies, and these centers may progressively coalesce as maturation occurs (Figs. 2 and 3).⁶⁴ The four types of OPLL include: the segmental form (39%) found behind the VBs; the continuous form (27%) extending from vertebra to vertebra; the mixed form (29%) including both continuous and segmental elements; and the other form (5%) located opposite the disc spaces with some rostral and caudal retrovertebral extension (Figs. 4 and 5). Reconstructed 2D- and 3D-CT, and myelo-CT scans provide greater detail of compressive changes in the spinal cord attributable to ventral OPLL, whereas dynamic studies often reveal ventral intrusion from kyphosis or dorsal compromise resulting from ossification of the yellow ligament, facet arthropathy, or laminar shingling (Fig. 6).^{3,11–14,20,22,25,30,31} Postoperative myelo-CT studies can be obtained to further document whether the cord has been adequately decompressed.⁴³

Documentation of Fusion by CT Scanning

Fusion is typically documented on x-ray studies where trabeculation and the lack of osseous lucency may be con-

Fig. 1. Postoperative Gd-DTPA-enhanced T₁-weighted MR image demonstrating adequate ventral cord decompression (arrow) 4 years after this patient underwent a C3–6 ACF and C2–7 PWF with an iliac crest autograft and an Orion plate.

Fig. 2. *Left*: preoperative midline sagittal 3D-CT scan obtained in a 70-year-old man demonstrating a pearl of ossification (arrow) that was contained within a hypertrophied PLL opposite the C3–4 disc space. Note how this markedly affected the anteroposterior diameter of the cervical canal. *Right*: a coronal 3D-CT scan obtained in the same patient, demonstrating the pearl of ossification (arrow) at the C3–4 level that contributed to right-sided cord compression.

firmed at the graft–VB interface. Dynamic radiographs confirm the absence of motion, ideally less than 1 mm between the tips of contiguous spinous processes, and the lack of subluxation or translation. Also, 2D-CT studies may provide a third criterion for fusion following allograft fibula strut placement by documenting cephalad and caudad bone ingrowth into the central fibular canal (Fig. 7).²³ In a recent personal series,²³ 18 patients undergoing ACF/PWF at an average of three levels, bone ingrowth was shown in 17 (94%) of the 18 from 3 to 6 months postoperatively at a rate of 1.5 mm to 3.5 mm cephalad and 2.1 mm to 4.6 mm caudad.

Computerized Tomography Signs of Dural Penetrance

Ossification of the PLL extending through the dura is rarely seen in the North American population; it was found in only three of our 65 OPLL cases.^{15,27,36,39} In these patients, CT examinations offered two signs of potential dural penetrance. The single-layer sign on CT scans was characterized by a solid ossified ventral OPLL mass, often accompanied by a lateral “C-sign,” indicating imbrication

Fig. 3. A transaxial myelo-CT study obtained at the C4–5 level, demonstrating early OPLL, punctuate ossification (short arrow), and a pearl of ossification (long arrows).

Fig. 4. *Upper left*: midline sagittal 2D-CT study revealing segmental OPLL directly behind the VB (double arrows). *Upper right*: paramedian sagittal 3D-CT scan demonstrating continuous OPLL extending across the dorsal C-4 and C-5 VB (black arrows) accompanied by kyphosis seen as the exaggerated separation of the laminae (white arrows). *Lower*: paramedian 3D-CT study revealing OPLL involving the C5–6 and C6–7 levels (arrows) with retro-vertebral extension crossing the dorsal aspect of the C-6 VB.

of the dura (Fig. 8).²⁷ In cases of the single-layer sign, ossification appears to occur from the inside-out of the PLL. Hida, et al.,⁴⁶ observed an 11 to 25% correlation of absent dura at surgery when OPLL occupied more than 50% of the spinal canal. Only one of their nine patients in whom this single-layer sign was demonstrated developed a CSF leak during surgery.⁴⁶

The double-layer sign, typified by a reversal of the ossification process from the outside-in, appears as a rim of OPLL surrounding the hypodense dura (Fig. 9).²⁷ The double-layer sign has proven the most pathognomonic for absent dura at surgery; it correlated with absent dura in 10 of 12 patients reported on by Hida, et al.⁴⁶

Diffuse Idiopathic Skeletal Hyperostosis

The syndrome known as DISH, which is characterized by ossification along the ventral aspect of the cervical vertebrae, is found in 15 to 30% of adults older than 65 years of age;^{53,69} OPLL accompanies DISH up to 50% of the time.^{33,61} Although DISH often becomes extensive, it rarely produces dysphagia, and careful diagnostic consideration should be given to other causes before considering resection with its attendant morbidity.^{61,67}

Ossification of the Anterior Longitudinal Ligament

It is thought that OALL may contribute to dysphagia. The ossified mass itself appears hypointense on T₁-

Fig. 5. Coronal 2D-CT study obtained at the C2–7 levels in four successive slices [(a) 2 mm; (b) 4 mm; (c) 6 mm; and (d) 8 mm into the spinal canal] beginning at the ventral aspect of the cervical spinal canal extending dorsally revealing massive continuous OPLL.

and T₂-weighted MR studies, whereas areas of bone marrow production appear hyperintense on T₁-weighted images.⁴⁰ At surgery, the adequacy of OALL resection may be checked on intraoperative lateral radiographs or fluoroscopy.

CONSERVATIVE COMPARED WITH SURGICAL MANAGEMENT OF OPLL PATIENTS

Most older patients (> 65 years of age) with asymptomatic OPLL but with significant medical comorbidities should be followed conservatively because prophylactic surgery in this age group plays a minimal role. For those with rapidly progressive myelopathy and several comorbidity factors, including cardiovascular disease, chronic obstructive pulmonary disease, diabetes, and peripheral vascular disease, nonsurgical management should be strongly considered because the risks of perioperative morbidity and mortality increase. In the series by Saunders, et al.,⁷¹ three of 31 postoperative deaths occurred in patients older than 70 years of age with significant cardiovascular comorbidities. Similarly, in my series^{20,36} of 44 patients undergoing multilevel ACF/PWF, two deaths occurred in patients with significant cardiac disease.^{20,36} Patients with severe, long-standing myelopathy (Nurick Grade V) and increased cord signals on T₂-weighted MR images, reflecting myelomalacia (apoptosis) and cord atrophy, are also poor candidates for surgery.

Alternatively, those patients younger than 65 years of age, without fixed deficits or major comorbidities, should be considered candidates for prophylactic surgery in the face of CT- or MR-documented severe compromise of the spinal cord. Surgery performed in these cases, prior to

Fig. 6. *Left*: midline sagittal 3D-CT study revealing C2–C5 OPLL (longer arrows) ventrally and marked shingling of the C3–5 laminae (shorter arrows) dorsally. *Right*: paramedian sagittal 3D-CT scan demonstrating ventral kyphosis attributed to marked degenerative subluxation of the C4–5 and C5–6 VB (arrows).

even minor cervical trauma, may avoid future quadripareisis or quadriplegia.^{42,50}

ANTERIOR SURGERY FOR OPLL

Direct anterior resection of OPLL results in improved postoperative outcomes. In the study by Fessler, et al.,⁴¹ Nurick grades improved 86% of the time following anterior surgical approaches. These patients improved an average of 1.24 Nurick grades, whereas those undergoing laminectomy improved only 0.07 Nurick grades.

Better clinical outcomes are encountered following anterior resection rather than posterior decompression of OPLL.^{12,14,20,35,36} The patients reported on by Kawano, et al.,⁵¹ showed an overall mean improvement rate on the Neurosurgical Cervical Spine Scale score of 78% for anterior compared with 46.1% for posterior decompressions.

Fig. 7. Six-month postoperative transaxial noncontrast-enhanced CT scan demonstrating osseous ingrowth into the central fibular canal (interrupted arrow) accompanied by bone trabeculation and the lack of osseous lucency at the external fibula–VB junction (rounded arrow).

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Fig. 8. Transaxial noncontrast-enhanced CT study revealing the combined “single layer” and “C” signs (arrow) that contributed to left-sided cord compression and imbrication of the dura, which indicates greater potential for an intraoperative CSF fistula.

Long-term outcomes were also superior following anterior resection of OPLL; scores for those undergoing anterior resection continued to rise postoperatively to 13 whereas for those undergoing laminoplasty a progressive decline to 9.7 was seen.

One-Level ACF

When OPLL involves two contiguous interspaces with significant retrovertebral extension, it is best resected with a one level ACF, with excision of portions of the cephalad and caudad VBs, two discs, and the intervening vertebra. One-level ACF requires fusion at two graft–VB interfaces rather than the four required for two-level ADF.^{7,16} Epstein¹⁶ reported fusion rates of 99% for 78 patients undergoing nonplated one-level ADF, but only a 90% success rate for those undergoing nonplated two-level ADF. Emery, et al.,⁹ observed a 16% pseudarthrosis rate following one- to two-level nonplated ADF. Plating reduced graft extrusion, kyphosis, and pseudarthrosis rates following one- and 2-level ADF, with some citing 100% fusion rates.^{5,7,15,29}

Dynamic Plating of One-Level ACF: Personal Series

A greater success rate was found following dynamic rather than fixed-plate in one-level ACF performed for OPLL. Operative failures, defined as graft–plate extrusion or pseudarthrosis, were studied following 57 one-level ACF surgeries. Fixed plates (Orion Plates and Atlantis Plates; Sofamor Danek, Memphis, TN) placed in the first 15 patients resulted in seven failures: one plate extrusion, three pseudarthroses, and three delayed midstrut fractures. Dynamic plates (ABC; Aesculap, Tuttlingen, Germany) applied in 42 patients resulted in four failures: one plate–graft extrusion, one pseudarthrosis, and two delayed midstrut fractures.²⁴ The placement of dynamic ABC plates allowed for up to 10 mm of cephalad and caudad migration of the plates over the screw heads within longitudinal grooves in the plates. Using dynamic plates, cephalad mi-

Fig. 9. Noncontrast-enhanced transaxial CT scan obtained at the C5–6 level, revealing dural penetration characterized by the “double-layer” sign; a large mass of ossification is seen within the spinal canal separated from the dorsal aspect of the VB by residual hypodense dura (arrows).

gration averaged 6.7 mm (range 3–10 mm), and caudad migration averaged 5.8 mm (range 3–8 mm). The heightened success when using the dynamic plates was variously attributed to their reduction of stress shielding and the allowance for greater compression, which facilitated stable fusion.

Multilevel ACF

More typically, OPLL involves several segments, warranting multilevel ACF. Ventral approaches to OPLL resulting in direct resection are correlated with better long-term outcomes, although immediate perioperative morbidity may prove higher.^{12,13,15,19–22,36,39,52,62,75} Epstein²⁵ noted that in 76 OPLL patients undergoing nonplated ADF (mean 3.5 levels) or ACF (mean 3 levels) that 13% developed pseudarthrosis/instability within 6 months of surgery. In 10% of the patients reported by Saunders, et al.,⁷¹ nonplated four-level ACF failed acutely. In another series of patients undergoing two- to four-level ACF performed with and without plates, a combined perioperative mortality and major morbidity rate of 22% was noted, despite an ultimate 97% fusion rate.⁵⁸ A 9% failure rate was observed by Vaccaro, et al.;⁷⁵ when using fixed plates to perform two-level ACF, the rate increased to 50% with three-level ACF. Eleraky, et al.,⁸ surprisingly found a 3.2% neurological complication rate, 98.8% fusion rate, and 86.5% improvement rate after having used plates in one-level ACF (87 patients) and two- to three-level ACF (98 patients).

Results Using Fixed Compared With Dynamic Plates

Lower complication rates were associated with using dynamic ABC plates for multilevel constructs combined with PWF. Two of 22 multilevel (two–four levels) ACF/PWF procedures performed without the benefit of anterior plates resulted in three immediate postoperative graft extrusions.²⁰ Fixed Orion plates used in the next 22 multilevel circumferential constructs resulted in two immediate inferior graft–plate extrusions.^{21,36} Applying Atlantis plates in 16 multilevel ACF/PWF procedures resulted in

Fig. 10. Lateral cervical x-ray film obtained 6 months following a C3–7 ACF and C2–T1 PWF with dynamic ABC plate placement; 5-mm cephalad and 4-mm caudad plate migration was observed (arrows).

three extrusions observed between 1 month (two patients), and 4 months postoperatively; all were inferior graft, plate, and screw extrusions.²⁷ Twenty-six multilevel ACF/PWF procedures performed with dynamic plates resulted in only one patient manifesting a “partial” pseudarthrosis of the anterior graft viewed on sequential CT studies; this patient required secondary PWF (Fig. 10).²⁴ The average dynamic plate migration after multilevel ACF/PWF was 6.3 mm (range 4–10 mm) cephalad and 5.9 mm (range 4–9 mm) caudad. Dynamic plating similarly appeared to limit stress shielding, promoted graft settling, and fostered fusion in multilevel constructs.²⁶

Posterior Fusion Techniques

Posterior fusions may include wiring of spinous processes or facets, or the use of lateral mass or pedicle screws with plates or rods. The addition of the dorsal fusion to provide a posterior “tension band” following multilevel ACF has been well-documented by Kirkpatrick, et al.⁵² They performed a biomechanical study in the sagittal plane and found that posterior fusion reduced the range of motion by 62%, compared with 24% with strut grafting only and 43% if an anterior strut graft and plate were applied.

Anterior Floating Method: an Option for Anterior OPLL Resection

The anterior floating method as an alternative to direct ventral OPLL resection may be offered, particularly when the OPLL fills more than 60% of the canal.⁷⁷ It requires more extensive lateral exposure (< 25 mm) to facilitate anterior migration of the OPLL mass and, therefore, poses a significant increased risk of vertebral artery and nerve root injuries. The lack of direct OPLL resection may likely lead to continued cord compression and pose the risk of ventral retethering.

COMPLICATIONS OF MULTILEVEL ACF/PWF

Vertebral Artery Injury

Endovascular repair of vertebral artery injuries sustained in the course of cervical surgery is preferred. For

those injuries less than 6 hours old, stent placement is feasible, whereas for injuries more than 6 hours old, trapping should be performed to occlude the vessel and avoid cephalad progression of a thrombus. Older techniques, including direct surgical repair of the vessel or indirect pressure/occlusion risk greater morbidity to the patient.

Cord and Root Injuries

A 2 to 10% incidence of quadriplegia and an approximately 5 to 17% incidence of root injury (typically C-5) has been reported in cervical surgery.⁸¹ Root injuries are less frequently attributed to direct manipulation than to rapid cord migration or the so-called untethering effect.⁷¹ To limit these complications, Saunders, et al.,⁷¹ recommended limiting the anterior trough to 15 mm and found that the frequency of root injuries was markedly reduced. The interpedicular distance, however, in many North American patients measures from 18 to 20 mm and a 15-mm decompression will prove inadequate.

POSTERIOR SURGERY

High-risk patients older than 65 years of age with OPLL but with adequate cervical lordosis may undergo posterior decompressive procedures, including laminectomy, laminectomy with posterior fusion, or laminoplasty, with a modicum of success (Fig. 11).^{4,18,28,45,48,49,57,76,80} The lordosis allows the cord to migrate away from ventrally situated disease, whereas kyphosis can result in tethering of the cord over ventral OPLL protrusions.

Laminectomy

Sufficient cord decompression may be accomplished by laminectomy alone when there is no evidence of spinal instability. If medial facetectomies and foraminotomies

Fig. 11. A CT study obtained in a 78-year-old patient in whom a cervical laminectomy was performed from C-4 to C-7 for multilevel OPLL, spondylosis, and stenosis (long arrows), along with a C2–C3 PWF (short arrows) for focal instability. Note how multilevel OALL (curved arrows) contributed to spontaneous ventral fusion from C-3 to C-6 (long arrows), and OPLL resulted in fusion from C-3 to T-1.

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are restricted to less than 25% of the facet joint, stability may be preserved, whereas facet removal of 50% or greater will likely result in destabilization.⁶⁶ Long-term neurological recovery rates of 44.2% at 1 year and 42.9% at 5 years following laminectomy have been documented, although outcomes typically deteriorate between 5 and 10 years postoperatively.⁴⁹ Poor prognostic factors include advanced deficits, trauma, and ossification of the yellow ligament, but rarely OPLL progression.

Laminectomy With Posterior Fusion

Laminectomy and posterior fusion may also be used to manage cervical OPLL in the presence of adequate lordosis. Postlaminectomy instability may also be avoided with the addition of posterior stabilization (Fig. 12).⁶⁶

Posterior Fusion Techniques

Posterior fusion alternatives include facet and/or spinous process wiring techniques, lateral mass plates, and pedicle screws, the latter using rod/plate systems.^{1,2,28,32,45,57,76} Epstein^{28,32} performed spinous process wiring and fusion successfully in 65 patients undergoing multilevel cervical ACF/PWF for stabilization; more recently this included 86 patients. Comparable neurological outcomes were observed in patients undergoing laminectomy (without instability) and laminectomy with fusion (for instability) in patients with cervical OPLL.⁴⁵ Using the Short Form 36, patient-based outcome data for 25 patients revealed adequate postoperative results following laminectomy with lateral mass plating for unstable spondylotic myelopathy.⁵⁷ No symptomatic postoperative instability or

increases in kyphosis were observed: 80% had good outcomes and none deteriorated. Lateral mass plates were similarly successful in the management of postlaminectomy instability; no significant complications were noted in the placement of 281 screws.⁷⁶ Dorsal decompression with or without fusion may not suffice in some patients with significant anterior disease and secondary anterior procedures are necessary.¹ Nevertheless, the use of lateral mass screws may result in "near misses" as shown in the postoperative study by Abumi, et al.,² who reported an incidence of screws perforating the cortex of the pedicles in 10 of 190 cases (5.3%). Long-term recovery rates of 44.2% were found after 1 year and were even maintained at 42.9% after 5 years; deterioration appeared between 5 and 10 years postoperatively at a rate of 32.8%.⁴⁹

ANESTHETIC PROTOCOL FOR CIRCUMFERENTIAL CERVICAL SURGERY

Circumferential cervical procedures with halo devices were performed to address multilevel OPLL. Patients were managed with a strict anesthetic protocol to avoid emergency reintubation or tracheostomy, which could result in acute graft and plate disruption, increased neurological deficit, hypoxia, and death.^{10,17} Awake fiberoptic intubation and positioning using continuous intraoperative SSEP monitoring is performed. Patients continue on intubation during the 1st postoperative night, and are extubated with fiberoptic assistance thereafter by a qualified anesthesiologist.¹⁷ Prior to extubation a patient must fulfill the following criteria: 1) direct fiberoptic evaluation of the trachea and vocal cords for swelling; 2) indirect assessment of swelling performed by letting down their endotracheal cuff checking for an air leak and the ability to verbalize; and 3) thorough review of the patients' attendant medical risk factors. Patients who are unable to undergo extubation by the 7th postoperative day receive prophylactic tracheostomies performed by ear, nose, and throat specialists. Fifty-eight patients who underwent an average three-level ACF and 6.5-level PWF for OPLL were managed using this strict protocol.¹⁷ Operative times were approximately 10 hours and required 600 to 800 ml of blood transfusion. Forty patients underwent fiberoptically assisted extubation on the 1st postoperative day, 15 on Days 2 through 7, and three required elective tracheostomy on the 7th day. Following this protocol, only one patient underwent emergency reintubation 20 minutes after having undergone extubation on postoperative Day 3. She had undergone a C4–7 ACF 3 years previously, was asthmatic, and her surgery spanned 14 hours, requiring both wound-peritoneal and lumboperitoneal shunt placement for a CSF fistula.

Seven major risk factors and complications correlated with delays in extubation or tracheostomy. These included in descending order: 1) operative time more than 10 hours (12 patients); 2) obesity greater than 220 lbs (12 patients); 3) transfusions of more than 1000 to 1200 ml of blood (10 patients); 4) secondary anterior cervical surgery (nine patients); 5) anterior surgery including the C-2 level (seven patients); 6) four-level ACF (five patients); and 7) asthma (five patients). Minor risk factors included: 1) advanced age (> 65 years old); 2) severe preoperative neu-

Fig. 12. A 3D-CT study revealing cervical stenosis accompanied by mild ventral OPLL and an adequately preserved cervical lordotic curvature that were treated with a C3–7 laminectomy (double arrows) and C2–T1 facet wiring and fusion by using braided cables placed from C-2 to T-1 (single arrow).

rological deficits (Nurick Grade IV–V moderate/severe myelopathy); and 3) intraoperative CSF fistula. Factors cited in the literature as contributing to airway complications included angioedema, recurrent laryngeal nerve palsy, dysphagia with or without esophageal perforation, and new spinal cord injuries.^{9,81}

MONITORING OF SSEPS AND MEPS

Intubation and positioning while the patient is awake, and continuous intraoperative SSEP monitoring of median/ulnar and posterior tibial potentials during cervical procedures, including OPLL surgery, limits postoperative morbidity.^{34,37,60} A 50% decrease in amplitude and a 10% decline in latency are significant.³⁷ Changes observed at 50 seconds may be reproduced within 100 seconds and require immediate resuscitative measures. Medical measures include the inducing of hypertension, warming of irrigating fluids, decreasing the concentration of inhalation anesthetic, and increasing oxygen concentration. Surgical resuscitative techniques include releasing distraction, removal of an oversized graft, and cessation of manipulation. A deterioration in SSEPs may signal flexion or extension of the neck, traction, or rotation or compression at the level of the shoulder, elbow or wrist. To avoid SSEP “drop out,” inhalation anesthetics (for example, isoflurane) are usually maintained at concentrations below 0.4% or a balanced narcotic technique is used. In a prospective study, Epstein and colleagues³⁷ found no cases of quadriplegia in 100 SSEP-monitored cases compared with eight of 218 unmonitored patients who became quadriplegic during the course of surgery performed by five different neurosurgeons. May and coworkers⁶⁰ monitored SSEPs during 182 cervical procedures; however, 10 patients developed new postoperative deficits. Major risk factors associated with greater deficits included: 1) multisegmental surgery; 2) more severe preoperative neurological status; and 3) placement of instrumentation. Half of the patients in whom complete SSEP signals were lost during surgery developed new postoperative deficits, whereas those in whom incomplete drop out of SSEP signal occurred or those with intraoperative recovery of SSEPs did not. False positives are more likely to be true “mini” positives, permanent deficits being avoided by the immediate institution of appropriate resuscitative measures. Monitoring of MEPS also provide helpful information regarding the status of the anterior spinal cord. Gokaslan and colleagues⁴⁴ transcutaneously placed electrodes for MEP monitoring during 16 anterior cervical fusion operations and with no complications were able to preserve MEPS, which correlated with good clinical outcomes.

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